The Economics and Management of Technological Diversification

Edited by John Cantwell, Alfonso Gambardella and Ove Granstrand

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

The Economics and Management of Technological Diversification

Recently, attempts have been made to understand the patterns of corporate technological diversification and their implications for the economics and the management of such diversification. This book consolidates this new line of research and breaks new ground by examining the patterns of technological diversification, and their relationship with internationalisation, economic performance and inter-company alliances.

Business diversification as a strategy came into fashion in the 1950s and 1960s. Following some conspicuous failures of highly unrelated conglomerates, the trend was reversed in the 1980s and 1990s. The reversal was described by terms such as back to basics, stick to your knitting, downsizing or outsourcing. Yet just when product diversification fell out of fashion, technological diversification came in. Scholars speak today of the "multi-technology corporation".

Following an introduction and a survey of product and technological diversification, the book begins with a statistical analysis of technological diversification, and its links with internationalisation and alliances. It continues with a range of industry and company case studies, and an assessment of historical evidence. The book provides a systematic analysis of data, case studies and other relevant material to understand this phenomenon. Contributors bring to bear significant experience with large data sets at the firm level on technological diversification and other strategic dimensions on which it has an impact.

This book will be essential reading for students and researchers in the fields of Economics, International Business, Business Strategy and Technology Management.

John Cantwell is Professor of International Business at Rutgers University, USA, and on leave as Professor of International Economics at the University of Reading, UK. His 1989 book *Technological Innovation and Multinational Corporations* helped to launch a new literature on multinational companies and technology creation. **Alfonso Gambardella** is Professor of Economics and Management at the Sant'Anna School of Advanced Studies, Pisa, Italy. His main research interests are Economics of Technological Change, Applied Industrial Organisation, and Strategic Management. **Ove Granstrand** is Professor in Industrial Management and Economics at Chalmers University and Chairman of the Center for Intellectual Property Studies. His research interests concern economics and management of technology and innovation.

Routledge studies in the modern world economy

1 **Interest Rates and Budget Deficits**
A study of the advanced economies
Kanhaya L. Gupta and Bakhtiar Moazzami

2 **World Trade after the Uruguay Round**
Prospects and policy options for the twenty-first century
Edited by Harald Sander and András Inotai

3 **The Flow Analysis of Labour Markets**
Edited by Ronald Schettkat

4 **Inflation and Unemployment**
Contributions to a new macroeconomic approach
Edited by Alvaro Cencini and Mauro Baranzini

5 **Macroeconomic Dimensions of Public Finance**
Essays in honour of Vito Tanzi
Edited by Mario I. Blejer and Teresa M. Ter-Minassian

6 **Fiscal Policy and Economic Reforms**
Essays in honour of Vito Tanzi
Edited by Mario I. Blejer and Teresa M. Ter-Minassian

7 **Competition Policy in the Global Economy**
Modalities for co-operation
Edited by Leonard Waverman, William S. Comanor and Akira Goto

8 **Working in the Macro Economy**
A study of the US labor market
Martin F.J. Prachowny

9 **How Does Privatization Work?**
Edited by Anthony Bennett

10 **The Economics and Politics of International Trade**
Freedom and trade: volume II
Edited by Gary Cook

11 **The Legal and Moral Aspects of International Trade**
Freedom and trade: volume III
Edited by Asif Qureshi, Hillel Steiner and Geraint Parry

12 **Capital Markets and Corporate Governance in Japan, Germany and the United States**
Organizational response to market inefficiencies
Helmut M. Dietl

13 **Competition and Trade Policies**
Coherence or conflict
Edited by Einar Hope

14 **Rice**
The primary commodity
A.J.H. Latham

15 **Trade, Theory and Econometrics**
Essays in honour of John S. Chipman
Edited by James C. Moore, Raymond Riezman and James R. Melvin

16 **Who Benefits from Privatisation?**
Edited by Moazzem Hossain and Justin Malbon

17 **Towards a Fair Global Labour Market**
Avoiding the new slave trade
Ozay Mehmet, Errol Mendes and Robert Sinding

18 **Models of Futures Markets**
Edited by Barry Goss

19 **Venture Capital Investment**
An agency analysis of UK practice
Gavin C. Reid

20 **Macroeconomic Forecasting**
A sociological appraisal
Robert Evans

21 **Multimedia and Regional Economic Restructuring**
Edited by Hans-Joachim Braczyk, Gerhard Fuchs and Hans-Georg Wolf

22 **The New Industrial Geography**
Regions, regulation and institutions
Edited by Trevor J. Barnes and Meric S. Gertler

23 **The Employment Impact of Innovation**
Evidence and policy
Edited by Marco Vivarelli and Mario Pianta

24 **International Health Care Reform**
A legal, economic and political analysis
Colleen Flood

25 **Competition Policy Analysis**
Edited by Einar Hope

26 **Culture and Enterprise**
The development, representation and morality of business
Don Lavoie and Emily Chamlee-Wright

27 **Global Financial Crises and Reforms**
Cases and caveats
B.N. Ghosh

28 **Geography of Production and Economic Integration**
Miroslav N. Jovanović

29 **Technology, Trade and Growth in OECD Countries**
Does specialisation matter?
Valentina Meliciani

30 **Post-Industrial Labour Markets**
Profiles of North America and Scandinavia
Edited by Thomas P. Boje and Bengt Furaker

31 **Capital Flows without Crisis**
Reconciling capital mobility and economic stability
Edited by Dipak Dasgupta, Marc Uzan and Dominic Wilson

32 **International Trade and National Welfare**
Murray C. Kemp

33 **Global Trading Systems at Crossroads**
A post-Seattle perspective
Dilip K. Das

34 **The Economics and Management of Technological Diversification**
Edited by John Cantwell, Alfonso Gambardella and Ove Granstrand

35 **Before and Beyond EMU**
Historical lessons and future prospects
Edited by Patrick Crowley

36 **Fiscal Decentralization**
Ehtisham Ahmad and Vito Tanzi

37 **Regionalisation of Globalised Innovation**
Locations for advanced industrial development and disparities in participation
Edited by Ulrich Hilpert

38 **Gold and the Modern World Economy**
Edited by MoonJoong Tcha

39 **Global Economic Institutions**
Willem Molle

40 **Global Governance and Financial Crises**
Edited by Meghnad Desai and Yahia Said

41 **Linking Local and Global Economies**
The ties that bind
Edited by Carlo Pietrobelli and Arni Sverrisson

42 **Tax Systems and Tax Reforms in Europe**
Edited by Luigi Bernardi and Paola Profeta

43 **Trade Liberalization and APEC**
Edited by Jiro Okamoto

44 **Fiscal Deficits in the Pacific Region**
Edited by Akira Kohsaka

45 **Financial Globalization and the Emerging Market Economies**
Dilip K. Das

46 **International Labor Mobility**
Unemployment and increasing returns to scale
Bharati Basu

The Economics and Management of Technological Diversification

Edited by John Cantwell, Alfonso Gambardella and Ove Granstrand

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

First published 2004
by Routledge
11 New Fetter Lane, London EC4P 4EE

Simultaneously published in the USA and Canada
by Routledge
29 West 35th Street, New York, NY 10001

Routledge is an imprint of the Taylor & Francis Group

This edition published in the Taylor & Francis e-Library, 2004.

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging in Publication Data
A catalog record for this book has been requested

ISBN 0-203-64203-1 Master e-book ISBN

ISBN 0-203-67465-0 (Adobe eReader Format)
ISBN 0-415-28570-4 (Print Edition)

Contents

Figures

Tables

Contributors

Stefano Breschi obtained his PhD from the Department of Economics, Università di Pavia (Italy) in 1994. He is Associate Professor of Industrial Economics and Deputy Director of CESPRI, Bocconi University, Milan, Italy. His main research interests are in the Economics of Technical Change, Industrial Organisation and Industrial Dynamics, Theory of the Firm and Networks, Economic Geography and Regional Economics. He participated in many national as well as international research projects of the European Commission and other institutions. Among his most recent publications: "Technological Regimes and Schumpeterian Patterns of Innovation", *Economic Journal* 110(463), 2000 (with F. Malerba and L. Orsenigo); "Networks of inventors and the location of academic research: An exploration of Italian data", *Research Policy* (forthcoming), (with M. Balconi and F. Lissoni); "Knowledge spillovers and local innovation systems: A critical survey", *Industrial and Corporate Change* 10(4), 2001 (with F. Lissoni).

John Cantwell is Professor of International Business at Rutgers University (USA), and on leave as Professor of International Economics at the University of Reading (UK). He has been a Visiting Professor at the University of Rome "La Sapienza", the University of the Social Sciences, Toulouse, and the University of Economics and Business Administration, Vienna. His 1989 book on Technological Innovation and Multinational Corporations helped to launch a new literature on multinational companies and technology creation, beyond merely international technology transfer, and this book alone has a cumulative social science journal citation count of well over 100. Altogether, in a career of less than 20 years so far, John Cantwell has published nine books, over 40 articles in refereed academic journals, and over 50 chapters in edited collections. He is a former President of the European International Business Academy, was an Associate Editor of the Journal of International Business Studies, and is an Associate Editor of the *Journal of Economic Behavior and Organization.*

Fabrizio Cesaroni obtained his PhD in Economics and Management of Innovation at the Sant'Anna School of Advanced Studies, Pisa, Italy with a thesis entitled "Technology Strategies in the Knowledge Economy", and he is currently research fellow at the same institution. His main research interests are in the economics and management of technology licensing, technology transfer and technology exploitation strategies, in both for-profit firms and no-profit research organisations, such as universities and public research laboratories.

Alfonso Gambardella obtained his PhD from the Department of Economics, Stanford University in 1991. He is Professor of Economics and Management at the Sant'Anna School of Advanced Studies, Pisa, Italy. His main research interests are Economics of Technical Change, Applied Industrial Organization and Strategic Management. He has been published in leading journals, and participated in several international research projects. In 2001 he co-authored *Markets for Technology: The Economics of Innovation and Corporate Strategy*, MIT Press, Cambridge, with Ahsish Arora and Andrea Fosfuri.

Paola Giuri is Assistant Professor in Economics and Management at Sant'Anna School of Advanced Studies in Pisa. She carried out research and teaching activities as Visiting Study Fellow at SPRU, University of Sussex with grants by the European Commission (TMR – Marie Curie Program) and by the Sant'Anna School in Pisa. She has a PhD in Economics and Management of Innovation and a Master in Management of Innovation from the Sant'Anna School. She teaches a course of strategy and is involved in the coordination of Management and Applied IO courses within the Doctoral Program of Economics and Management at Sant'Anna School. She is author of publications for journals such as *International Journal of Industrial Organization, Research Policy, Structural Change and Economic Dynamics* and of book chapters for Edward Elgar and Springer Verlag. Her current research activities are carried out within national and international research projects in the fields of economics of innovation and patenting, entrepreneurship and innovation in different regimes of IPR (in particular open-source software), large and small firms' technology strategies.

Ove Granstrand was educated at Chalmers University of Technology, University of Göteborg, Sweden and Stanford University with graduate degrees in mathematics, economics and engineering and a PhD in Industrial Management and Economics. His work experience includes teaching, research and consultancy in various Eastern and Western countries. He serves as Professor in Industrial Management and Economics at Chalmers University and Chairman of the Center for Intellectual Property Studies. His research interests concern economics and management of technology and innovation. In particular, he has studied innovation, corporate strategy and diversification in multi-technology corporations in Europe, Japan and the USA, as well as various issues related to R&D, intellectual property and intellectual capital more generally. He has authored and edited several books and articles on these topics, a recent one being *The Economics and Management of Intellectual Property. Towards Intellectual Capitalism* (Edward Elgar, 2000).

John Hagedoorn is Professor of Strategic Management at Maastricht University and professorial fellow with the Maastricht Economic Research Institute on Innovation and Technology. He has held visiting professor positions at the University of Sussex, Stanford University, The George Washington University, University of California at Berkeley and the University of Paris. His main fields of interest are: alliances, inter-firm networks, technological change, mergers and acquisitions and international business. His research has been published in journals such as the *Academy of Management Journal*, *Industrial and Corporate Change*, *International Studies of Management and Organization*, *Journal of International Business Studies*, *Journal of Management Studies*, *Journal of Common Market Studies*, *Organization Studies*, *Research Policy*, *Review of Industrial Organization*, *Strategic Management Journal*, and *World Development*.

Francesco Lissoni is Associate Professor of Applied Economics at the University of Brescia, Italy, specialising in Economics of Innovation, and Deputy Director of CESPRI, Bocconi University. He graduated from Bocconi University in 1990, and undertook his graduate study at the School of Economic Studies, University of Manchester, UK, 1992–1995. His publications deal with the adoption and diffusion of innovations, the economics of technology transfer and the geography of innovation. His work at CESPRI includes the creation of a number of patent-based datasets on technological activities by firms and individuals in the US, Europe and Japan.

Franco Malerba is Professor of Industrial Economics at Bocconi University, Milan, Italy, and Director of CESPRI, Research Center on Innovation and Internationalization, also Bocconi University. He received his PhD in Economics from Yale University. He is the editor of the journal *Industrial and Corporate Change*, advisory editor of *Research Policy*, and associate editor of the *Journal of Evolutionary Economics*. From 2002 through 2004 he holds the post of President of the International Schumpeter Society and in 2003 was elected President of EARIE – European Association of Research in Industrial Economics. His research expertise covers a variety of fields, including innovation, industrial dynamics, industrial economics, the Italian national system of innovation and European public policy. He has published extensively in journals such as *Research Policy*, *Economic Journal*, *Industrial and Corporate Change*, and *International Journal of Technology Management*.

Myriam Mariani is lecturer at the University of Camerino, Italy. Her research interests are in the economics of innovation. At present, she is investigating how much of the value of an innovation depends on firms' competencies *vis-à-vis* the geographical characteristics of the location in which the innovation is produced. She was a Marie Curie Fellow in 2000–2002 at Merit, University of Maastricht. She is currently a research fellow at the Laboratory of Economics and Management (LEM) of the Sant'Anna School of Advanced Studies in Pisa, Italy. She participated in research projects of the European Commission, DG Science and Technology.

Sandro Mendonça is lecturer at the Department of Economics of ISCTE University (University Institute of Business and Social Sciences), Lisbon, Portugal and a member of Dinâmia, Research Centre on Socio-Economic Change. He graduated in Economics (Technical University of Lisbon) and has an MSc in Science and Technology Policy from SPRU, University of Sussex, UK. He taught at Nova University of Lisbon and has been a researcher at CISEP, Research Centre on the Portuguese Economy. He has been involved in several international research projects and his work has appeared in journals like *Industrial and Corporate Change, Futures and Journal of Economic Issues.* He has provided advice to the Portuguese Ministry of Science and Higher Education, the Portuguese Patent and Trademark Office and the Ministry of Labour and Solidarity as well as private national and multinational business organisations. His professional interests are related to economics of innovation, science and technology policy and management, industrial dynamics, knowledge networks, organisational change, strategic foresight, business history and long-term technological change.

Fabio Pammolli is Professor of Economics and Management at the University of Florence. He is the Director of CERM, Center for Economic Analysis of Competitiveness and Market Regulation. His work has been published in, among others, *Management Science*, the *International Journal of Industrial Organization*, *Research Policy*, *Physica A*, *Small Business Economics*, and the *Revue of Economie Industrielle.*

Andrea Prencipe is Associate Professor of Economics and Management of Innovation at the Faculty of Economics, University G. d'Annunzio, Pescara, Italy and Fellow at the Science and Technology Policy Research Unit (SPRU), University of Sussex, UK. He holds a BA in Economics and Business, an MA in Innovation Management from the

Sant'Anna School of Advanced Studies, Pisa, Italy and an MSc in Technology Innovation Management from SPRU. He was awarded his PhD at SPRU for his thesis on the technology strategy of firms operating in the aeronautics industry. His research interests include organisational implications of modularity, division and coordination of innovative labour, organisational memory in project-based firms. He has published his work in *Administrative Science Quarterly, Industrial and Corporate Change, Journal of Management and Governance, Journal of Management Studies*, and *Research Policy.*

Lucia Piscitello is Associate Professor in Industrial Economics and Management in the Department of Economics and Production at the Politecnico de Milano. She is also Visiting Research Fellow in the Department of Economics at the University of Reading. Her main research areas are the economics of technological change and the theory of multinational enterprise. In a career of less than ten years so far, she has published 20 articles in refereed journals on the international aspects of technological change, and on multinational firms' corporate strategies.

Massimo Riccaboni is Assistant Professor of Economics and Management at the University of Florence. His work has been published in, among others, *Management Science,* the *International Journal of Industrial Organization,* and *Research Policy.*

Salvatore Torrisi is Associate Professor of "Economics and Management" at Camerino University, Italy. He graduated from Bocconi University (Economics), Italy, and obtained his PhD from SPRU, University of Sussex, UK. He has published various articles and books on issues concerning the economics and management of innovation, the impact of ICT on firm's capabilities and organisation, technological and business diversification, and the linkages between multinational corporations and host countries' firms. He has published in, among others, *Research Policy and Economics of Innovation and New Technology.* He is a Research Associate in the Laboratory of Economics and Management (LEM), Sant'Anna School of Advanced Studies, Pisa, Italy.

Preface

This book has grown out of ongoing discussions since the mid-1990s among a group of economists and management scholars on the puzzling nature of diversification in industry. Diversification with its many facets is at the core of the evolution of companies. Diversification has in fact more distant origins than the internationalisation of companies, despite the virtues of specialisation hailed since Adam Smith. In other words multi-product corporations (MPCs) predate multinational corporations (MNCs) as a phenomenon. At the same time most research, and there has been quite a lot of it, has not been able to show any strong positive links between product diversification and economic performance in terms of growth and profitability, quite the contrary. From being fashionable in the 1960s in the US and somewhat later in Europe, diversification fell completely out of fashion in the 1980s in the West, being replaced by its antidote specialisation, while it continued to flourish another decade or so in Japan and most NICs or near-NIC countries. Some observers even claimed diversification was the engine of the high-tech miracle in Japan, or at least a necessity for catching up. Thus, a number of questions arose. Are there different types of diversification, having different effects on economic growth? Had the pendulum of fashion in management and strategy swung too far, first towards diversification and then later back towards specialisation, wasting economic energy by overshooting? Is diversification a more suitable recipe for firms in developing countries that are catching up? Also more theoretical questions arose. In light of the resource-based view of the firm, should not resource diversification and its links with product diversification be addressed? Some research had pointed to the virtues of technology-related product diversification and the pivotal role of technological diversification for growth, even for highly specialised companies.

Questions like these were raised and discussed in a series of meetings, in Göteborg, Sweden 1997, Pisa, Italy 1998 and Pisa 2000, supplemented by various other informal meetings. Our group benefited from also becoming part of a related EU-funded project on “Dynamic capabilities, growth and long-term competitiveness of European firms: a diagnosis and the implications for EU policies” (Dynacom) which was coordinated by

Giovanni Dosi from 1998–2000. We decided early on to focus in particular on the phenomenon of corporate technological diversification and to write a book based on new research, of which there had so far not been much. Hereby, a hitherto new perspective on diversification in general could be added. This perspective could hopefully contribute to resolving some of the puzzles and, equally importantly, contribute to discovering new puzzles. Thus, this book is really a multi-authored book stemming from a long-term collaborative effort rather than an edited book stemming from a specific one-off conference. As such, we as editors (or lead authors) hope the book will prove to its readers to be reasonably coherent, besides being original and comprehensive about an emerging new line of research.

Along the way we have left ourselves with debt of gratitude in various ways. First and foremost we want to thank all the contributors for their endeavours. Some of us also thank others for their endurance. Ove Granstrand wants to thank the Swedish government agency for technical development NUTEK (now Vinnova), the Salén foundation and Telia for financial support. John Cantwell wishes to thank Kathryn Chapman, who was his secretary in Reading, and did a great job in coordinating our efforts as the book was collated, and we are also grateful to John Cantwell's father, J.D. Cantwell, who kindly compiled the index to the book. In finalising the manuscripts our thanks go to Eva Burford in Göteborg. Most recently, following John Cantwell's move to the US, we are extremely grateful to Katherina Glac for editorial assistance, without which this book could not have been finished.

Finally, but very importantly, we need to remember somebody else who sadly is no longer with us. Keith Pavitt was present at our early meetings, and this book is largely a result of his encouragement. It was Keith who was largely responsible for sharpening the formulation of the notion of corporate technological diversification, for stressing how centrally it connected with other key issues in the field of innovation studies, and then for popularising the concept and its use among a wider circle of researchers. He was without doubt a key intellectual inspiration for us in working on this topic, and in continuing to work on it. Keith was a great friend to all of us and we miss him greatly. We are proud to dedicate this book to the memory of Keith Pavitt.

John Cantwell
Reading, UK
and
Rutgers, NJ, USA

Alfonso Gambardella
Pisa, Italy

Ove Granstrand
Göteborg, Sweden
August 2003

Abbreviations

A-div	application diversification
ASICs	application specific integrated circuits
ATC	anatomic therapeutic classification
C&C	computers and communications
CAB	Civil Aeronautics Boards
CFD	computational fluid dynamics
CIPO	Canadian Intellectual Property Office
CTF	core technical fields
CV	coefficient of variation
DBFs	dedicated biotech firms
DIV	diversification
DSPs	digital signal processors
EPCs	established pharmaceutical companies
EPMD	external diversification in production and marketing activities
EPO	European Patent Office
ETD	external technological diversification
FAA	Federal Aviation Administration
FADEC	full authority digital engine control unit
GPT	general purpose technology
H	Herfindhal index
IAE	International Aero Engine
IATA	International Air Transport Association
ICT	information and communication technology
INPI	Institut National de la Propriété Industrielle
INT	internationalisation
IOM	industry of manufacture
IOU	industry of use
IPC	international patent classification
IT	information technology
ITD	internal technological diversification
ITT	International Telephone and Telegraph
JAA	Joint Aviation Authorities
LB	line of business

LDCs	less developed countries
LW	long wave
M&A	merger and acquisition
M-div	market diversification
MDS	multi-dimensional scaling
MNC	multi-national company
MPC	multi-product company
MPC/MTC	multi-product multi-technology corporation
MTC	multi-technology corporation
MTU	Motoren und Turbinen Union
NIH	not-invented here
OST	Observatoire des Sciences et des Techniques
OTAF	Office of Technology Assessment and Forecast of the USPTO
P-div	product diversification
P/L	profit and loss
PBX	private branch exchanges
PE	polyethylene
PHID	pharmaceutical industry database
PP	polypropylene
R&D	research and development
RR	relatedness ratio
RRSP	risk and revenue sharing partnership
RTA	revealed technological advantage
S&T	science and technology
SDC	Securities Data Company
SEFs	specialised engineering firms
SIC	standard industrial classification
SPRU	Science and Technology Policy Research Unit at the University of Sussex, UK
SR	specialisation ratio
SUPR	seemingly unrelated Poisson regression
T-div	technological diversification
TP-structure	technology-product structure
USPTO	US Patent and Trademark Office
WAR	weighted-average-relatedness
WARN	weighted-average-relatedness of neighbours.
YTC	Yale–Technology–Concordance

1 Technological and corporate diversification

John Cantwell, Alfonso Gambardella and Ove Granstrand

1 Introduction

1.1 To diversify or specialize? The diversification dilemma

To diversify or not to diversify – that is the question. As such it is and has been perpetually plaguing company managers and strategic advisors supposedly more decision-oriented than Hamlet. Companies have also been surprisingly Hamletian about it, and as with any soul-twisting strategic question, it has led to ambivalence, conflicts, delays, exaggerated responses and not seldom economic tragedy.

With the usual lag behind management practice, scholars (presumably more Hamletian than managers) in many quarters have in recent decades begun to be puzzled and plagued by the question.[1] At the center-stage of their analysis is the link between diversification and economic performance – a link still missing, despite much search and research, using a variety of tools.

1.2 Purpose

The purpose of this book is to provide a research-based view with a new perspective on corporate diversification, focusing on a particular dimension of diversification – namely, technological diversification and its economic and managerial implications.

1.3 Objectives of the book

A major motivation for this book is that while there are many contributions in the literature on the business diversification of firms, only very recently has there been some initial attempt to understand the patterns of corporate technological diversification, and their implications for several economic and managerial dimensions, such as internationalization, business diversification, economic performance etc. This book attempts to fill that gap. Moreover, in doing so, the book provides a systematic analysis of data, case studies, and other relevant material to understand this phenomenon. As a matter of fact, most of the contributing authors have significant experience with large data sets at the firm level on technological diversification and the other strategic dimensions mentioned. While having a clear analytic content, systematic use of (available) data is another important feature of this book.

The main issues that will be treated in the book are:

- technological diversification and product diversification;
- technological diversification and economic performance;
- technological diversification and internationalization;
- technological diversification and strategic alliances;
- cases of technological diversification in specific industries;
- corporate case studies of technological diversification;
- technological diversification and managerial and organizational issues.

1.4 General overview of the topic

Diversification as a general concept for extending activities of some sort into new areas obviously defines a very wide-ranging and pervasive topic. Diversification in this sense applies to various entities – human cells as well as humans, companies as well as industries, regions as well as nations etc. How human stem-cells diversify or differentiate is largely a puzzle (as of the time of writing) providing a hot research topic. How individuals with different competence profiles perform differently along a vector of high (low) specialization – low (high) diversification has always been an issue, for employers and employees alike, and not least for all students. Adam Smith, Frederick Taylor and Henry Ford settled the issue in favor of specialization, at least for manual tasks, while research in recent decades has instead been pointing towards the virtues of a moderate degree of diversification or multi-skilling. One of the earliest pieces of research on individual diversification in R&D is provided by Pelz and Andrews (1966). They found among many things that scientists with a moderate degree of diversification performed best (in a specified sense) while the best-performing engineers were either highly specialized or highly diversified (i.e. generalists). Why this difference occurs between science and engineering is still an unsolved puzzle.

At a regional level, one could observe industrial districts that are highly specialized such as in northern Italy, but others that are highly diversified such as in Silicon Valley; an observation that parallels the findings of Pelz and Andrews for engineers. Research on links between regional industrial diversity and economic performance is of recent origin and not yet conclusive, however. In a study of seven European core regions Cantwell and Iammarino (2001) find that a region like Basel is highly specialized while

Box 1.1 Adam Smith on specialization – diversification

Adam Smith reversed the causality of the conventional wisdom of his day that the differentiation of skills and abilities among individuals led to specialization; instead, according to Smith, specialization (the division of labor) led to the development of locally distinctive skills and capabilities (Loasby, 1999). For Smith, specialization led to a greater inventiveness, owing to the more focused problem-solving of workers themselves when concentrating on more narrowly defined tasks, owing to the emergence of specialist machine-makers, and owing to the emergence of specialist thinkers or integrators (which today might be thought of as the R&D function). With the tremendous increase in the use of machinery in production that followed Smith's day, and more so with the arrival of science-based and then information-based innovation that came later still, it would be fairer to say that technological change has more typically led the division of labor, and led the social organization of production. However, an enduring strength of Smith's approach is that he saw specialization and the creation of knowledge as co-evolving. The advance of knowledge depends upon a cumulative interaction between the processes of differentiation (the focus associated with specialization) and integration (the new combinations or new applications that result from utilizing a diversification of activity through discovering or exploiting complementarities between different fields).

one like the South-East of the UK is highly diversified, although they have both enjoyed success in their own ways. They show too that trends towards either a reinforcing or a broadening of specialization may equally well occur in the same large area (in this case Europe). A summary indicator of the degree of diversification (DIV) is given by the reciprocal of the coefficient of variation (CV), since CV is a measure of the degree of concentration of an index of specialization across sectors (the CV is the standard deviation divided by the mean of a distribution). Table 1.1 presents

Table 1.1 Technological diversification indicators for eight European regions for 1969–1977 and 1987–1996

	DIV (1969–1977)	*DIV (1987–1996)*
South-East UK	2.100	1.121
Basel region	0.440	0.381
Île de France	1.605	1.100
Stockholm-East Central Sweden	0.785	0.740
Baden-Württemberg	0.815	1.058
Flanders-Brussels	0.833	0.998
South Netherlands	0.811	0.838

Source: Cantwell and Iammarino (2001).

the diversification indicators in two time periods for eight European regions, with an increase in DIV indicating a rise in diversification, and a fall representing a more concentrated or narrower focus of specialization. As can be seen from Table 1.1 the South-East of the UK, the Basel region, Île de France and Stockholm-East Central Sweden have narrowed their regional specialization profile, while the profiles of the regions of Baden-Württemberg, Flanders-Brussels and South Netherlands show an increase in diversification.

Box 1.2 Should regions or countries diversify or specialize?

A study by Dalum *et al.* (1999) shows that specialization particularly in high opportunity technological areas has a positive impact on growth, but over the years this impact seems to have decreased. The relationship between specialization and growth has been found to be a complex one, since demand-side and supply-side mechanisms do not necessarily work in the same direction, which creates difficulties for policy makers. Considering that the observed path-dependency of profiles of specialization implies the feasibility of only incremental change, active policy to increase the degree of specialization in some favored areas might not result in an adequately fast response. Furthermore, as Cantwell and Iammarino (2001) have argued, the direction of cumulative change and diversification, depends also on the strategy followed by the MNCs that are active in the respective regions and how they interact with the local environmental conditions for innovation. Therefore the question "Should regions diversify or further specialize?" might rather become one of "Can policy makers influence the pattern of specialization?" and if the answer is no or very little, "Under which circumstances do regions specialize?"

The national level resembles the regional one to some extent in this context. Not surprisingly large nations like the US, India or Japan have a diversified industrial base, but there are diversified small countries as well. Sweden for example, has a highly diversified industry for her size, with a portfolio of industries that are also highly internationalized. The industry structure differs e.g. compared to Japan, in that Sweden has a diversified portfolio of large, weakly diversified MNCs, each with a small portfolio of specialized businesses, while Japan has a diversified portfolio of large, highly diversified MNCs. However, in contrast to regions it is difficult to find nations that are highly specialized, despite years of international trade, influenced by free-trade policies hailing the virtues of comparative advantage and the international division of labor.

The dynamic trends in trade and technological specialization patterns are not quite conclusive either (Laursen, 2000). Measuring the degree of specialization at a national level by the standard deviation of the cross-sectoral distribution of Revealed Symmetric Comparative Advantage (for trade) or of Revealed Symmetric Technological Advantage (for the pattern of technological activity), an increase in the standard deviation represents a rise in the degree of concentration of the index across fields or a narrowing of specialization. Conversely, a fall in the standard deviation of the indicator denotes an increased diversification or a broadening out of specialization. The ratio of the standard deviation around 1990 to the equivalent about 20 years earlier is shown in Table 1.2 for the OECD countries – ratios above one indicate a rise in the standard deviation (higher concentration or more focused specialization), values below one represent a fall (lower concentration or greater diversification). While overall the degree of international trade specialization has slightly decreased over the long term, i.e. a rise in diversification has occurred, the findings for technological specialization do not show the same clear trend, which might be an indication that "countries increasingly specialize according to consumer preferences (for differentiated products within the same industry) rather than specializing in different industries" (Laursen, 2000: 434).

Table 1.2 The development of specialization patterns for the OECD countries

	Ratio of the degree of concentration of export specialization in 1992 to that in 1965	*Ratio of the degree of concentration of technology specialization in 1989–1991 to that in 1971–1973*
Australia	0.97	0.78
Austria	0.89	1.10
Belgium	0.96	0.98
Canada	0.88	0.99
Denmark	0.88	0.88
Finland	0.91	0.89
France	0.90	0.49
Germany	0.70	0.95
Greece	1.10	0.89
Italy	1.06	1.14
Ireland	0.95	n.a.
Japan	1.07	1.11
The Netherlands	0.94	1.00
New Zealand	1.20	0.89
Norway	0.92	0.82
Portugal	0.84	0.93
Spain	0.57	0.79
Switzerland	0.96	n.a.
Sweden	0.91	0.69
Turkey	0.83	n.a.
The United Kingdom	0.80	1.19
The United States	1.01	2.18
Mean	0.91	0.98

Sources: Trade specialization data: Dalum *et al.* (1998). Technological specialization data: Laursen (2000).

Perhaps some degree of moderate diversity of national industries is a good thing even in a free trade world with various comparative advantages, dispersed around the globe. Thus, Pasinetti (1981) has argued that owing to the stimulus for improvement provided by import competition, and the benefits from learning and applying technologies that are developed elsewhere – which idea can be extended to the potential for inter-industry spillovers – it is better for a country not to become too narrowly specialized.

Finally, at the company level, which is our focus, diversification is a key strategic variable together with a few others like internationalization. In this context, diversification is usually taken to mean extending the company's portfolio of products or businesses into new product or business areas. (In this sense, diversification includes vertical integration.) Few aspects of strategy have stirred as much controversy as diversification. This is despite its key role in the evolution of companies historically, and its long standing as a phenomenon, actually preceding internationalization.

In fact, in a general sense that will be explained in the following chapters, corporate (or company) diversification together with its converse, divestment or de-diversification, are dual processes that define corporate evolution. It is thus quite natural that strategic decisions about entering and exiting specific areas stir up controversies among company owners and managers from time to time.

Box 1.3 Natural resource-based diversification – the case of Stora Kopparberg

The Scandinavian corporation Stora Kopparberg (later named Stora, and subsequently merged to form Stora-Enso) is claimed to be one of the world's oldest joint stock limited companies, established as it was by royal charter in 1347. Thus, the company has a long history and it illustrates nicely the diversification dynamics of a natural resource-based company. As of 2003 the company has entirely left its original core business (copper mining) and transformed itself into an integrated forest-product concern, i.e. it is still a natural but now a renewable resource-based company. The firm was founded as a mining company based on a giant deposit of rich copper ore in Falun in mid-Sweden. The extraction of the ore required, among other things, wood for construction, heating and smelting, power for hoisting and logistics, ropes for hoisting and a number of mechanical devices for efficient operations, for instance a water wheel, which in its own day was as important as was the steam engine in a later era. At the same time the composition of ore enabled production of some other metals and by-products, such as iron sulfur, red paint and vinegar. Needless to say, technical and managerial knowledge and skills from running a host of mining-related operations also provided a wide range of opportunities to enter new businesses. At the same time resource depletion imposed exits.

Thus over the centuries, on the input side the composition and availability of the mined resources, as well as the composition of other inputs needed for efficient mining led the company to diversify outside its core copper business into forestry, water power, iron, paint, food and various other areas. Let us mention just two specific by-product related examples of such "evolutionary business chains". Ropes for hoisting ore were made of ox hides with ox meat as a by-product from which (still very popular) sausages were made. The copper ore was vitriolic which led the company to successfully produce a special type of red paint (still very popular for painting houses red, which is characteristic of rural Scandinavian villages). On the output side several of the company's outputs were generic (as with key metals and materials in general) and created broad interfaces with many product areas and customer business chains, which provided opportunities for forward integration (e.g. into copper cannons and coins) or into other related types of diversification (e.g. iron works).

There were also diversification failures. Less commonly at the time, one such failure was R&D-related. A gifted inventor, Christopher Polhem, managed in the early eighteenth century the equivalent of a corporate R&D lab ("Laboratorium Mechanicum") and made numerous inventions, as well as basic contributions to mechanical technologies and to mechanical science. However, their cost-effectiveness for the company was dubious and their continued implementation eventually came to be opposed by corporate management, providing an early example of the failure of the transfer of technology from corporate R&D to business operations.

Over the centuries the company moved its business base considerably through entries and exits and eventually moved away from its business roots in copper mining. To briefly summarize the main forces behind a 650-year long business history of diversification is difficult but some salient features have been: (a) a dynamic (evolutionary) interaction between business (output) diversification and resource (input) diversification with business diversification being driven by (b) generic applicability of outputs and (c) resource composition of both outputs (requiring mixes of existing and new inputs) and inputs (enabling economically successful mixes of existing and new businesses, e.g. through new knowledge and by-products); (d) resource availability (e.g. abundant but depletable resources, enabling as well as compelling diversification); governed by (e) market, management and institutional factors (e.g. weak competition, corporate wealth, entrepreneurship and regulation).

The nature of controversy in the industrial and financial community relates to whether a diversification strategy or corporate policy conducive to diversification in general pays off or not. Separation of ownership and management has created problems with owners and managers having separate goals (i.e. principal agent problems) and different types of diversification support different goals. As will be dealt with in Chapter 2, diversification into completely unrelated businesses is in a certain sense a superior strategy for risk-reduction, while diversification into related businesses is preferable for sustaining growth. Profitability in turn is influenced by the nature of relatedness, which is a somewhat complex issue in itself, and the magnitude of market transaction costs and management costs. If external financial markets are perceived as more efficient than internal capital markets in companies, investors may then prefer to diversify their portfolio of holdings themselves, investing in an unconnected set of specialized companies, while corporate managers with different preferences and perceptions may want to diversify their portfolio of businesses to boost growth and stabilize earnings, which are in turn conducive to their bonuses, salaries and status. Thus, at a company level, diversification can occur at several related levels – at the investor level as between different firms or at the individual company level or at the divisional and business unit level within large corporations. Diversification processes at different levels may then be at least partially in conflict with one another due to their differing goals.

Sources of diversification controversies go beyond goal conflicts between and among owners and managers, however. It is in the nature of corporate strategies that they easily become perceived in one period as new and innovative, experience some initial successes, become overimitated and carried to extremes, then produce some failures and overreactions to other extremes in another period with some delays from place to place. Diversification as a strategy came into fashion in the 1950s and 1960s in the US for various reasons – the emergence of a new organizational form (M-form), accounting capabilities, information processing capabilities and a general top-management ideology, all enabling management of a more complex set of businesses. In addition growth opportunities were abundant in numerous old and new product areas (including military ones), the financial markets were not as developed – at least compared to internal capital markets in some leading companies – and on top tax conditions and anti-trust considerations were favorable to diversification. This period was characterized by a scale-based paradigm linked, for example, to oil-related technologies (Freeman and Perez, 1988), and there was a premium attached to large firm size (Chandler, 1990).

The diversification fashion spread to Europe, aided by US consultancy firms to some extent. At the same time large diversified corporations had emerged in Europe long before (e.g. Philips, Siemens) and long ago also in developing countries catching up, Japan in particular, but for another set of reasons connected with the benefits of applying what was learned from foreign technologies across a broader front. Thus, the diversification wave gained momentum but after a number of conspicuous failures of highly unrelated conglomerates (e.g. ITT, RCA) and otherwise over-diversified companies, de-diversification set in, eventually leading to a wave of specialization in the 1980s and 1990s, termed variously back to basics, stick to your knitting, a focus on core business, downsizing, stemming, outsourcing etc. This movement – or rather set of connected movements – was now fuelled by developments in financial markets and financial management, accompanied by activated ownership shifting power from corporate management to corporate boards and shifting focus to shareholder value, in turn requiring company transparency for stock analysts, and a number of value-creating company splits and sell-outs or public offerings of single businesses. International competition had also increased considerably since the 1960s together with some recessions, calling for readjustments and new strategies. These events were allied to a shift in paradigm toward so-called flexible specialization linked to information-related technologies, which required a tighter control over the holding of inventories but a greater responsiveness to (sometimes subtle) changes in demand. Pressures for greater technological diversification to support any given product range were also a factor (Granstrand, Patel and Pavitt, 1997), as well as limitations on the resource spread that could be sustained, given that any given product now required a more widely distributed set of competences.

At the same time the 1980s were the high tide for technology-related diversification in Japan, appearing at the top of strategic issues in several polls of key management concerns and being praised as one factor behind Japan's technology-based economic success. In connection with studies of technology related diversification and diversification Japanese style in particular, the prevalence and importance of technological diversification, i.e. extension of corporate activities into new technological areas, thereby extending the technology base, became recognized if not discovered. This was a phenomenon of long standing, of course, but its magnitude, even in specialized companies, and apparently strong links to growth of sales as well as growth of R&D and external technology acquisitions was a new finding.

A certain backlash against diversification then occurred with the severe economic downturn in Japan in the 1990s. Still a number of highly diversified corporations have prevailed in Japan as well as in the NICs and near-NICs and so too has General Electric in the US throughout the years as one of the most highly diversified as well as valued corporations in the world (as of the time of writing). Markides' (1995) survey of diversification trends at the corporate level (for Fortune 500 firms), as presented in Tables 1.3 and 1.4, shows an initial increase in diversification starting around 1950 and into the 1970s, followed by a subsequent refocusing and

Table 1.3 Refocusing and diversification, 1949 to 1987 (%)

	1949–1959	*1959–1969*	*1981–1987*
Firms refocusing	1.3	1.1	20.4
Firms diversifying	21.7	25.0	8.5

Source: Markides (1995).

Table 1.4 Distribution of firms by diversification strategy, 1949 to 1987 (% in each category)

Strategic category	*1949*	*1959*	*1974*	*1981*	*1987*
Single business	42.0	22.8	14.4	23.8	30.4
Dominant business	28.2	31.3	22.6	31.9	28.1
Related business	25.7	38.6	42.3	21.9	22.4
Unrelated business	4.1	7.3	20.7	22.4	19.0

Source: Markides (1995).

declining diversification from the 1980s onwards. While the refocusing efforts are similar across firms in different countries, there might be societal and structural barriers, such as the socially embedded Japanese keiretsu system, which inhibit the same level of refocusing as was achieved in the US.

Of course the account given above is very simplified as it is of necessity brief and sweeping, but hopefully it conveys some general patterns and issues about diversification strategies and movements. Internationalization and globalization movements on the other hand have been more unidirectional on average, although counter-trends have occurred as well (e.g. regarding the creation of fully global products or fully denationalized MNCs). The benefits to companies from internationalization have also been clearer. It is still uncertain whether diversification pays off and what type and degree of diversification should be sought in different situations, apart from a consensus that pure conglomerate diversification does not pay off as a rule, in other words that diversification has to be related. As mentioned already empirical research has not found strong links between (product) diversification and economic performance, despite numerous attempts with a variety of research tools. The state-of-art regarding such a link is more like an absence of evidence than evidence of absence, however. Part of the problem, as we will see, is that concepts, typologies and measurements of diversification are not yet sufficiently developed. Finally, various theories of the firm have provided little predictive or normative guidance beyond explaining why firms diversify if they do and what determines in the abstract the boundaries of the firm. True, there are versions of neo-classical theory or mathematical programming models of the firm that have worked out optimality conditions for multi-product, multi-factor firms operating in markets under static competitive or monopolistic conditions, but they have little to say about optimal degrees and types of relatedness in diversification under dynamic conditions or optimal transformation of product, market and factor mixes in multi-period settings. The latter limitation (regarding transformation) also applies to a number of econometric studies that have used aggregate measures or indicators of diversity without recognizing the identity of individual products and resources and their mutual coupling.

1.5 Key concepts

1.5.1 General definition

Generally speaking "diversification" can be taken to mean the degree of spread the range of activities or outcomes of activities A associated with some organized unit B. Thus, in this book by diversification we mean the level of the breadth or spread of some dispersed activities, and not the process by which that dispersion might be extended, which in our terms would amount to an increase (a change) in the diversification of activities or outcomes A. In the context here, B can be a company, industry, nation or region as well as an individual or a collection of individuals, while A can refer to a set of portfolio of products, applications or markets, or resources like technologies, competencies, or labor skills. Usually the elements in the set A are classified or categorized according to some taxonomy (typology, decomposition, disaggregation) and extending the range means including from one point in time to another new elements of a new type (class, category) not covered at the previous point in time. Thus, the concept of diversification and its measurement depends upon the choice of classification and points in time considered. What makes the definition somewhat ambiguous is that an increase in diversification may also occur if diversity is increased, which may happen even without any extension of the range, depending upon how diversity (variety, dispersion, heterogeneity) is measured, as explained further below. Essentially we have a definite, discrete distribution of elements in a number of classes and a possibly multi-dimensional diversity measure defined on the set of such distributions, and such a measure could very well increase without including elements of new types. Besides numerous diversity measures are conceivable.

1.5.2 Types of diversification

From the point of view of a firm a number of types of diversification can now be defined. Traditionally diversification has referred to the range and distribution of outputs of the firm, classified in terms of products, (output) markets or businesses. Here we complement these types of *output diversification* with different types of *input diversification* or resource diversification. These latter types refer to the range and distribution of inputs (factors, resources) of the firm, classified not only in terms of raw materials, physical capital, and financial assets but also in terms of technologies, knowledge, competences, IPRs, network relationships and other forms of intangible inputs (resources, assets, capital). In particular, we will focus in this survey on *technological diversification,* which is then liable to increase as the diversity of technologies is increased. Technologies are usually taken to mean bodies of technical knowledge, thus making technological diversification a special case of *knowledge diversification* (or *competence diversification*). Thus, in the evolution of a multiproduct, multifactor firm, diversification takes place both in product space and in resource space, giving rise to *diversification trajectories* in these spaces. If the original range (set of types of products or factors) remains unchanged, then diversification is (product or factor) *rooted*, otherwise it is *floating*. The *direction of diversification* refers to the direction of the trajectory in those spaces. Concurrent diversification, which is referred to by some authors as "hybrid diversification", is diversification that takes place in several dimensions concurrently (which has proven to be risky).

Market diversification usually refers to the diversification of output markets. In cases where regional or national markets are focused, market diversification amounts to the same thing as internationalization.[2] In cases in which the applications to which products or techniques are put are focused one can speak of application diversification. The latter concept has not been dealt with traditionally, but extension over time of the range of applications for new products and technologies is an important phenomenon, especially for generic (pervasive, multi-purpose) technologies (by definition). Based on some notion of relationships or relatedness (see below) between the old and the new elements included, diversification could be further characterized as related or unrelated. The unrelated form is also referred to as conglomerate diversification, meaning diversification which is unrelated except for financial and managerial relationships within the same (conglomerate) firm. When the relationships are buyer/seller relations, diversification amounts to vertical integration (or vertical diversification), while horizontal (or lateral) diversification (or integration) involves competitive relationships.[3]

Two modes of diversification are generally distinguished – diversification through internal development and diversification through acquisition.

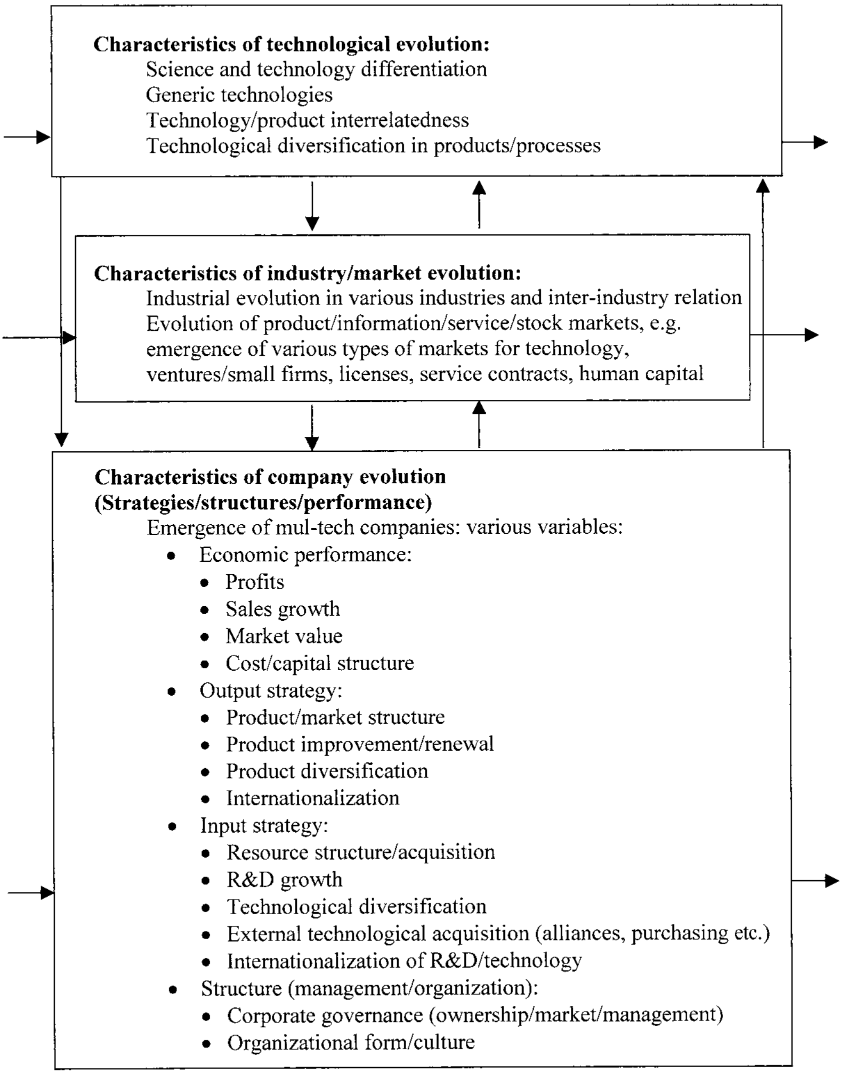
1.5.3 Related concepts

Diversification involving an extension of the firm's range of inputs and/or outputs into new types is essentially the same as *entry*. If the new types are not only new to the firm but new to the world, diversification is essentially the same as *invention*, and if commercially successful the same as *innovation*.[4]

Product differentiation could be seen as a special case of related product diversification if product types are distinguished at a fine level of detail. However, usually product diversification is distinguished from product differentiation with the latter referring to increasing the range of product varieties within a specific but not too narrowly defined product area or or group. See Lancaster (1990) for an excellent survey.

1.6 *Overview of the book*

Figure 1.1 provides an overview of the topic as reflected in the structure of the book. The book is divided into four parts.



NB: 'Technology' could be taken to include relevant sciences.

Figure 1.1 Economics and management of technological and corporate diversification.

1.6.1 Overview of topic and book structure

Chapter 2 reviews the literature on corporate and technological diversification. Among other things, it focuses on the nature (and theory) of the multi-product/multi-technology firm. The chapter also sets the stage for the following chapters by highlighting issues in the literature and in practice on the relationships between technological diversification and economic performance, product diversification, internationalization, corporate governance and organization, etc.

Chapter 3 uses European patent data to provide an overall picture of the patterns of technological diversification in Europe. The paper uses a new methodology developed by the authors to assess the extent of technological diversification in different industries. It then focuses on comparisons of the patterns of technological diversification among larger and smaller firms, and among different countries and regions.

Chapter 4 uses US patent data of the world's largest firms since the beginning of the century. The chapter focuses on how the internationalization process of the firms affects and is affected by technological diversification. It is shown that owing to the mutual association of the diversification and internationalization of corporate technology with the growth of the firm's competence base, internationalization influences diversification (and vice versa). Historically they were negatively related, while more recently they are positively related. However, the negative historical linkage operates only through the mutual interdependence of each of diversification and internationalization with growth, while the more recent positive relationship between diversification and internationalization holds even after allowing for their respective interplay with growth.

Chapter 5 uses extensive data on strategic alliances to address questions such as: How do strategic alliances affect technological diversification and to what extent do firms use alliances to diversify technologically? What are the relevant patterns? The chapter also compares the behavior of the largest US, European and Japanese firms in different industries, and it will assess the relationships between technological diversification and the patterns of product and business diversification developed through strategic alliances.

Chapter 6 deals with the patterns of technological diversification in a leading hi-tech industry, pharmaceuticals-biotech. Using regression analyses, the chapter assesses the extent to which technological diversification affects the licensing behavior (in and out) of the companies (whether large firms or biotech concerns), and the effects of more "generic" vs more specific pharmaceutical technologies. The chapter uses an extensive and original data base on drug R&D projects in the world.

Chapter 7 focuses on the chemical processing industry and the relationships between the internal technological competencies and diversification of the large chemical corporations worldwide, and their propensity to license out such technologies. On a more general ground, the chapter assesses the extent to which technological diversification is also used by the larger corporations to acquire rents in the "market for technology", rather than simply as a means for using different and broad technological bases for their own products and businesses. The chemical processing industry is a natural test-bed for this question, as it provides a variety of examples of different strategies and implications in this context. The chapter uses an extensive data base of the licensing activities of the major chemical companies worldwide.

Chapter 8 examines the differences in movement toward technological diversification across technological fields, particularly focusing on the tendency of firms to patent in ICT when they patent outside their core technical domains. An analysis of patent data of the 200 largest US manufacturing firms shows that large firms are increasingly diversifying into ICT, Drugs and Biotech, and Materials technology and that the ICT field attracts more patents of companies patenting outside their core technical fields than other technologies. It is argued that the expansion of the ICT component in the corporate knowledge base may be a specific feature of an ongoing process of structural change associated with the arrival of the new techno-economic paradigm.

Chapter 9 investigates the dynamics of the boundaries of firms operating in the aircraft industry and to what extent engine manufacturers externalize parts of their activities in relation to the research, design, development and manufacture of new engines. The nature of the aircraft engine, which is a multitechnology and multicomponent product, combined with the existence of various driving forces that impinge upon the in-house technological capabilities of the engine manufacturer lead to greater division of labor between the manufacturer and the suppliers. However, the extensive use of collaborative agreements and outsourcing of components does not imply a technological specialization or outsourcing of knowledge. Rather, the need to coordinate the network of diverse actors, integrate the different knowledge domains, translate regulatory requirements into technical specifications and identify business opportunities requires the engine makers to maintain a broad range of in-house technological capabilities. The analysis of patent data confirms this argument and shows that the breadth of capabilities has increased over time.

Chapter 10 focuses on case studies of individual firms. The approach is to examine the corporate technological trajectories of selected large firms in the chemical and electrical equipment industries through their patterns of US patenting, with reference to the relevant business history literature. The chapter highlights economic, strategic and managerial issues behind the diversification of firms, emphasizing technological diversification and its relationships to business diversification and the various other dimensions mentioned earlier. It is suggested that the underlying rationale behind technological diversification has shifted from one linked to business diversification and scale historically, to the benefits of increasing technological interrelatedness more recently.

Chapter 11 deals with the way technologically (and product- or business-) diversified firms are managed and organized. How are these firms typically managed and organized? What specific managerial assets and capabilities are required by technologically and/or business-diversified firms? What specific organizational assets and characteristics do they require? The chapter develops cases of new and innovative managerial and organizational practices in technologically (and product or business) diversified firms. It also compares cases from Europe, the US and Japan, building on a large interview and questionnaire study.

Chapter 12 finally summarizes the preceding chapters and provides overall conclusions. It highlights six key themes that have emerged, and also attempts to point toward fruitful directions for further research and theorizing.

Notes

1 One of the main themes at the annual meeting of the American Economic Association in 2001 was announced as: "Corporate Diversification: Good, Bad or Neutral?"

2 Internationalization will not be dealt with in this survey. Despite its close conceptual relationship to diversification, the literature on internationalization and MNCs is quite separate from the literature on diversification and MPCs, although several works on strategy cover both phenomena and their interaction.

3 Some authors speak about diversification as distinct from vertical integration.

4 Extension of the range may be taken to mean a net extension after also allowing for any divestments, or a gross extension with or without divestments. Here extension is used in the latter sense.

References

Cantwell, J.A. and Iammarino, S. (2001), "EU regions and multinational corporations: change, stability and strengthening of technological comparative advantages", *Industrial and Corporate Change*, 10 (4), 1007–1037.

Chandler, A.D. (1990), *Scale and Scope: The Dynamics of International Capitalism*, Cambridge and London: Harvard University Press.

Dalum, B., Laursen, K. and Verspagen, B. (1999), "Does specialization matter for growth?", *Industrial and Corporate Change*, 8 (2), 267–288.

Dalum, B., Laursen, K. and Villumsen, G. (1998), "Structural change in OECD export specialization patterns: de-specialization and 'stickiness' ", *International Review of Applied Economics*, 12 (3), 423–443.

Freeman, C. and Perez, C. (1988), "Structural crises of adjustment, business cycles and investment behaviour", in G. Dosi, C. Freeman, R.R. Nelson, G. Silverberg and L.L.G. Soete (eds), *Technical Change and Economic Theory*, London: Frances Pinter.

Granstrand, O., Patel, P. and Pavitt, K.L.R. (1997), "Multi-technology corporations: why they have 'distributed' rather than 'distinctive core' competencies", *California Management Review*, 39 (1), 8–25.

Lancaster, K.J. (1990), "The economics of product variety: a survey", *Marketing Science*, 9 (3), 189–206.

Laursen, K. (2000), "Do export and technological specialisation patterns co-evolve in terms of convergence or divergence? Evidence from 19 OECD countries, 1971–1991", *Journal of Evolutionary Economics*, 10 (4), 415–436.

Loasby, B.J. (1999), *Knowledge, Institutions and Evolution in Economics: The Graz Schumpeter Lectures*, London and New York: Routledge.

Markides, C.C. (1995), *Diversification, Refocusing, and Economic Performance*, Cambridge and London: MIT Press.

Pasinetti, L.L. (1981), *Structural Change and Economic Growth: A Theoretical Essay on the Dynamics of the Wealth of Nations*, Cambridge and New York: Cambridge University Press.

Pelz, D.C. and Andrews, F.M. (1966), *Scientists in Organizations – Productive Climates for Research and Development*, London and New York: John Wiley and Sons.

Part I

Background

2 Technological and business diversification

A survey of theories and empirical evidence

Salvatore Torrisi and Ove Granstrand

1 Introduction

Most economics and business literature focuses on business or product diversification. A standard dichotomy is between related and unrelated diversification, but little is in fact known about the nature of the alleged positive relationship between business diversification and particular resources such as different technologies. This chapter attempts to fill in part of this gap by making a survey that draws on various streams of the theoretical and empirical literature – economics, strategic management and technology management.

The analysis of the linkages between technology and business diversification is of fundamental importance to understand the difference between related and unrelated diversification, the differences among sectors and the economic implications of competence diversity.

The main questions addressed in this chapter are the following. What does diversity mean for firms? Do firms *converge* or diverge in their technological and product profiles and if so, why? Which factors affect the decision to differentiate the mix of technological capabilities and lines of business? What does it mean for a firm to enter different technologies and sectors?

Firms' diversity and diversification, and their implications for performance, are treated with different emphasis in various lines of economics and business research. The business history, the evolutionary theory and the resource-based theory of the firm share the idea that firms are bundles of capabilities, intangible resources and organisational routines that are difficult to replicate and transfer across firms. The accumulation of technological, market and organisational knowledge is characterised by path dependency, tacitness, idiosyncrasy and complex interactions within the firm and across firms. All these characteristics make the knowledge profile of the firm highly specific, differentiated and persistent over time (Nelson and Winter, 1982). In this view, the evolution of business diversification and corporate performance reflects the accumulation of firm-specific, often unique, technological and organisational capabilities (Winter, 1993; Chandler, 1990).

In the standard industrial organisation literature, firms' capabilities as such do not explain the diversity of firms' strategy and performance. Firms participating in the same industry tend to converge towards similar strategies and performance. In this stream of the literature, corporate and business-unit effects on the performance of business units are reported to be far less important than industry-specific effects (Schmalensee, 1985). Empirical studies in business strategy have provided mixed evidence as to what is the relative importance of firm or organisational-specific factors vs industry-specific ones in the generation of corporate quasi-rents (see, for example, Rumelt, 1991; McGahan and Porter, 1997). For instance, Rumelt (1991) found that differences in corporate returns reflect differences in corporate business portfolios. However, contrary to the expectations of the 'resource-based' theory and other streams of the business strategy literature, he did not find any evidence of 'synergy' among diverse business units belonging to the same corporation. Ironically, these results apparently contradict earlier empirical evidence, pioneered by Rumelt himself, which highlighted the economic benefits of related diversification and exploitation of quasi-public inputs, including technology (e.g., Rumelt, 1974).

This chapter is organised as follows. Section 2 is centred on the patterns of technology and business diversification reported in the literature. Section 3 focuses on the comparison among different theories. Section 4 summarises the similarities and differences between technology and business diversification, and discusses some management implications. Section 5 closes the chapter while the Appendix provides a brief illustration of concepts and measures of diversification.

2 Empirical evidence

2.1 Business diversification

2.1.1 Early conceptualisations of diversification

Generally and loosely speaking, 'diversification' can be taken to mean the process through which the range of some thing A, associated to some thing B is extended or the diversity of A is increased. In the context here, B can be a company, industry, nation or region as well as an individual, or collectivity of individuals, while A can refer to a set of portfolio of products, applications or markets, or resources like technologies, competencies or labour skills. Usually the elements in the set A are classified or categorised according to some taxonomy (typology, decomposition, disaggregation) and extending the range means including, from one point in time to another, new elements of a new type (class, category) not covered at the previous point in time. Thus the concept of diversification depends upon the choice of classification and point in time considered.

The economics and strategic management literature provides several and sometimes contrasting definitions of diversification. For instance, in his seminal work Gort (1962) defined diversification as 'heterogeneity of output' which derives from low cross-elasticity of demand and high costs of reallocation of inputs across different lines of businesses. Ansoff (1957) defined diversification as the process of entry into a new market area and/or a new product area (new to the company, not necessarily new to the markets). This definition overlaps with that of product innovation (i.e. products new to the market) in the economics and management of innovation.[1] Similarly, Booz, Allen and Hamilton (1985) defined diversification as a strategy pursued by investing in new products or services, new customer segments or new geographical markets (internationalisation). Ramanujam and Varadarajan (1989) defined diversification as entry of a firm or business unit into new lines of activity. Following Chandler's and Rumelt's seminal works on the relationship between strategy and structure, Ramanujam and Varadarajan clarify that diversification must imply changes in the 'administrative structure, systems and other management processes' (ibid., p. 525). Extensions of product lines (and therefore product innovations in themselves) without any organisational implications do not qualify for business diversification in their terminology

2.1.2 From conglomerate diversification to de-diversification?

The evidence collected by Gort (1962) and Rumelt (1974) for the US firms showed several patterns of diversification during the period between 1929 and 1969.

Gort (1962) analysed a sample of 111 large US manufacturing firms between 1929 and 1954 and found that the specialisation ratio (SR) declined (diversification increased) over time. The sample firms did not appear to follow a random selection of sectors for their diversification. Instead, they diversified mostly into industries with rapid technological change and thus contributed to the growth of these industries. Over the same period, however, many new single-product firms entered these markets, so that the average degree of diversification of the US manufacturing industries increased only slightly. Firms based in R&D intensive sectors (electrical machinery) diversified more than the average while, on the contrary, firms based in more traditional sectors (tobacco and food products) diversified less than the average.

The evidence reported by Rumelt (1974) shows a more complex picture. He has developed the first categorical measures of diversification and introduced a diversification taxonomy, which relies on the SR, which is the percentage of total sales accounted for by the largest line of business of the firm, and a relatedness ratio (RR), which is the percentage of related lines of business (see the Appendix for these definitions).

Examining data for the 500 largest US firms listed in Fortune, Rumelt found that single business firms as a share of total firms declined sharply from 42 per cent in 1949 to about 15 per cent in 1969. Over the same period, the percentage of related-linked and unrelated business firms grew dramatically (from about 9 per cent and 4 per cent to 20 per cent and 19 per cent, respectively), while the percentage of other categories of diversified firms remained relatively stable. This trend continued through the mid-1970s (Rumelt, 1974, p. vi). An illustrative example of this evolution is represented by Carborundum, Inc. During the period between 1949 and 1969 this firm grew by following a Related-Constrained strategy to exploit its basic competence, which was represented by 'the efficient production of high quality grains of silicon carbide and aluminium oxide, and the competence in the material sciences necessary to engineer these materials to various uses' such as abrasives, electrical resistors and heating elements (ibid., pp. 18–19). Since 1962, however, Carborundum initiated a Related-Linked strategy:

> The skills acquired in manufacturing abrasive machines were applied to other types of industrial machinery, and nonabrasive cleaning and descaling equipment was added . . . by adding new businesses in such a way that each was related to at least one – but often no more than one – of its current activities.
>
> (ibid., p. 19)

Rumelt also noticed that the increase of overall diversification (both related and unrelated) was paralleled by a dramatic diffusion of the product-division organisation, which was adopted by 20 per cent of the sample firms in 1949 and 76 per cent in 1969. These quantitative studies have been paralleled by a vast amount of qualitative evidence collected by business historians who have illustrated the growth of diversified and multidivisional firms in the US after World War II (Chandler, 1990, and Box 2.1).

Box 2.1 Related diversification: The case of Du Pont after World War I

The chemical firms after World War I grew by exploiting their organisational capabilities. Business diversification of these firms was sustained by the adoption of the multidivisional structure and the organisational capabilities formed through the exploitation of economies of scope.

For industrial chemical firms the period between the two wars was characterised by rapid growth and diversification driven by economies of scope arising from products and processes of production and distribution. For consumer chemicals, food and electrical machinery the leading firms grew both by exploitation of economies of scale (and internationalisation) and economies of scope (diversification). Growth by M&As often was also explicitly aimed at exploiting economies of scope. For instance, the five companies that formed Allied Chemical & Dye in 1920 pursued 'Greater diversification of output and correspondingly greater stability of business . . . not to mention the various economies in operation ordinarily available only to an organisation of the scope here contemplated' (The Committee of Organisation, reported in Chandler (1990, p. 179)).

Du Pont pioneered both the strategy of diversification and the adoption of the M-form. At the beginning of the 1920s Du Pont's organisational capabilities relied fundamentally on the exploitation of nitrocellulose technology used in the production of explosives and propellants. During the 1920s and the 1930s Du Pont diversified first into dyestuffs and ammonia by using German technology and then developed proprietary technologies in the field of organic chemicals (tetraethyllead, a gasoline additive jointly developed with General Motors, and Freon, a refrigerant for household refrigerators, and Teflon, a material resistant to acid and other corrosive substances). The incentives to engage in a diversification strategy came first from the need to employ underutilised resources. As a matter of fact, in 1915 the Executive Committee of Du Pont established an 'Excess Plant Utilisation Division' in its Development Department (Chandler, 1990, p. 176). The incentives to continue diversification, however, came from new market opportunities (ibid., p. 189). The entry into synthetic materials, synthetic ammonia, gasoline additives, fast drying lacquers, refrigerators, antifreeze, titanium dioxide pigments, nylon and neoprene were developed by the fundamental research laboratories as 'clear responses to market opportunities' (ibid.). The collaboration with General Motors, where Du Pont invested, greatly helped to catch market opportunities and to find technical solutions.

The strategy of diversification adopted by other chemical firms in the US intensified competition and favoured lateral entry. Most firms that entered new or established market segments were established, diversifying firms like Du Pont. Increasing competition during the two world wars spurred Du Pont to invest in fundamental research while diversification required a greater ability to understand technological complexity of product and processes.

Finally, the organisational complexity induced by growth and diversification greatly contributed to separate management from control. Unlike many chemical firms where full-time, career managers 'controlled the instruments of power', at Du Pont family members continued to hold more than 2 per cent of the company stock and held top-level positions in the corporation (as inside directors or full-time managers) until World War II. Even in firms where the separation between ownership and control was more marked there was a substantial convergence of interests (i.e., to achieve long-term profits) between inside and outside directors.

Source: Chandler, 1990, ch. 5

Many firms that diversified during the 1960s and 1970s have restructured and re-focused their businesses activities in the subsequent decades. Something happened in the economic environment, especially in the US, that led these firms to change their strategy.

Empirical evidence concerning the US market shows that the number of firms listed in the NYSE with only one line of business (LB) rose from 38.1 per cent in 1979 to 55.7 per cent in 1988 (Comment and Jarrell, 1995). It is unclear to what extent this is the result of refocusing of diversified firms or the entry of new single-product firms.

Other studies on US firms have explored the degree of coherence or relatedness in the 1970s and 1980s (Scott, 1993; Teece *et al.*, 1994). These studies draw on objective, continuous measures of diversification and reach the conclusion that the observed diversification of their sample firms is far more 'coherent' or 'purposive' than that expected under the null hypothesis of random walk ('Clearly multimarket contact among large US manufacturers is far more than would occur by chance', Scott, 1993, p. 46).[2]

In-depth case studies of eight European MNCs reported in Granstrand (1982) showed that innovation-based engineering companies internationalised early on while they diversified (beyond of few product areas) much later, around the booming 1960s, considerably influenced by management ideas and consultants from the US, leading also to the rapid adoption of the M-form. The latter enabled better top management control of growth and diversification. Good economic performance also had a positive impact on diversification initiatives. Raw-material and chemical-based companies, on the other hand, diversified early on while they started to internationalise late, again around the 1960s. In the 1970s diversification had failed to deliver results and became significantly de-emphasised as a strategy by corporate management in contrast to internationalisation, especially in the innovation based companies. At the same time an economic recession during the same years had set in and competition stiffened in Europe, not least from Asia.

More recent large-scale investigations reveal that firms operating in Europe actually show a diversification pattern similar to that observed in the US (Davies and Lyons, 1996). These studies draw on LBs' sales data concerning a sample of 313 manufacturing firms (of which 223 are diversified) operating in Europe (including the subsidiaries of non-European multinationals) for 1987. The average sample firm operates in 4.9 3-digit SIC sectors (related diversification) and 2.89 2-digit sectors (unrelated diversification); 28 per cent of firms' total output is outside their primary 3-digit sector while only 17 per cent of total output is outside the primary 2-digit sector. This study does not provide any evidence of the LBs' performance as a result of firm diversification.

However, the picture of de-diversification during the 1980s is more complicated than that described before. US firms which have restructured in the 1980s show a bimodal (or trimodal) distribution: related-diversified have reduced their diversification while unrelated-diversified have increased their diversification (Hoskisson and Johnson, 1992). Moreover, if one looks at the largest 500 firms in the US, their level of diversification (measured by the number of SIC codes assigned by Compustat) has remained high if not increased during the period 1985–1992 (Montgomery, 1994). Montgomery also notices that there are persistent, significant differences across countries, with firms of Canada, the UK and Japan remaining among the most diversified worldwide (ibid., p. 164).

Why are there still many conglomerate firms while many others refocus their business? Hoskisson and Johnson (1992) suggest that some firms aim (and are able) to exploit the financial economies arising from unrelated diversification. Another conjecture is that diversification is a profitable strategy in the long run. It is also likely that firms with long experience in unrelated sectors have developed a unique ability to exploit the benefits and to reduce the costs of unrelated diversification. Although business history shows several examples of firms, such as RCA, that have dissipated core competencies and failed because of excessive diversification, there are examples of thriving, highly diversified firms with General Electric as a prime example. In the 1960s and 1970s unrelated diversification was often pursued by M&As (Ravenscraft and Scherer, 1987), sometimes also as an unintended consequence of them. A large number of divestitures in the 1980s had as an object earlier acquisitions in businesses unrelated to the firms' core business (Montgomery, 1994, p. 170). For this reason, several empirical studies have focused on M&As rather than internal growth to analyse business diversification. As we discuss later on, however, internal growth is the most traditional way to exploit 'excess resources' and quasi-public input. Today the exploitation of internal inputs or resources requires the access to complementary resources external to the firm. This should make the association between related diversification and M&As more likely. For example, the majority of M&As registered in the software industry between 1984 and 1992 were centred in the same industry and a pattern of related diversification was also observed in the strategic alliances of the largest EU electronics firms during 1984–1997 (Torrisi, 1999; Giarratana and Torrisi, 2002).

Most studies of diversification have concerned US firms, some studies European firms and comparatively few studies (in English at least) Asian and other firms. However, this pattern does not match the extent of diversification in non-Western firms, as it is quite common with large, highly diversified business groups in NICs, near-NICs and other developing countries. Thus, our understanding of the causes and consequences of the propensity for diversified groups and conglomerates to emerge in these countries is limited, although less so for Japan. The propensity is clear, however, with well-known zaibatsu's and later keiretsu's in Japan, chaebols in Korea, large state-owned conglomerates in China, Russia etc., complemented by private ones as in India, Brazil and Indonesia. Often firm growth in developing countries takes the form of vertical integration rather than horizontal integration or diversification. One economic rationale is that diversified groups fulfil an important economic function as a response to relative market inefficiencies, characteristic for developing countries but also typical of certain sectors such as natural resource processing and chemicals. However, a whole range of institutional, political, social, historical and cultural factors come into play, such as state-led industrialisation, political connections in a political-economic elite, procurement policies, political ideologies, protectionism, import substitution, defence politics, bank-oriented finance systems, competition laws, inheritance laws, tax laws, employment rules, nepotism etc. (see further e.g. Suzuki (1980), Chang and Hong (2002) and Chu (1999)).

2.1.3 Diversification and performance

The literature on business diversification relies on different measures of performance, all of which have merits and drawbacks (see Appendix for a comparison).

In his pioneering exploration of diversification, Gort (1962) did not find any significant association between diversification and firms' performance measured by sales growth and profit rates. Rumelt (1974) reached more clear-cut conclusions. His analysis shows that Dominant-Constrained firms (very moderate diversifiers) and Related-Constrained (moderate related diversifiers) performed well above the average in terms of sales growth and profit rates. By contrast, the profitability of Acquisitive Conglomerates (unrelated diversifiers whose growth is based on M&As) was on average while their sales growth was above the average. According to Rumelt these results show the benefits of 'controlled diversity'. The best performers have grown by diversifying only into sectors that build on or reinforce the 'central strength or competence' of the firm (ibid., p. 151). Rumelt has subsequently analysed the performance of US manufacturing firms in the period between 1974 and 1977 and did not find evidence of corporate synergy (Rumelt, 1991). His analysis shows that the performance of the corporate's business units was largely explained by business-specific resources rather than corporate resources. And different sectors offer different opportunities of rent creation.

Further empirical evidence, however, shows a positive relationship between refocusing and firm performance. This evidence largely focuses on the process of restructuring and business re-focusing occurring in the US during the 1980s and the 1990s. For example, the analysis of Census Bureau data on over 17,000 manufacturing establishments in the US shows that increasing business focus during the 1980s had positive effects on plant total factor productivity (Lichtenberg, 1992). Moreover, Ravenscraft and Scherer (1987) noted that post-merger performance (accounting profits) of acquired firms under new ownership declined particularly in pure conglomerate acquisitions 'in which the parents' managerial experience was least well-suited to crisis problem solving (ibid., p. 193).

Similar results are shown by the analysis of stock market performance of diversified firms. The market reaction to related and unrelated acquisitions did not differ in the 1970s, while in the 1980s 45.6 per cent of bidders in related acquisitions had positive stock returns against only 32.2 per cent of bidders in unrelated acquisitions (Morck *et al.*, 1990).

By the same token, Comment and Jarrell (1995) show a positive correlation between revenue-based Herfindhal index and stock return, while other works indicate a positive correlation between related diversification, profitability and Tobin's *q*, which is the ratio between the market value and the replacement costs of assets, usually confined to physical assets (Rumelt, 1974; Markides, 1995; Robbins and Wiersema, 1995; Montgomery and Wernerfelt, 1988).[3]

More recent empirical evidence also shows that conglomerate growth reduces the market value of the firm. For example, Berger and Ofek (1995) analysed the importance of conglomerate discount, i.e., they found that the market valuation of the internal unit of a multidivisional firm is lower than for a corresponding specialised firm. The amount of corporate discount is significant (between 13 per cent and 15 per cent) and increases with diversification. Denis *et al.* (1999) show that the conglomerate discount is particularly high in firms with low ownership concentration (manager-controlled corporations). They also found that the Tobin's *q* is lower in manager-controlled corporations than in owner-controlled ones. Other studies also show that internally controlled firms with large-block ownership by corporate insiders show a better performance (Amihud and Lev, 1999, p. 1066).

A careful analysis of the relationship between diversification and Tobin's *q* is made by Lang and Stulz (1994), who show a negative effect of diversification on q, even when controlling for industry effects and other variables commonly used to explain q (e.g., size, access to capital market, R&D intensity).[4] Lang and Stulz, however, admit that their results do not clarify to what extent diversification has negative effects on performance. They found that US firms that diversified during the 1980s performed poorly before increasing their level of diversification. Probably, these firms diversified to find new, and more profitable, investment opportunities outside their existing businesses. Post-diversification performance then might depend on which sectors these firms entered (whether related or unrelated to existing businesses) (ibid., p. 1278). This analysis points out that the interpretation of the association between diversification and performance is controversial.

To summarise the empirical analysis discussed so far, it is worth highlighting two major results:

1 Business diversification has become more 'coherent' or 'purposive' during the 1980s and 1990s, even though there are still many diversified firms around, including conglomerate diversifiers, which require further, fine-grained empirical evidence and theoretical explanations;
2 The performance of the firms (either profits, productivity or stock returns) appears to be positively related with business focus or related diversification, but the interpretation of relationships between diversification and performance remains quite controversial.

In section 3 we provide various, often contrasting, explanations of these results.

2.2 Technological diversification

The evidence about technological diversification shows that firms large and small, single-product or multi-product tend to increase the diversity of their technical capabilities over time as a result of exploration of and experimentation with new technologies, and especially the fact that products and processes become increasingly multi-technological ('mul-tech' rather than hi-tech) over time. At the same time the demand and competitive supply of new technologies increase and firms increasingly acquire them externally to save money and time as a complement to their in-house R&D. Moreover, the variety of technologies developed in-house tends to be larger than product variety, although these varieties are different and not easily comparable. Furthermore, multi-technology corporations combine new technologies with old technical capabilities, even though new technologies may substitute for old ones and have destructive effects on established firms that find it difficult to exist old technologies and/or to perceive (and respond quickly to) the opportunities and challenges arising from new technologies. Finally, technological diversification can be described as an evolutionary process and the pattern of entries and exits to and from various technological areas can be represented by 'technological trajectories'.

2.2.1 Increasing technological diversification and multi-technology firms

There is a body of empirical studies focusing on the phenomenon of technological diversification at various levels and also its relations to business diversification (e.g., Pavitt *et al.*, 1989; Patel and Pavitt, 1994a and 1994b; Granstrand *et al.*, 1997; Gambardella and Torrisi, 1998).

Of course, diversity of S&T and R&D activities has always been observed, but less systematic attention has been paid to the processes of diversification. In case studies of large firms Granstrand (1982) identified four types of R&D (or technology) diversification and close connections between growth, diversification and internationalisation of the firms and growth, diversification and internationalisation of their R&D, with the former processes usually spurring the latter. Kodama (1986) and Pavitt *et al.* (1989) pioneered the notion of technological diversification at industry level and the notion of technology fusion (Kodama), e.g. of mechanical and electronic engineering into mechatronics.[5] Granstrand *et al.* (1989) made case studies of technological diversification in Japanese firms and Swedish firms, with a first although crude indication of a significant positive impact of technological diversification upon growth of firms (Granstrand and Sjölander, 1990). This study was extended to interview and questionnaire studies of 14 Japanese, 20 European and 16 US large firms, accounting for significant shares of industrial R&D in the world, confirming the prevalence of technological diversification as a phenomenon and its links to growth of sales, product diversification, growth of R&D costs and external acquisition of technologies (Granstrand *et al.*, 1992; Granstrand, 1998). Oskarsson (1993) extended the sample of large firms further to 57 large OECD firms, confirming and elaborating previous results, plus identifying strategic groups of firms employing different sequences of technology, product and market diversification (T-div, P-div and M-div respectively, M-div denoting internationalisation). The fastest-growing group were so-called 'aggressive diversifiers', with T-div followed by P-div and/or M-div, with Canon as a prime example. The results were not significantly influenced by type of technology (or of type of region) and thus were not solely a result of the advent of generic or general-purpose technologies, such as ICTs, although their genericness was important.

In this set of studies, technology management capabilities were also assessed, albeit qualitatively, with Japanese firms on average being most dedicated to diversification and representing best practices regarding management thereof. In contrast to the US and Europe a majority of large Japanese corporations had large central laboratories for long-range, strategic, interdivisional R&D. A centralised technology management structure at corporate level was also common in order to reap economies of scale, scope and speed. Technology issues were of top concern in the corporations, which all had a vice president with corporate-wide executive powers. Intra-firm (interdivisional, interfunctional) technology coordination and transfer was much attended to and relatively successful, largely because of intra-firm mobility of engineers and communication-rich corporate behaviour. Japanese industry had developed special skills in exploiting new technologies commercially through synergetic product and technological diversification, speed to technology and speed to market, application and user orientation and IP protection, licensing and patent monitoring.

A set of related studies has been conducted by Keith Pavitt with Pari Patel and other colleagues at SPRU. They analysed 440 large firms in 1970–1990 and found that these firms have been granted a large share of patents by the US Patent Office in technical fields outside their expected core or distinctive technologies (reported in Granstrand *et al.*, 1997). For instance, firms operating in electrical/electronics industries were granted over 34 per cent of patents in nonelectrical and electronic fields, chemical firms 33 per cent outside chemical fields and automobile firms outside the transportation field.

Many of these firms accumulate technological capabilities in nonelectrical machinery, instruments and controls, chemical processes and computing to develop other products that embody a rising amount of these technologies. Obviously, the comparison between technology and business diversification is potentially biased by different classification criteria, but the level of aggregation used is sufficiently high to make such comparisons quite meaningful. For instance, firms were classified in one out of sixteen product groups (e.g., pharmaceuticals, computers and motor vehicles) and their technical activities into 34 technology fields (e.g., drugs and bioengineering, calculators and computers, road and vehicle engines). These scholars also report on few case studies that illustrate the importance of technological diversification and the process of 'competence accumulation' over time. For instance, Rolls Royce has increased the number of technologies in which it has competencies and exited only one technology between the 1970s and the 1990s (piston engines) (cf. ibid., p. 13). At Rolls Royce established core technologies have continued to co-evolve with new technologies such as electronic sensors, displays and simulators. The example of Ericsson is also useful (see Box 2.2).

Drawing on patent shares and revealed technological advantage, the authors classify firms' technological competencies into four categories – distinctive technologies, background technologies, marginal technologies and niche technologies.[6] Distinctive technologies are those where the firm has a share above the average and an RTA above 2 (which indicates a marked specialisation in a given technology). This category corresponds to Prahalad and Hamel's 'core competencies'. Other categories represent different combinations of patent shares and RTAs. This exercise in technology mapping confirms that many large multi-technology corporations accumulate a significant share of technical capabilities outside the field of their distinctive competencies, although there are differences across firms of different sectors. For instance, 76 per cent of Bayer's patents during 1985–1990 were in organic chemistry while only 19 per cent of Ford's patents were concentrated in vehicles and engines, with instrumentation and production technologies representing over 43 per cent of its technological competencies. To summarise the main result of this analysis, we can conclude that core technical competence does not describe accurately the range of relevant technologies that a multiproduct firm has to possess to maintain a sustainable competitive advantage. The reasons for these patterns of technological diversification are illustrated later on (see section 3.2).

Box 2.2 Increasing technological variety in multi-technology corporations: the case of Ericsson

Ericsson is a telecom equipment manufacturer that until the 1950s relied mostly on electro-mechanical switching, cable transmission technologies and radio transmission technologies. With the microelectronic 'revolution' Ericsson invested in digital switching technologies to modernise its traditional core business (equipment and cables for public telephony) and entered a new business (cellular mobile communication) by combining new digital switching technology with its established radio technology. Technological diversification required significant investments and led to a considerable increase in R&D costs after the 1950s. R&D expenditures reached 20 per cent of total sales in 1990 and the number of engineers rose by over 80 per cent between the 1980s and the 1990s. A variety of new skills were hired (electronics engineers, physicists and computer scientists) but also the number of traditional mechanical engineers rose dramatically (by over 260 per cent) over the same period. The number of technologies embodied in Ericsson's products grew accordingly – from 5 to 14 between the earliest and the latest generation of cellular phones (NMT-450 and GSM, respectively) and from 5 to 10 between the traditional coaxial to the new optical telecom cables. The number of patent classes in which Ericsson was active in this period rose as well – from 17 to 29 for cellular phones and from 14 to 17 for cables. As a consequence of this rising technological diversification, R&D costs increased dramatically. It is important to note that new technologies embodied in new product generations have not replaced Ericsson's established technologies – in only two cases has this firm exited a technology field. This is therefore a case of 'competence accumulation' that dominates 'competence destroying' in the technological activities of multiproduct corporations.

Source: Granstrand *et al.*, 1997, pp. 14–15

2.2.2 General-purpose technologies and diversification

To conclude the analysis of technological diversification we now focus on the pattern of evolution of technical capabilities at the firm level. In particular, we are interested in the direction and timing of entry in new technical fields by a firm that has expertise in another technical field. This issue has been addressed by Kim and Kogut (1996) who highlight the importance of 'platform technologies' as a source of options for diversifying in new technical fields and markets.

Scholars of technical change have analysed the role of natural trajectories which, broadly speaking, represent paths of technical change for the solution of specific sets of problems, such as aircraft design, that are driven by bottlenecks, experience and technicians' beliefs about which directions can be pursued and which scientific principles or technologies can be referred to (Rosenberg, 1976; Nelson and Winter, 1982; Dosi, 1982).[7]

Technological trajectories imply that technical change takes given directions as a consequence of dynamic increasing returns and path dependence – i.e., the direction of future research is affected by the firm's past experience with specific technologies. The process of technology branching then is not a random walk but an evolutionary process characterised by cumulativeness and 'local' search. However, the patterns of technological evolution vary across technologies and industries. In particular, there are technologies, such as electricity and information technology, which have many potential applications in different sectors and can be combined with a multitude of other technologies (e.g., mechanical engineering or chemistry) (Bresnahan and Trajtenberg, 1995; Bresnahan and Gambardella, 1998; David and Wright, 1999). The knowledge of these 'generic' or 'general-purpose' technologies provides firms with significant opportunities to try different applications and therefore to enter a variety of markets. Kim and Kogut (1996) have analysed the patterns of diversification in US semiconductors firms and explored how expertise in 'platform technologies' (which correspond to 'general purpose technologies') impacts upon the pattern of diversification. They rely on technical literature, expert opinions and patent histories to see whether the experience in a given technical field serves as a platform to enter another technical (and business) field. The history of semiconductors shows that the evolution of memories is dynamically and cross-sectionally related to a variety of other subfields such as application-specific integrated circuits (ASICs), digital signal processors (DSPs) and telecommunications (which are a hybrid of analogue and digital technologies). By contrast, other technologies, such as microcomponents and optoelectronics, appear to be unrelated to other subfields (cf. Kim and Kogut, 1996, table 3, p. 289). These scholars have also analysed the conditional waiting time, or hazard, of diversification. They estimated the probability to enter a market (and technology) **i** at time **t** given no previous diversification in the sector as a function of the firm's experience in other markets (and technologies) and other controls, including the growth of the target market.[8] Logit regression analysis confirms that experience in memory leads to faster diversification than other technologies.

These results suggest that subfields such as memory serve as 'platform technologies' or 'general-purpose-technologies' since they offer options to enter a variety of other subfields and can be combined with many other technologies. By contrast, other technologies, like ASICs, can represent a source of 'competence traps' for the firm because of strong lock-in effects.

2.3 Technological diversification, business diversification and performance

Is there any causal link between technology and business diversification? In theory, there is a two-way relationship between them. On the one hand, the larger and diversified a firm is the larger are its opportunities to appropriate the results of diversified R&D activities (Nelson, 1959). On the other hand, the more diversified the body of technology of a firm is, the greater is its incentive to enter a variety of markets, including technology markets.

In fact, many high-growth firms in different countries and industries seem to follow a sequential diversification path, starting with technological diversification and then increasing their product or market diversification (Oskarsson, 1993; Granstrand, 1998). This pattern can be described as follows. For a given product, new customer requirements and technological opportunities spur the firm to acquire or develop new technologies (product-related technological diversification). The increased scope of technological capabilities then pushes the firm towards technology-related product diversification, which allows the firm to exploit economies of scale and scope (ibid., p. 473).

The pattern of evolution varies across countries and industries. For example, firms whose main activities belong to electrical and mechanical engineering show a pattern of ‘rooted’ diversification (which corresponds to Rumelt’s related-constrained diversification), sticking to the original product business area, while firms in raw materials and chemicals appear to follow a type of ‘floating diversification’ (which corresponds to Rumelt’s related-linked diversification).

From a normative perspective, it is important to see whether the differences discussed between technology and business diversification impact upon the performance of the firm. Gambardella and Torrisi (1998) analysed the patterns of diversification of the largest US and European ICT firms listed in Fortune 500 between 1984 and 1992. They found that technological and business diversification have opposite effects on performance (sales growth and labour productivity), with technological diversification showing a positive effect. They explain these findings by noting that product and process complexity, and imperfections in the market for technology, lead firms to widen the span of technologies that they have to monitor and use to keep abreast of innovation in their own core sectors. On the other hand, the expansion of business activities in areas distant from the firm’s core business is limited by managerial and marketing bottlenecks which generate barriers to diversification even across technologically related sectors, such as telecommunications equipment and computers (see Box 2.3 for an example).[9]

Box 2.3 Barriers to diversification: the case of AT&T

With the divestiture in 1984, AT&T was allowed to utilise the same sales forces for telecommunications equipment and computers. At that time, AT&T top management was convinced that a telephone network was like a big computer and therefore they could have easily entered the computer market. AT&T’s diversification strategy was mostly pursued through M&As and agreements as a way to complement the great technological capabilities of its Information Systems division and the Bell Labs. The main attempts to enter the computer market are the following. First, the strategic alliance with Olivetti in 1984, which ended up at the end of the 1980s after AT&T's computer division registered negative results.

In 1987 AT&T signed an agreement with Sun Microsystems, a new firm specialised in RISC-based workstations. In 1991 AT&T acquired NCR (National Cash Registers) and sold its 19 per cent stake in Sun Microsystems. AT&T strong technology was complemented by NCR's large installed base of customers in the financial and retail sectors. NCR had also a strong international position (about 60 per cent of its sales came from abroad). seeming to underestimate the differences between computers and telecommunications activities, AT&T appointed as NCR chief executive officer Jerre Stead, a former president of AT&T's Global Business Communications Systems unit, with experience in PBX (private branch exchanges), wireless communications equipment, voice recognition and messaging. The poor performance of AT&T Information Systems division after the acquisition of NCR and the problematic combination of telecommunications service and equipment reveal that economies of scope from this business mix are not easy to achieve, despite technological convergence.

A major source of economies of scope is the use of quasi-public inputs across different lines of business. In the case of AT&T this means that important inputs such as sales and software consulting, employed, for example, in the PBX division, could be utilised at no extra cost in the computer division. However, the differences across the type of customers and the specificity of products have probably reduced the importance of this source of economies of scope. Another source of economies of scope are spillovers. Potential spillovers are those from AT&T's capabilities in digital networks technology to computer networks services and facility management for the financial sector which are the domain of NCR's competencies. The poor performance of AT&T's computer division indicates that, despite technological spillovers, there are few economies of joint production and commercialisation of telecommunications equipment and computers. Moreover, AT&T was not able to cover the high fixed costs required by the downstream assets that are specific to the computer market because of NCR's relatively small market share (about 2 per cent in 1990). In 1995 AT&T broke up its activities into three separate companies: AT&T Services which includes its core business (long distance network services) and mobile telephone, AT&T network equipment and AT&T Global Information Systems. After a decade of attempts, AT&T top management came to the conclusion that 'synergy is dead, and the concept of converging communications and computer markets, which drove the NCR deal, is an illusion'. Probably, if NCR had continued its business on its own performance would have not been much different than that registered after the acquisition. However, the separation from AT&T's core business should reduce misallocation of resources and improve managerial efficiency of computer activities.

Source: Gambardella and Torrisi (1998) based on *Business Week*, January 20, 1992, p. 36; *Datamation*, June 15, 1989, p. 84; *Financial Times*, June 4, 1991, p. 17; *Electronic Business*, May 1993, p. 35; *Datamation*, June 15, 1991, p. 12; *Business Week*, October 2, 1995, p. 28

Unlike earlier studies that have focused on the incentives to over-diversification, these results point out the importance of barriers to business diversification. Besides technological capabilities, business diversification requires other 'complementary' capabilities that established firms may be unable to develop promptly. The inability to develop these capabilities may have destructive effects on established firms.[10] As Pavitt (1998) has pointed out, these effects have mostly to do with the inability to develop the organisational capabilities required for 'linking technologies, products, their production and their markets'. Thus, most stories of failure reported by the literature (e.g., photolithographic aligners in Henderson and Clark (1990) and computer disk driver's in Christensen and Rosenbloom (1995)), 'had less to do with cognitive failure by design engineers to recognise the value of alternative product architectures, than with organisational factors', including the inability to recognise the changes in 'value network' introduced by architectural innovations (see Christensen and Rosenbloom, 1995). Even though this body of the literature is mostly centred on the competition between established firms and newcomers, the concept of complementary capabilities is useful to understand the patterns of business diversification and the differences with technological diversification.

3 Theory

Why is business focus positively associated with firm performance? Why do conglomerate firms still exist and, on some occasions, continue to make profits? What is the role of technology in business diversification?

This section addresses these questions by focusing on different strands of the literature on diversification. The survey of the literature is far from being exhaustive. Here we try to take account primarily of more recent studies published during the 1990s in order to complete in part the picture sketched in earlier surveys, such as that of Ramanujam and Varadarajan (1989), and to highlight the role of new explanatory factors. Moreover, our survey departs from earlier ones because we explicitly attempt to point at the links between theories of business diversification and theories of multi-technology firms.

3.1 Business diversification

The body of theoretical explanations of business diversification is very articulated. In order to simplify the discussion we can group these studies into four main approaches in research.

3.1.1 Superiority of internal capital market

The first approach draws on the idea that diversification is a strategy that allows firms to increase efficiency conditional upon various kinds of imperfections in the input markets, especially in the capital market (Gort, 1962; Rumelt, 1974). The inefficiency of arms'-length market transactions compared with hierarchy arises from information asymmetry, complexity and uncertainty, bounded rationality and transaction-specific investments (Williamson, 1970 and 1985). The main hypothesis of this theory is that lateral integration (diversification) leads to greater efficiency provided that the corporate structure is adapted to a wide product and market scope. Diversified firms then have to adopt a multidivisional form of organisation if they want to exploit the economies of the internal capital market and to keep division managers under the control of stakeholders. This approach can explain why there still exist conglomerate firms even after the wave of de-diversification and refocusing occurred during the 1980s and 1990s. But it does not help to explain the direction of diversification.

3.1.2 Economies of scope

A second approach combines the transaction-cost economics with economies of scope. The main underlying idea is that diversification is an efficient strategy when the production function exhibits given characteristics (super additivity) and the markets for intermediary goods (financial capital and knowledge) are inefficient compared to alternative governance mechanisms (hierarchy) (Panzar and Willig, 1981; Teece, 1980). This approach is fundamentally static in nature, since it posits that the rational firm plans the level of lateral or vertical integration on the basis of the degree of economies of scale and the cost of use of the price mechanism at a given time. However, it is possible to cast the concept of quasi-public inputs into a dynamic framework, where firms grow and diversify to exploit internal excess resources and thus enjoy dynamic economies of scale and scope (Penrose, 1959). Not surprisingly, this latter view of diversification has become popular in business history studies (Chandler, 1990) and the strategic management literature, and is often referred to as the 'resource view' because of its emphasis on the accumulation of intangible resources and capabilities (Montgomery, 1994).

3.1.3 Agency costs

The third approach, based on the agency theory, is very popular in the financial economics literature. This approach points to diversification, particularly unrelated diversification, as the (inefficient) result of 'free cash flow' and the separation between management and control (Jensen and Meckling, 1976; Amihud and Lev, 1981; Jensen, 1986). Contrary to what is predicted by the transaction-cost approach, multidivisional, conglomerate firms tend to produce a suboptimal level of diversification and a below-average corporate performance. For the advocates of agency theory, internal incentives adopted in multidivisional firms are not enough to induce efficient managerial behaviour. Only the financial markets (i.e., the threat of takeover, leverage buyouts etc.) can impose discipline on managers by forcing them to invest in projects with a positive net present value.

3.1.4 Market power and strategic interactions

The fourth approach is entrenched in the industrial organisation tradition and considers diversification as the (inefficient) result of strategic interaction and rent-seeking. Originally, this approach pointed to the relationship between multi-market contact and market power. This approach posits that multimarket contact favours the emergence of 'spheres of influence' and recognition of interdependence among diversified firms (Edwards, 1955; Bernheim and Whinston, 1990; Scott, 1993). In the new industrial organisation literature, diversification is also viewed as the result of the strategic interaction among non-collusive competitors (Deneffe, 1993; Dixon, 1994). In what follows we analyse these different approaches by focusing on the following dimensions:

- the key variables that are used to explain business diversification and the main predictions of each theory;
- the implications for the evolution of industry structure;
- the impact of diversification on private and public efficiency;
- the association between diversification and the organisation of the firm.

3.1.5 Excess capacity, internal capital market and corporate diversification

The earliest studies on business diversification highlighted two basic explanatory factors of diversification. First, excess capacity of productive factors that can be exploited through firm growth. Second, the reduction of corporate risk which is made possible by the diversification of the products/markets portfolio. These two variables are used to explain both related and unrelated (conglomerate) diversification.

As for excess capacity, Chandler (1962) and Penrose (1959) pointed to the economies arising from the use of idle capacity. In particular, Penrose emphasised the importance of accumulated excess intangible resources (management, technical-engineering and R&D knowledge) as a source of dynamic economies of growth and diversification. Similar arguments have been used by scholars of multinational corporations to explain international expansion with the use of 'generalist' skills (see Dunning, 1993, for a survey). Subsequent studies on business diversification have also pointed out the crucial role of 'general management skills' in modern, diversified, divisionalised firms. For instance, Rumelt (1974) has made the point that 'training and effective employment of generalists must become the prime concern of any firm that has goals that include growth by diversification or participation in the new technologies that quickly produce a proliferation of new products' (ibid., p. 157). Also technical skills represent another critical input that can be re-used to nurture diversification, especially if one considers that firms usually tend to enter into industries characterised by rapid growth and technical change. Analysing the patterns of diversification of US firms between 1929 and 1954, Gort (1962) noticed 'firms that employed in their main activities a relatively large number of technical personnel were in a stronger position to enter industries that had proved most attractive as diversification outlets, and thus diversified more frequently than other firms' (ibid., pp. 6–7). These considerations highlight the importance of quasi-public inputs whose role in explaining related diversification is reprised in subsequent, more formal studies that we discuss later on.

The second motivation for diversification discussed in these pioneering studies on diversification is represented by risk reduction. By adding products to existing lines of business a diversifying firm can take advantage of asynchronous peaks and downturns across different industries with different cyclical patterns. The reduction of risk and the stabilisation of profits and total sales is a reason for random, unrelated diversification (ibid., p. 106). Drawing on Markovitz's (1959) theory of diversification of financial portfolios, Rumelt (1974) claims that the optimal diversification strategy is different from that postulated by the advocates of the random walk hypothesis (unrelated diversification). In the presence of major economic cycles, which affect the majority of industries, investments in completely unrelated areas are too risky while in normal economic conditions this strategy yields only average performance. By contrast, 'controlled diversification' can reduce a particular type of risk which is that associated with product lifecycles rather than random market variability per se. To reduce corporate risk the business portfolio of the firm has to include products positioned in different stages of their lifecycle: 'the best defence against a declining market is not a new unrelated activity but a new product that is functionally related to the reasons for the declining sales or profitability of the old' (ibid., p. 81).

Despite the different views about risk diversification, both Gort and Rumelt believe in the superiority of the corporate financial market compared with the external capital market. This superiority is primarily attributable to the ability of generalist managers to evaluate projects that are intrinsically difficult to evaluate by outsiders. As a matter of fact, the financial markets often produce random discrepancies in buyers' and sellers' valuations of assets and this makes the internal capital market relatively more efficient (Gort, 1962, ch. 1). Relatedly, diversified firms can quickly relocate resources across industries with different growth and profit rates (Gort, 1962, p. 4; Rumelt, 1974, p. 159).[11] In the same line of reasoning, Williamson (1970 and 1985) and Comment and Jarrell (1995) pointed to the comparative efficiency of intra-firm financial transactions compared with the capital market.

This approach does not explicitly examine the implications of diversification for market structure even if it recognises that ex ante market structure can affect the decision to enter an industry. High entry barriers in the target industry imply high market concentration and presumably weak competition. These conditions 'may operate as inducements to entry for large firms' that enter by diversification (Gort, 1962, p. 107). Furthermore, diversification is not considered as a possible way to increase market power. On the contrary, it is argued that diversification is often a source of new competition (ibid., p. 4). Therefore, the expected superior performance of diversified firms against non-diversified firms is believed to be the result of greater efficiency rather than greater market power.

An important variable that is accounted for in these studies is organisation and management (see especially Chandler, 1962; Williamson, 1970 and 1985; Rumelt, 1974). This stream of the literature relies on the idea that strategy and corporate structure must evolve together in order to respond to changing environmental conditions. In particular, the development of multiple product lines requires a product division structure which favours the development of an internal pool of managerial resources from which to draw on to enter new markets (ibid., p. 37). M-form has a comparative advantage when environmental change is fast, particularly when technical change is rapid and firms grow internationally (Lawrence and Lorsch, 1967; Fouraker and Stopford, 1968). This explains why the vast majority of diversifiers analysed by Rumelt between 1949 and 1969 have also adopted a multidivisional form.

Although this approach does not explicitly explore the relationship between business and technological diversification, technological capabilities of firms and industries are explicitly considered as an important factor that explains the choice and the direction of diversification. As mentioned before, technological capabilities of the firm represent an important prerequisite to enter the most attractive industries, which in turn are those with the highest rate of technical change (Gort, 1962). Gort's concept of 'technological propinquity' and Rumelt's concept of 'relatedness' implicitly rely on the idea that technological distance between sectors matters to explain the extent and, especially, the direction of business diversification.

Gort (1962) proposed two definitions of 'technical propinquity between products'. First is the propinquity that arises from the use of similar or complementary products, raw materials and production processes. Second is propinquity that comes from the use of intangible resources such as R&D staffs, experienced salesmen, and managerial skills for two or more products. Gort also noticed that the latter type of propinquity among sectors has increased over time (ibid., pp. 57–58). Moreover, he showed that technological propinquity increases the probability that a firm from one sector diversifies into another sector. Technological propinquity makes managers of one sector more aware of the potentialities of new products in close sectors. Moreover, managers can draw upon their previous experience in one sector to operate in a related sector. Finally, if two sectors share similar equipment and plants, then diversification allows the use of excess capacity (ibid., pp. 107–108). Rumelt has elaborated upon the concept of propinquity to define the sources of relatedness among sectors. He distinguishes three types of relationship among sectors: 1) use of similar markets and distribution systems; 2) use of similar production technologies and 3) exploitation of science-based research (Rumelt, 1974, p. 17). Rumelt noted that related diversification allows firms to exploit the benefits of negatively correlated returns arising from sectors with different growth rates. Relatedness thus makes it possible to maintain a variety of products that address similar functions, such as information processing or photography, and are continuously innovated to meet the evolution of the economic and technological environment (ibid., p. 157).

The seminal works of Gort and Rumelt have inaugurated a new line of empirical research that has tried to measure the importance of relatedness and the effects of relatedness on corporate performance. In particular, this line of research suggests that related diversification allows firms to increase efficiency and profitability.

3.1.6 Economies of scope, market imperfections and related diversification

More recent studies have explained business diversification by combining the effect of firms' quasi-public inputs, capabilities or resources with that of transaction costs (Teece, 1980).

A fundamental intuition of this approach is that the market for quasi-public factors such as managerial and technical knowledge is imperfect because these inputs are intangible, idiosyncratic and context-specific. The knowledge underpinning many innovative processes is complex and tacit. This is one reason why diversification (lateral integration) is believed to improve firms' ability to re-deploy their resources among markets in response to new demand and technological opportunities (Teece, 1980). Moreover, this strand of the literature defines formally the role of excess resources as a source of economies of scope (Teece, 1980; Panzar and Willig, 1981).

The concept of economies of scope draws on the Marshallian economies of joint production. Economies of scope can be determined by the use of public inputs, which once used in one activity can be used at no cost in other ones: $C(k^1, k^2 \dots k^n, B) = \beta \max_i (k^i)$, where k^i is the vector of inputs employed in the activity i and B is the vector of input prices.

However, the use of pure public inputs is not necessary for economies of scope. A necessary and sufficient condition for economies of scope is that the cost function is strictly sub additive in the relevant range: $C(k^1 + k^2, B) < C(k^1, B) + C(k^2, B)$.

Subadditivity in turn depends on indivisibility of inputs (Panzar and Willig, 1989) and complementarity (Milgrom and Roberts, 1990).[12] Another, less explored, source of economies of scope is represented by externalities among different activities. These externalities occur when the activity i generates an output (e.g., knowledge) that spills over another activity costlessly or at low cost (Henderson and Cockburn, 1993). Externalities and cross-fertilisation occur especially in the use of 'general-purpose technologies' and flexible production techniques.

Appropriability of inputs or resources that can be shared among different markets and the imperfections in the markets for these resources are important explanations of diversification, especially related diversification (Teece, 1980; Teece *et al.*, 1994; Montgomery and Wernerfelt, 1988).

Firms may appropriate the rents from the use of excess factors outside their current business scope, but the marginal rents of these factors decline with the distance among sectors (Montgomery and Wernerfelt, 1988). With the distance the use of common competitive factors such as R&D, production and organisation techniques and distribution channels become less efficient. Firms endowed with more industry-specific factors will exploit these factors by diversifying into close sectors, if these sectors offer entry opportunities. If entry opportunities are concentrated in distant sectors, industry-specific factors will be employed in the current core sector because the marginal rent of industry-specific factors decreases quickly with the distance between sectors. Firms endowed with less industry-specific factors, such as 'general-purpose technologies', will try wider diversification because the marginal rents of these factors decline less markedly with the diversification distance. However, the average rent yielded by less specific factors is smaller than that of more specific factors. As a consequence, more diversified firms will have lower average rents compared with less diversified firms. To summarise, in Montgomery and Wernerfelt's model the diversification strategy of the firm depends on the specificity of excess factors and the location of entry opportunities in the marketplace.

This theory accounts for the lower profitability of diversified firms reported in the empirical literature. However, due to its static approach it does not explain the process of diversification, i.e. entry to and exit from markets over time. Under conditions of time-invariant demand with static economies of scope, a perfectly rational firm will start up as a multiproduct firm and no diversification will occur afterwards (Deneffe, 1993, p. 263). An attempt to introduce a dynamic dimension in the framework of economies of scope is made by Deneffe (1993), who modelled diversification as a process of sequential entry in sectors that are new to the firm. Established firms (active in another sector) may delay entry because of two effects: 1) an experience effect; and 2) a relatedness effect. These two effects jointly determine cost externalities across sectors: established firms may prefer to wait, accumulate experience in their core sector and enter later into the new sector. By delaying the entry the firm will benefit from a reduction of cost in the core sector (experience effect) that can be transferred to the new sector (relatedness effect).

3.1.7 Information asymmetry, agency costs and conglomerate diversification

Financial markets make mistakes. In the 1960s the stock market responded positively to diversification by M&As. Thus it provided wrong signals and incentives to manager-controlled firms: ‘the fact that the market thought that conglomerates were a good idea does not mean that they were’ (Schleifer and Vishny, 1991, p. 58). During the 1980s the capital markets revised their valuation of conglomerate growth after taking into account the deteriorating performance of many conglomerate firms. The financial market has probably learned by past mistakes. Moreover, the efficiency of capital markets appears to improve over time because of deregulation, increasing international competition and the introduction of new requirements to information disclosure by firms (Markides, 1995).

Also, the costs of diversification have probably risen with the globalisation of markets (which imposes new managerial burdens on firms) (Schleifer and Vishny, 1991; Markides, 1995). Financial economists believe that the improved efficiency of the financial markets has increased the monitoring capacity of shareholders (financial institutions) and imposed more discipline (and efficiency) upon managers by making takeovers more credible. Moreover, it is quite likely that managers have learned from experience and corrected their optimism about their ability to manage a great variety of different businesses.[13] The relative inefficiency of financial markets and the agency costs arising from the separation between ownership and control represent the principal determinants of business diversification for the agency theory of the firm.

A fundamental concern of this stream of the literature is to determine why managers tend to overdiversify and under which conditions they will invest in projects with a negative net present value. Conglomerate, unrelated diversification is the main target of these studies.

Contrary to Gort–Rumelt’s conjecture, which pointed to the financial economies arising from diversification, the agency view highlights the negative implications of conglomerate growth for firms’ efficiency. Diversification increases with unused borrowing power, large free cash flows and cross-subsidies, monitoring costs and management behaviour oriented to the reduction of risk (Jensen and Meckling, 1976; Jensen, 1986; Rotemberg and Saloner, 1994).[14]

In firms with substantial separation between ownership and control, managers tend to overdiversify, that is, to invest in low-benefit or value-destroying investments for the following reasons:

- free cash flow in excess of the level required to fund projects with a positive NPV and information asymmetry (Jensen, 1986; Comment and Jarrell, 1995);
- the prestige and power arising from bigness (Jensen, 1986);
- with diversification the internal demand for managers and, consequently, their compensation increase (Jensen, 1986; Schleifer and Vishny, 1991);
- unlike shareholders, who can reduce their diversifiable risk by diversifying their asset portfolios, managers cannot diversify their employment risk and therefore seek to reduce the firm risk by increasing business diversification (Montgomery, 1994).

Overdiversification and agency costs are likely to manifest in mature sectors, where firms produce earnings in excess of the investment opportunity offered by the sector, and in manager-controlled corporations, where stakeholders do not observe directly the efforts of managers.

The attention to the relationship between corporate control and diversification has been recently revamped by the debate between financial economists (e.g., Amihud and Lev, 1981 and 1999; Denis *et al.*, 1999) and strategic management scholars (e.g., Lane *et al.*, 1999). In particular, Lane *et al.* (1999) dispute the idea that managers always behave as self-interested agents and bring firms to excess, value-destroying diversification. These authors claim that strategic management sees firms as sets of resources and capabilities, 'agency problems with oneself' or 'self-control' which can lead individuals to take opportunistic actions that are harmful to themselves and to others: 'self interest is not necessarily the primary motive behind managerial behaviour'; 'whether a manager acts opportunistically depends in large part on how that manager feels about its work situation…' (Lane *et al.*, 1999, p. 1079). On the other hand, financial economists observe that diversification is likely to decrease (and profitability to increase) when managers are subject to significant disciplinary events, such as a block purchase or a threatening acquisition, and when the monitoring or control by lenders increases (e.g., through leverage buyout).

Relying on similar data sets, which yield similar results, these two streams of the literature reach opposite conclusions as to what is the relationship among ownership structure and diversification. Future empirical research should attempt a more careful qualitative analysis of these two contrasting theories about the relationship between ownership structure (corporate governance), diversification and performance. Another promising direction for future research should address the issue of different organisational forms and how they impact upon the relationship between diversification and performance. Unfortunately, as noted by Hill (1994), most of current research in this field does not recognise that apparently similar organisational structures (M-form) rely in fact on different centralisation, integration and control mechanisms. Within multidivisional organisation we can find two radically different structures – cooperative organisations and competitive ones. The former organisations aim at exploiting interdependencies and 'synergy' among divisions by relying on centralising and integrating mechanisms.[15] Cooperative organisations use incentive systems that combine objective measures of divisional performance (such as rate-of-return) and subjective modes of evaluation. Moreover, incentive schemes aim at stimulating cooperation among divisions (e.g., profit bonuses for divisional managers are associated with corporate rather than divisional profitability). These types of organisations are efficient if firms pursue a strategy of related diversification and therefore aim at exploiting economies of scope. A particular source of economies of scope in a dynamic perspective arises from the reuse of inputs across different generations of technological systems.[16] These economies are associated with reuse of knowledge, savings in testing and production costs (initial design costs include testing and coordination of different components). These economies are made possible by the use of modular, upgradable technological systems, standard components or gateway technologies that allow ex-post compatibility among incompatible components. On the other hand, modular and upgradable systems imply higher initial design costs, significant coordination costs among component designers and search costs due to the location of reusable components that increase with the number of available components.

Firms can economise the use of inputs and components by designing organisations that promote cooperation, knowledge sharing and transfer across divisions, business units etc. (Hill *et al.*, 1992). On the other hand, competitive organisations are best suited to attain benefits from efficient internal governance of the capital market. These forms of organisations emphasise the autonomy of division managers and rely on objective incentive schemes (such as rate-of-return) that reward each division without any connection with the performance of other divisions. Moreover, each division is put in competition with other divisions for the allocation of corporate cash flow. Competitive organisations mimic the capital market and should be comparatively efficient in firms that pursue a strategy of conglomerate diversification (Hill, 1994). This distinction makes it clear that different strategies (related diversification against conglomerate diversification) require different sets of structures and control systems.[17] One reason why the empirical evidence has not reached clear-cut conclusions concerning the association between diversification and performance relies most probably on the fact that the analysis that has yielded these results fails to explicitly deal with unobserved heterogeneity due to differences in management systems across diversified firms.

The agency theory is not interested in exploring the implications of diversification for the market structure; neither does it address the issue of what are the relationships with technology. In this view of the firm, technology and competencies are not relevant dimensions. The firm is considered as a nexus of contracts whose nature is not substantially different from market relationships.

Moreover, this approach does not account for the fact that efficient financial markets, with powerful institutional investors (e.g., investment funds and pension funds) that can exercise their voice, drive managers towards short-term horizons and therefore may have negative effects on investments in R&D (Hansen and Hill, 1991). Since these investments represent a major source of economies of scope for the firm, the short-term orientation of managers induced by the capital market can inhibit related diversification and growth.

3.1.8 Purposive diversification and the market power hypothesis

The idea that competition among multimarket firms eases overt or tacit collusion was first introduced by Edwards (1955) and developed subsequently in the 'new industrial organisation' literature (e.g., Bernheim and Whinston, 1990). In Edwards' view, multimarket contacts lead conglomerate firms to avoid aggressive price competition in order to reduce the risk of generalised price conflicts. Conglomerate firms will find an equilibrium where, for example, each firm behaves as a leader in markets where it is stronger (because of cost advantage or the like) and as a follower in markets where it is weaker. Through multimarket contacts, non-cooperative firms can reduce information lag or uncertainty about rivals' defection and learn how to converge on a 'focal' equilibrium (a set of strategies that supports a cooperative-like outcome): 'some modus vivendi for coordination will arise' among rivals that take part in a multiperiod game which yields multiple equilibria (Kreps, 1990).

More recently, Scott (1993) tried an empirical test of multimarket contact and market power (extra-profits) in diversified firms. The main result achieved by this study is that multimarket contact alone, measured by the number of 'meetings' between different firms in the same LBs, is not conducive to market power, proxied by profitability.[18] On the contrary, multimarket contact alone has a negative effect on profitability. However, as earlier studies have demonstrated, multimarket contact and market concentration (a proxy for the presence of barriers to mobility of resources across sectors) have positive joint effects on profitability. This result lends support to Edward's hypothesis. Groups of interdependent sellers (linked by multimarket contacts) recognise that mobility of resources reduces their profits and therefore seek to meet in concentrated markets where barriers to mobility are high and coordination is easier. According to Scott this is an important facet of 'purposive' diversification.

Scott concedes that diversification may be driven by the search for technical efficiency (exploitation of economies of scope etc.), market power being an 'innocent' by-product of this process. However, when multimarket firms meet in high concentrated markets purposive diversification and market power are probably the intentional result of strategic interaction.

In contrast with the market power hypothesis, theoretical studies in the industrial organisation literature have demonstrated that multimarket contact may be the outcome of competition rather than (the search for) collusion. For instance, Roller and Tombak (1990) show that in oligopolistic markets firms that enter into technologically related markets, can exploit the benefits of economies of scope arising from the use of flexible technologies. Moreover, entry may increase competition and reduce prices. The beneficial effects of competition on social welfare can be outweighed by the negative effects of inefficient production when diversification occurs in the presence of diseconomies of scope (Dixon, 1994).[19]

The market power hypothesis has found quite weak support in the empirical evidence. As discussed before, most evidence shows that diversification is not conducive to higher corporate performance. On the contrary, many studies have found a negative association between diversification (especially unrelated diversification) and performance.

3.2 Technological diversification

This section explores the causes and consequences of technological diversification. Moreover, we ask whether the forces that govern technological diversification differ substantially from those that affect business diversification.

Most of the approaches surveyed in previous sections do not provide any theory of technological diversification, nor do they explore the relationship between the span of technologies accumulated by the firm and the scope of business activities. This relationship is quite complex, as recent empirical studies have demonstrated. As mentioned before, Granstrand and Sjölander (1990), Patel and Pavitt (1994a and 1994b), Granstrand *et al.* (1997) and Gambardella and Torrisi (1998) have shown that large corporations make use of, and develop, in-house capabilities in many different technologies, including mechanical engineering, chemicals and IT. But this does not elicit a corresponding degree of product diversification. For instance, large chemical and electrical firms accumulate more competencies in non-metallic minerals technologies than the large firms in non-metallic minerals technologies themselves.

3.2.1 The reasons why firms accumulate technical competencies outside their core business

Why do firms accumulate technical competencies outside their core business? There are two broad categories of reasons. First, product complexity and systemic interdependencies among technologies embodied in products. Second, the limits to appropriability of technology and opportunities to reduce R&D risk and costs. Large multi-technology firms develop complex products and systems that combine and integrate different technologies. As mentioned earlier, in many industries (from electrical household appliances to electronics) the number of distinct technologies embodied in products has risen steadily over the past decades. Moreover, new technologies often do not substitute for old ones but are combined with them to produce new products or to improve established lines of business. This pattern of technological accumulation contributes to widen firms' technological portfolios (Granstrand and Oskarsson, 1994; Granstrand and Sjölander, 1990; Patel and Pavitt, 1994a).

Although some technologies can be acquired on the market, firms must have some knowledge of most of the technologies underlying their products. One reason is that changes in one component of a complex system usually require adaptation of other components or the re-design of the system architecture (Henderson and Clark, 1990). When the supply chain is complex, as in the case of telecommunications equipment or automobiles, the accumulation of technical capabilities in different fields outside the firm's distinctive capabilities is more important, especially when the inputs acquired are very specialised. For instance, Ericsson has maintained in-house technological and design capabilities in semiconductors used in its mobile phones even when relying on external suppliers (Granstrand *et al.*, 1997). These capabilities outside the firm's distinctive technologies have provided Ericsson with the ability to evaluate, absorb and integrate external knowledge not available 'off the shelves' (cf. the notion of absorptive capacity in Cohen and Levinthal, 1989).

Moreover, often coordination with external suppliers requires significant flows of proprietary knowledge that is difficult to protect (e.g., knowledge about processes or software) and the risk of opportunistic behaviour is high due to the small number of available suppliers. In these conditions the market for technologies is inefficient and firms are spurred to internalise the development (and probably also the production) of key inputs.

Other factors that induce to technological diversification are associated with the efficiency of R&D activities and appropriability. A diversified technological basis increases the ability of firms to appropriate the returns from innovative efforts. Compared to specialised firms, a diversified firm may have a better perception of the potential applications of a discovery. This appropriability advantage yields greater expected profit from innovation (Nelson, 1959). Relatedly, the ability to recognise more quickly the potential applications of R&D reduces the probability of market preemption by rivals. Furthermore, technological diversification reduces the risks of failure of innovative investments. As the market cannot provide complete insurance against such risk, a diversified R&D portfolio may represent an efficient alternative form of insurance (Scott, 1993). Finally, technological diversification may reduce the average costs of R&D because of economies of scope and spillovers across R&D projects. The specialised inputs needed in one research project, such as know-how and indivisible physical assets, cannot be easily traded on the market, while they can be shared with other research projects within the same firm (Henderson and Cockburn, 1993).

3.2.2 Technological diversification and competition

The studies discussed so far explain the rising technological diversification and the differences with business diversification by focusing on the increasing complexity of process and product technology and the imperfections in the market for technology. But, with few exceptions, they do not explicitly link technological diversification with competition.

However, competition can have significant effects on technological diversification. First, firms operating in competitive markets are spurred to improve efficiency and quality by integrating different technologies (e.g., microelectronics or new materials with mechanical engineering). Moreover, to escape the rent-destroying effects of price competition, firms seek to differentiate their products by improving their functionality. This affects technological complexity and diversity (Scott, 1993).

Second, the nature of competition and its effects on technological diversification varies across sectors. In markets characterised by a low degree of product substitution, i.e. by a high preference for variety, and a relatively high elasticity of R&D costs to product quality, firms cannot easily displace their rivals by raising R&D intensity, while it is profitable to introduce new varieties of goods. This strategy leads to a proliferation of technologies (supporting new varieties) at the industry level (Sutton, 1996). Whether this will result in a greater technological diversification of the firms depends on the degree of complementarity and spillovers between technologies, and imperfections in the markets for these technologies. The presence of multi-technology corporations in reality suggests that complementarity and imperfections in the market for technology are important.

Finally, patented technologies can be used to deter potential competition. This is a process similar to brand proliferation in the product markets and gives rise to 'sleeping patents' by established firms.[20]

4 Technology and business diversification: summary and management implications

4.1 Types of diversification

A number of types of diversification patterns have been discussed in this survey. In the evolution of a multiproduct, multitechnology firm, diversification takes place both in the product space and in the resource space. If the original range (set of types) (of products or factors) persists over time with the diversification process, then diversification can be defined as (product- or factor-) *rooted*, otherwise it is *floating*. The *direction of diversification* refers to the direction of the trajectory in those spaces. Concurrent diversification or 'hybrid diversification' (by some authors) is diversification taking place in several dimensions concurrently (which has proven to be risky). Moreover, based on some notion of relations or relatedness between the old and the new elements included, diversification is further characterised as *related* or *unrelated* or *conglomerate*. When the relations are buyer/seller relations, diversification amounts to vertical integration (or *vertical diversification*), while *horizontal (or lateral) diversification* (or integration) involves competitive relations.[21]

Traditionally the literature on diversification has referred to the range and distribution of outputs of the firm, classified in terms of products, (output) markets or business. Here we have complemented these types of *output diversification* with different types of *input diversification* or resource diversification. These latter types refer to the range and distribution of inputs (factors, resources) of the firm, classified not only in terms of raw material, physical capital, and financial assets but also in terms of technologies, knowledge, competences, IPRs, network relations and other forms of intangible inputs (resources, assets, capital). In particular, our survey has focused on *technological diversification*.

Formal models at firm level that try to analyse different diversification trajectories and their interaction are still lacking, although there are theoretical frameworks discussed in our survey that point to the interaction between technology, product and market diversification. Other variables included in these models are R&D cost escalation, increasing external technology sourcing (and thereby use of various types of technology markets), and technological and business opportunities through growth and differentiation of S&T and market needs (allowing for division of labour), in order to meet company objectives in terms of profits, growth and risk exposure through different strategies. Naturally, a host of additional internal and external factors (economic, institutional, political, social, cultural etc.) affect the diversification processes and strategies.

Figure 2.1 attempts to summarise and extend previous conceptual models, and indicate the main feedback links, e.g. behind the dialectics between technology and product diversification.

As discussed earlier, technological diversification is affected by forces that are in part different from those governing business diversification. Moreover, the same forces that affect both technology and business diversification may have a different impact upon each of them. This accounts for the substantial differences between technology and business diversification observed by the empirical literature.

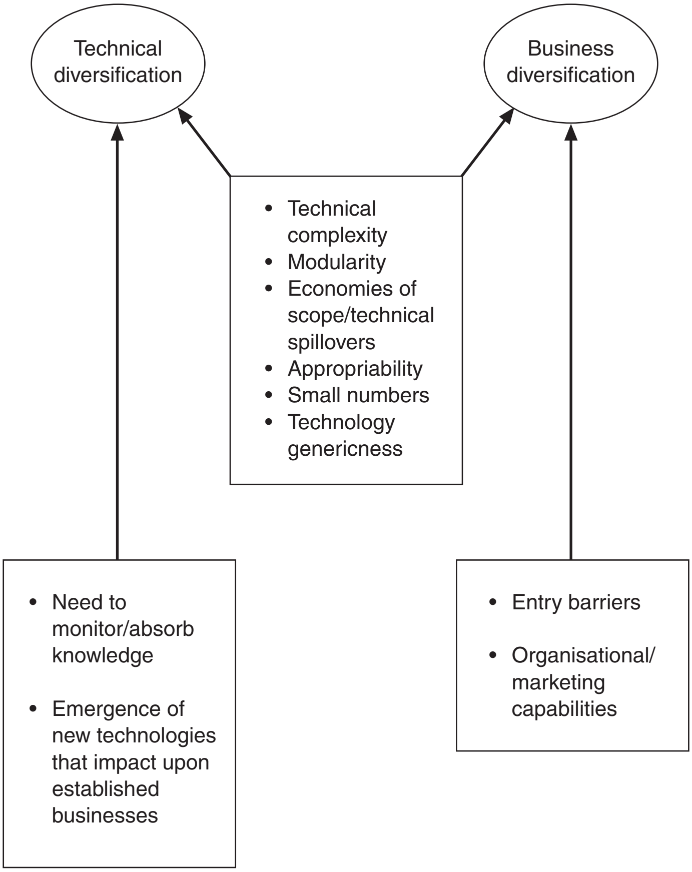


Figure 2.1 Variables affecting technology and business diversification.

As Figure 2.1 illustrates, there are three broad different sets of variables that affect technology and business diversification:

- variables related to system complexity, R&D efficiency and transaction costs;
- variables related to new technological opportunities and competition;
- variables related to the institutional environment (including the financial markets and regulation of products' markets).

The first category of variables includes system complexity, i.e. the existence of systemic interactions among different technologies embedded in product subsystems or processes. Technological complexity in turn affects the possibility to pursue autonomous innovations (which can be developed independently from other innovations) and systemic innovations (which must be developed in close connection with complementary innovations). Complexity can be reduced by the standardisation of component technologies and the use of modular technological systems. As mentioned earlier, modularity has a significant impact upon the organisation and firms can choose among different levels of modularity and task partitioning to pursue different diversification strategies.[22] Modern manufacturing systems allow a high level of modularity in production and spur the adoption of complementary organisational innovations (e.g., in marketing). As Milgrom and Roberts (1990) have pointed out, complementarity makes it unprofitable to change only one or few dimensions of a manufacturing system (e.g., CAD/CAM) without changing other dimensions (e.g., the ordering and delivering process). Because of complementarity, then, the adoption of modular technological systems is a choice characterised by non-convexities and increasing returns that can lead to growth and diversification.[23] On the other hand, however, modularity favours the division of labour among firms and therefore may reduce the need for diversification.

The appropriability of technology and small numbers (of available suppliers) also affect the incentive to lateral or vertical integration of technologies and businesses.

Finally, technological 'genericness' affects diversification. As discussed before, firms that accumulate capabilities in general-purpose (or platform) technologies can enter a large number of different sectors.

The second set of factors affecting technology and business diversification is related to opportunities and challenges arising from the emergence of new technologies. New technologies open new windows of opportunity to existing firms and may result in process or product innovations or product differentiation. However, new technologies can also have disruptive effects on established firms for the benefit of newcomers. For these reasons the accumulation of capabilities in technical fields outside the firm's core technologies can be a rational strategy since it allows the firm to monitor, anticipate and absorb new knowledge that is relevant for the existing business activities. However, technological diversification spurred by new technologies does not necessarily lead to business diversification. For one thing, business diversification in a given market probably requires much more expertise than that required to monitor or absorb knowledge produced by others. Moreover, business diversification may require significant investments in complementary capabilities and is often hampered by 'innocent' or 'strategic' entry barriers.[24] Finally, the management of a diversified portfolio of business activities is often much more compelling than coordinating a portfolio of different technologies (i.e. multi-technology management). As a matter of fact, firms like AT&T or Xerox have demonstrated a unique ability to manage a diverse range of technologies, from transistors to telecommunications and computing, but have failed to enter many downstream markets. These experiences suggest that there are factors, such as industry-specific organisational capabilities, which affect business diversification but not technological diversification, and vice versa.

5 Conclusions

This chapter analyses different patterns of diversification and provides a critical assessment of the main factors that impact upon technology and business diversification. The chapter shows that there are factors that affect both technology and business diversification and factors that influence only one of these dimensions of the firm's strategy. To our knowledge this is the first attempt to compare different streams in the literature on technological and business diversification.

The survey indicates that large firms operating in different sectors, from automobiles to telecommunications equipment, tend to become multi-technology corporations. For these firms technology conservation and diversification dominate over technology substitution and competence destruction. This pattern of technological accumulation implies an increasing technological diversification that, however, does not translate into a similar level of product diversification. In fact, there exist very different patterns of business diversification – from related diversifiers to conglomerate corporations. Related diversifiers tend to be 'coherent' in their patterns of growth since they enter new businesses that have in common with their old business significant technology or marketing capabilities. These firms, including most multi-technology corporations, then aim to exploit economies of scope and spillovers across technologies and markets. Conglomerate diversifiers pursue a different strategy centred on different types of economies (e.g., financial economies). These differences in diversification patterns are reflected in different organisations and management structures – cooperative vs competitive (and divisionalised) ones.

In this survey we have compared different hypotheses about business diversification. The transaction-cost approach is overly optimistic about the ability of corporate managers of diversified firms to organise an internal capital market more efficiently than the external market. Williamson assumed that, by introducing a formal separation between corporate (top) and division managers, diversified firms could keep the monitoring costs of hierarchy under control. Moreover, Williamson relied on the assumption that corporate managers were immune from the problem of 'on-the-job consumption' since their hierarchical position should provide them with a 'psychological commitment' to maximise profit. Both assumptions are arguable and have not found robust empirical foundations (Hill, 1994). On the other hand, the agency theory appears overly optimistic about the disciplinary effect of the capital market. As the empirical evidence clearly shows, capital markets are not immune from mistakes and in certain circumstances have provided wrong signals and incentives to managers of diversifying firms (Schleifer and Vishny, 1991). Moreover, this theory tends to overlook the potential negative effects that the 'short-termism' of institutional investors may have on long-term, risky investments such as those in R&D, which represent an important source of a firm's growth (Hansen and Hill, 1991).

Other views of business diversification, which point out the importance of economies of scope and transaction costs, also have their own limitations (e.g., Teece, 1980; Montgomery and Wernerfelt, 1988). This stream of the literature largely focuses on firms as organisations endowed with *given* capabilities which choose among a *given* set of available businesses on the basis of different criteria, including the existence of exogenously given (technological or commercial) similarity among different business sectors. But firms can choose/modify their mix of technological capabilities (obviously under constraints discussed before). Moreover, through innovation and modification of technological capabilities, firms can affect the technological relationship among business sectors, thus opening up new opportunities of business diversification, and the set of business sectors available for diversification. For instance, the invention of the microprocessor has created new technological connections among sectors (e.g., computers and telecommunications) and has spawned several new products and business activities.

Finally, while there are some studies that are concerned about the implications of business diversification for allocative efficiency in the product markets, to our knowledge there are no attempts to see whether the observed levels of technological diversification are dynamically efficient. Recent restructuring and spinoffs of technological activities by large corporations like AT&T (Lucent) suggest that, despite significant differences, the management of technology portfolios is probably subject to problems similar to those experienced for the management of product portfolios, including information asymmetry, 'hubris' and agency costs, which can lead to overdiversification of technological activities and excessive duplication of R&D efforts. Future empirical research should address this issue and analyse the implications for economic performance.

6 Appendix – Measures of diversification

The diversity and diversification phenomena are universal and so is the need to characterise and measure them. The resulting variety of diversity measures in fact calls for a survey in its own right, as well as more theoretical developments to guide the design and choice of measures. Here we have to confine ourselves to some of the main approaches to measurements.

A key idea underlying our discussion is that the concept of diversification depends upon the choice of classification and points in time considered. What makes the definition somewhat ambiguous is that diversification may also occur if diversity is increased, which may happen even without extension of the range of activities, depending upon how diversity (variety, dispersion, heterogeneity) is measured.

6.1 Categorical measures of diversification

Categorical measures of product diversification were introduced by Rumelt (1974) and further elaborated in Rumelt (1982). He introduced a diversification taxonomy that relies on the specialisation ratio (SR), which is the percentage of total sales accounted for by the largest line of business of the firm, and a relatedness ratio (RR), which is the percentage of related lines of business.

The RR is based on similarity between businesses in terms of production technology, customer base and commercialisaton assets (similarity of markets and distribution channels), and exploitation of common 'science-based research' (p. 17). Drawing on an earlier taxonomy developed by Wrigley (1970), Rumelt has distinguished among the following types of diversification strategies: Single Business ($SR > 0.95$), Dominant ($0.70 < SR < 0.95$), Related ($RS < 0.70$ and $RR > 0.70$) and Unrelated ($SR < 0.70$ and $RR < 0.70$). Within the Related category, Rumelt distinguishes between Related-Constrained and Related-Linked. The former is focused on the exploitation of a 'common core' of activities while the latter draws on 'a linked network of disparate businesses'.

6.2 Objective, continuous measures of diversification

Continuous measures of diversification are based on SIC codes (Berry, 1971; Jacquemin and Berry, 1979; Montgomery, 1982; Palepu, 1985). The most popular SIC-based indices of diversification are the Herfindhal index and the Entropy index (Hart, 1971). The former is the sum of the squared shares of the lines of business' sales ($H = \Sigma_i x^2_i$) while the latter is the sum of the shares of the lines of business' sales times their logs ($E = \Sigma_i x_i \mathrm{Log} x_i$). Jacquemin and Berry (1979) developed a measure of diversification based on the concept of Entropy. They also distinguished between related and unrelated diversification. In studies that use continuous, SIC-based indices of diversification, the measure of relatedness simply relies on the level of aggregation of industrial classification. This stream of the literature often measures 'unrelated diversification' with the number of 2-digit SIC industries in which a firm operates while 'related diversification' is measured by the number of 3-digit SIC industries (see, for instance, Markides, 1995; Davies and Lyons, 1996; Byrd and Hickman, 1992). Others studies use a different level of aggregation to distinguish between related and unrelated diversification. For instance, Morck *et al.* (1990) refer to unrelated diversification when the bidder and the target of M&As operate in two different 4-digit SIC industries.

We must notice that SIC measures depend on the reliability of segment-reporting data, which are subject to firms' accounting procedures and managers' perceptions of business segments. To correct in part this potential drawback, some studies have used Census Bureau data on employment at individual plants and establishments that rely on SIC codes assigned by external analysts such as Compustat and TRINET in the US. Census Bureau data reduce managerial discretion since the Financial Accounting Standards Board imposes separate accounting for business segments which represent at least 10 per cent of the consolidated firm's assets, profits or sales (Lichtemberg, 1992; Comment and Jarrell, 1995).

But SIC-based measures have a supply-side or technological orientation and they virtually ignore differences in marketing and distribution channels between sectors. In order to overcome the limitations of a purely supply-side approach, Scott (1993) grouped 4-digit SIC manufacturing categories into ten 3-digit SIC wholesale categories. Each wholesale category includes industries that share similar distribution channels, regardless of technological distance or similarity among them. Drawing on data for large US manufacturing firms, Scott found that multimarket firms share similar distribution channels (see Scott, 1993, ch. 1).

Another potential drawback of SIC-based measures of diversification is that they only account for potential relatedness. Actual relatedness requires additional sources of information beyond the information provided by SIC codes (Stimpert and Duhaime, 1997). Since managers have different beliefs and perceptions of relatedness, Stimpert and Duhaime suggest studying managers' conceptualisation of different dimensions of relatedness: product-market relatedness (centred on customers, distribution, manufacturing process), differentiation relatedness (R&D, quality, advertising and marketing skills), financial relatedness (cost leadership, capital requirements etc.), commodity relatedness (access to raw materials, vertical links etc.). In this behavioural perspective, then, managerial discretion is not viewed as a source of measurement errors but as a source of new information that can improve the precision of empirical analysis. Despite the different underlying approaches, continuous measures of diversification appear to be highly correlated with categorical measures, as different studies have demonstrated (Montgomery, 1982; Hoskisson *et al.*, 1993; Lubatkin *et al.*, 1993).[25] In particular, Hoskisson *et al.* (1993) assessed the construct validity of both categorical and objective measures of diversification showing that the entropy approach yields results similar to those of Rumelt's subjective measure. They also suggest using jointly subjective and objective measures in order to maximise measurement accuracy.

6.3 Other measures of diversification

Another measure of corporate diversification used in the financial literature is represented by the ‘market model’:

$$\pi_{it} = \alpha_i + \beta_i rm_t + \epsilon_{it}$$

where π_{it} is the equity return on firm **i** in period **t**, rm_t is the market equity return and ϵ_{it} is the residual return whose risk is diversifiable. The R^2 statistic from this model, $1 - Var(\epsilon_{it})/Var(\pi_{it})$, indicates the extent to which equity performance of the firm is explained by the market performance. Thus the greater R^2 the larger is the level of diversification of risk – a $Var(\epsilon_{it})/Var(\pi_{it})$ ratio around zero signals that the level of firm’s diversification approaches that in the market (Amihud and Lev, 1999).

6.4 Distance and relatedness among sectors

Diversity is a useful concept in many disciplines. The conceptualisation of diversity implies in turn a conceptualisation of differences or dissimilarities between business lines or industries, and technologies. Indices of similarity (or dissimilarity) could then be designed in numerous ways, some of which could be used for a proper measure of distance or metric in the standard mathematical sense (e.g. fulfilling the triangle inequality, implying that no detour can be a short-cut). Similarity indices and metrics in particular could then be used for cluster analysis, again with numerous techniques available. The diversity of measures thus prompts for a great deal of caution in comparing results. In addition it is quite common to use terms such as distance, closeness and proximity in just a qualitative, intuitive way (see e.g. Montgomery and Wernerfelt, 1988).

Rumelt pioneered the empirical analysis of degree of dissimilarity among sectors by focusing on similarities or commonality in resources such as technologies, skills and distribution channels across sectors.[26] Subsequent studies have developed further the measurement of relatedness. For example, Scott (1993) and Teece *et al.* (1994) use a similar methodology to calculate ‘relatedness’ among sectors and ‘corporate coherence’ in diversification. Scott relies on a sample of 437 firms participating in the Federal Trade Commission Line of Business Programme in 1974 (Scott, 1993, ch. 4) while Teece *et al.* (1994) analysed the data of 18,620 US diversified companies provided by 1987 TRINET large establishment tape. The approach shared by these two studies is based on the comparison between the number of observed meetings (joint occurrences) of industries i and j (number of firms that are active in both industry i and industry j), $J_{ij} = \Sigma_k C_{ik} C_{jk}$, and the expected number of meetings under the hypothesis of random diversification (see Teece *et al.*, 1994, p. 6; Scott, 1993, p. 45).

Vonortas (1999) uses a similar measure of relatedness between industries in studying how firms diversify when engaging in research joint ventures. The idea that the nature of R&D in two industries influences the direction of diversification in terms of the probability that firms in one industry enter into another industry goes further back to Scherer (1965), MacDonald (1985), Scott (1982) and Scott and Pascoe (1987). We should note, however, that beyond R&D and resource relatedness, differences in profitability across industries also influence the probabilities of inter-industry diversifications. This is more likely when there are large, sustained profitability gaps between two industries (or business areas), spurring entries from one to the other (possibly followed by exits). Measures of relatedness like these discussed here apply quite generally, and could be used as measures of relatedness between technologies as well (see for instance Jaffe, 1989; Granstrand, 1994).

6.5 Performance

There are different measures of performance that have been associated with business (and technological) diversification. We can distinguish between accounting measures, such as profitability (net profits, ROS, ROA and ROE), sales growth, foreign sales and productivity, and market measures, such as stock market valuation and return on equity. Purely accounting and market measures of performance suffer from many drawbacks. These measures should both be adjusted to account for risk. In comparing the (accounting) performance of diversified with undiversified firms, one has to consider the fact that the latter might perform better because they have to offer greater expected returns to their shareholders as a 'premium' for a greater risk. The comparison can also be affected by size effects, which play the same role as diversification (and indeed are often correlated with diversification). Unfortunately it is difficult to find proper risk adjustment instruments (Lang and Stulz, 1994, p. 1252).

Indicators that combine accounting and market values have been used to overcome in part these drawbacks. The most popular of such indicators is the Tobin's q, that is, the ratio between a firm's market valuation and the replacement cost of its tangible assets (which is proxied by the book value of physical assets). Tobin's q does not require risk adjustment since it incorporates the capitalised value of diversification (and other assets) at a given point in time. Moreover, it reduces the typical distortions arising from accounting conventions and tax laws (Montgomery and Wernerfelt, 1988, p. 627). Tobin's q also has some drawbacks, the most important of which is that it relies on the hypothesis of efficient financial markets, which amounts to saying that the market value of a firm is an unbiased estimate of the present value of its future cash flows (Lang and Stultz, 1994; Hall, 1999).

6.6 Diversification modes

External growth through M&As and internal growth are often viewed as alternative modes of product as well as technological diversification or entry, just as divestment through external sales and internal closure are alternative modes of exit (de-diversification). Like other scholars, Hill (1994) has noticed that related product diversification most often is pursued by internal growth to exploit idle resources (p. 301). The survey by Ramanujan and Varadarajan (1989) illustrates this issue at length. However, there is no clear evidence about the association between the mode of diversification and relatedness between sectors (Yip, 1982; Chatterjee, 1990; Chang and Singh, 1999). Chang and Singh, in relating modes of exit to modes of entry, use different measures of relatedness, including R&D distance, market relatedness (measured by advertising intensity) and human-resource differences between sectors. Only market relatedness and human-resource relatedness are associated with M&A diversification events. Case studies also indicate that at least sometimes a mix of internal development followed by related acquisitions is used, just as some unrelated diversifications occur as a by-product of acquisitions or simply as an experimental learning exercise in a new area, thereby blurring relatedness (Granstrand, 1982).

Notes

1 The term diversification can be used in one of two ways, and both uses can be found in other chapters of this book (although most other chapters adopt mainly the first usage rather than the second). First, diversification may mean the degree of dispersion of activities over some established range. Second, alternatively, diversification may mean a process of an increase over time in the degree of dispersion of activities over a range, or an extension in the range of activities conducted itself. Diversification involving an extension of the firm's range of activities is essentially the same as entry. If the new types are not only new to the firm but new to the market, diversification is essentially the same as invention (rather than simply adoption), and if commercially successful it is the same as innovation. Finally, product differentiation could be seen as a special case of related product diversification if product types are distinguished at a fine level of detail. However, usually product diversification is distinguished from product differentiation with the latter referring to increasing the range of product varieties (horizontal differentiation) or quality (vertical differentiation) within a specific but not too narrowly defined product area, or group (see Lancaster 1990 for an excellent survey).

2 See the Appendix for an illustration of objective measures of diversification and the analysis of relatedness or coherence.

3 It is worth reporting in particular the results of Markides (1995) and Robbins and Wiersema (1995). Markides focuses on US firms that restructured and refocused their businesses during the 1980s. This analysis shows that profitability increased after refocusing, thus suggesting that the sample firms were over-diversified. Robbins and Wiersema's paper focuses on US firms during the 1970s. The results of this paper are then particularly useful since they are not affected by the wave of restructuring and refocusing that occurred in the

1980s. This paper shows that firms that have diversified around their 'core business' have outperformed conglomerate diversifiers.

4 It is worth noting that earlier studies have failed to separate industry effects from the effect of corporate diversification. For instance, analysing the performance of firms in different diversification categories, Rumelt admitted that he was not able to say whether related business firms performed well because they were active in rapidly growing 'science-based' sectors or, on the contrary, the presence of firms with exceptional structural and strategic characteristics made these industries particularly dynamic (Rumelt, 1974, p. 123).

5 The instance of fusing or merging technologies or confluence of technologies (Jantsch, 1967) should, strictly speaking, be distinguished from combining or integrating different technologies into a product, still with their distinctiveness maintained, e.g. in engineering education.

6 Patent share is the share of technology i in the firm's total patents; revealed technological advantage (RTA) is the share of firm **i** in technology **j**'s total patents relative to the firm's share of total patents in all technologies. The RTA indicates the comparative advantage of a firm in a given technical field. An RTA above 1 (below 1) indicates that the firm has a comparative advantage (disadvantage) in a given technology.

7 Nelson and Winter (1982) pointed to the existence of complementarities among various trajectories or natural trajectories that are common to a wide range of technologies, such as mechanisation of operations (ibid., p. 259). Dosi (1982) focused on the role of 'technological paradigms' that represent significant discontinuities in technological trajectories.

8 The logit model tested by Kim and Kogut is specified as follows: $\log [Pit/(1-Pit)] = \alpha + \beta Xit$, where Xit is the vector of covariates and $Pit = Pr(T = t \mid T \geq t)$. The latter is the hazard rate defined as the probability of entry at time t given no earlier diversification.

9 For another discussion see Pavitt, Robson and Townsend (1989).

10 Organisation scholars have analysed the role of 'competence-destroying' innovations which introduce radically new products or processes and introduce significant discontinuities in cost, performance and quality advantage compared with earlier products or processes (see Anderson and Tushman, 1990).

11 It is useful to recall that Rumelt (1974) was very critical to the managerial view of the firm, according to which the separation between ownership and control and the diffusion of M-form would bring about an inefficient allocation of resources and the dominance of objectives other than profit maximisation. On the contrary, Rumelt claimed that the observed poor performance of diversified firms most probably depends on inappropriate organisational structures. Moreover, he pointed out that we must distinguish between different forms of diversification, which yield different expected financial results. However, prefacing the 1986 edition of his book, Rumelt admitted the 'unanticipated side effects' of the multidivisional form, including the excessive financial orientation and the drawbacks of its planning systems (p. ix).

12 Milgrom and Roberts (1990) use the term 'complementarity' in the broad sense of relation among groups of activities: 'if the levels of any subset of the activities are increased, then the marginal return to increases in any or all of the remaining activities rises' (ibid., p. 514).

13 In the strategic management literature this optimism is referred to as the 'hubris hypothesis' (see Roll, 1986).

14 Free cash flow is measured by operating income before depreciation less interest expenditures, taxes, preferred and common dividends. Other costs associated with the growth and diversification are bureaucratic costs, which include the costs of hierarchy (salaries of higher-level managers), on-the-job consumption by

managers, incentive distortions and influence costs (Williamson, 1985). In the transaction costs perspective these costs must be compared with the cost of use of the price mechanism to determine the optimal level of internalisation of transactions.

15 Drawing on a sample of Fortune 500 firms, Argyres (1996) found that firms with less divisionalised M-form organisational structure pursue a diversified R&D strategy. Argyres argued that weak boundaries among divisions favour internal communication and are consistent with a capability-broadening (technological diversification) strategy. By contrast, strong inter-divisional boundaries are associated with a capability-deepening (specialisation) strategy.

16 Garud and Kumaraswamy (1995) refer to this source of economy of scope as ‘economies of substitution’, which take place when the ‘cost of designing a higher-performance system through the partial retention of existing components is lower than the costs of designing the system afresh’ (ibid., p. 96). A technological system can be either a product, such as a computer, or a process, like a chip fabrication system or an automobile manufacturing system.

17 Besides Chandler, many scholars of organisation, such as Mintzberg (1983), have pointed out the importance of coherence between diversification strategy (‘related-product’ vs ‘conglomerate’) and corporate structure. The analysis of causal links between strategy and structure goes beyond the purposes of our discussion here.

18 More precisely, Scott develops a measure of multimarket contact called ‘probabilistic size’, which is a measure of the difference between the observed number of contacts (or meetings) among firms and the theoretical number of meetings under the hypothesis of non-purposive diversification (random walk) (see Scott, 1993, ch. 4).

19 Large and diversified firms may incur managerial diseconomies that counterbalance the benefits of flexible technologies or complementarity in production (Dixon, 1994).

20 Another reason behind technology proliferation, which is directly or indirectly related to competition, is represented by peer recognition – by investing in niche technologies, firms pay a ticket to enter the scientific community. Finally, patented inventions (or inventions reported in scientific journals) can be used as a corporate reward system (see Frumau, 1992).

21 Some authors distinguish diversification from vertical integration.

22 The implications of task partitioning for problem solving and technology management have been analysed by von Hippel (1990). The opportunities of standardisation of components and modularity are particularly high in sectors based on mechanical engineering, electrical and electronics technologies as compared with chemicals and pharmaceuticals.

23 Modularity gives rise to economies of scope and may give rise to product differentiation and to related diversification.

24 Obviously, there are entry barriers also in the technology market (e.g., patents, secrecy and lead time). However, these barriers are often easy to circumvent by imitation and inventing around activities (except in chemicals and pharmaceuticals.

25 These results hold also when unweighted measures of diversification are used (i.e., product counts).

26 The classification procedure does not establish a distance function or metric in the standard mathematical sense of distance, fulfilling the triangle inequality requirement.

References

Amihud, Y. and Lev, B. (1981) 'Risk reduction as a managerial motive for conglomerate mergers', *Bell Journal of Economics*, 12, pp. 605–617.

Amihud, Y. and Lev, B. (1999) 'Does corporate ownership structure affect its strategy towards diversification?', *Strategic Management Journal*, 20, pp. 1063–1069.

Anderson, P. and Tushman, M.L. (1990) 'Technological discontinuities and dominant designs: a cyclical model of technological change', *Administrative Science Quarterly*, 35, pp. 604–633.

Ansoff, H.I. (1957) 'Strategies for diversification', *Harvard Business Review*, 35 (5), pp. 113–124.

Argyres, N. (1996) 'Capabilities, technological diversification and divisionalization', *Strategic Management Journal*, 17, pp. 395–410.

Berger, P.G. and Ofek, E. (1995) 'Diversification's effects on firm value', *Journal of Financial Economics*, 37, pp. 39–65.

Bernheim, W.J. and Whinston, M.D. (1990) 'Multimarket contact and collusive behavior', *Rand Journal of Economics*, 21, pp. 1–26.

Berry, C.H. (1971) 'Corporate growth and diversification', *Journal of Law and Economics*, 14 (2), pp. 371–383.

Booz, Allen and Hamilton (1985) *Diversification: A Survey of European Chief Executives*, Booz, Allen and Hamilton Inc., New York.

Bresnahan, T. and Gambardella, A. (1998) 'The division of inventive labour and the extent of the market', in Helpman, E. (ed.), *General Purpose Technologies and Economic Growth*, MIT Press, Cambridge, MA.

Bresnahan, T. and Trajtenberg, M. (1995) 'General purpose technologies: engines of growth', *Journal of Econometrics*, 65, pp. 83–108.

Byrd, J. and Hickman, K.H. (1992) 'Do outside directors monitor managers?', *Journal of Financial Economics*, 32, pp. 195–221.

Chandler, A.D. (1962) *Strategy and Structure: Chapters in the History of the American Industrial Enterprise*, MIT Press, Cambridge, MA.

Chandler, A.D. (1990) *Scale and Scope. The Dynamics of Industrial Capitalism*, Harvard University Press, Cambridge, MA.

Chang, S.J. and Hong, J. (2002) 'How much does the business group matter in Korea?', *Strategic Management Journal*, 23 (3), pp. 265–274.

Chang, Y. and Singh, H. (1999) 'The impact of modes of entry and resource fit on modes of exit by multiproduct firms', *Strategic Management Journal*, 20, pp. 1019–1035.

Chatterjee, S. (1990) 'Excess resources, utilization costs, and mode of entry', *Academy of Management Journal*, 33 (4), pp. 780–800.

Christensen, C. and Rosenbloom, R. (1995) 'Explaining the attacker's advantage: technological paradigms, organizational dynamics, and the value network', *Research Policy*, 24, pp. 233–257.

Chu, W. (1999) 'The changing pattern of diversification of business groups in Taiwan', *Working Paper*, presented at the Strategic Management Society Conference, Berlin.

Cohen, W. and Levinthal, D. (1989) 'Innovation and learning: the two faces of R&D', *The Economic Journal*, 99, pp. 569–596.

Comment, R. and Jarrell, G.A. (1995) 'Corporate focus and stock returns', *Journal of Financial Economics*, 37, pp. 67–87.

David, P.A. and Wright, G. (1999) 'General purpose technologies and surge in productivity: historical reflections on the future of the ICT revolution', *Discussion Papers in Economic and Social History*, University of Oxford, 31 September.

Davies, S. and Lyons, B. (eds) (1996) *Industrial Organisation in the European Union*, Oxford University Press, Oxford.

Deneffe, D. (1993) 'Cost externalities and corporate diversification', *International Journal of Industrial Organisation*, 11, pp. 261–282.

Denis, D.J., Denis, D.K. and Sarin, A. (1999) 'Agency theory and the influence of equity ownership on corporate diversification strategies', *Strategic Management Journal*, 20, pp. 1071–1076.

Dixon, H.D. (1994) 'Inefficient diversification in multi-market oligopoly with diseconomies of scope', *Economica*, 61, pp. 213–219.

Dosi, G. (1982) 'Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change', *Research Policy*, 11 (3), pp. 147–162.

Dunning, J. (1993) *Multinational Enterprises and the Global Economy*, Addison Wesley, Wokingham.

Edwards, C.D. (1955) 'Conglomerate bigness as a source of power', in NBER, *Business Concentration and Price Policy*, Princeton University Press, conference report, Princeton.

Fouraker, L.E. and Stopford, J.M. (1968) 'Organisational structure and multinational strategy', *Administrative Science Quarterly*, June, pp. 64.

Frumau, C.C.F. (1992) 'Choices in R&D and business portfolio in electronics industry: what the bibliometric data show', *Research Policy*, 21, pp. 97–124.

Gambardella, A. and Torrisi, S. (1998) 'Does technological convergence imply convergence in markets? Evidence from the information technology industry', *Research Policy*, 27 (6), pp. 445–463.

Garud, R. and Kumaraswamy, K. (1995) 'Technological and organisational designs for realising economies of substitution', *Strategic Management Journal*, 16, pp. 93–109.

Giarratana, M. and Torrisi, S. (2002) 'Competence accumulation and collaborative ventures: Evidence from the largest European electronics firms and implications for the EU technological policies', in Lundan, S.M. (ed.), *Network Knowledge in International Business*, E. Elgar, Cheltenham, pp. 196–215.

Gort, M. (1962) *Diversification and Integration in American Industry*, Princeton University Press, Princeton.

Granstrand, O. (1982) *Technology, Management and Markets: An Investigation of R&D and Innovation in Industrial Organizations*, Pinter Publishers, London.

Granstrand, O. (ed.) (1994) *Economics of Technology*, Elsevier, Holland, pp. 1–36.

Granstrand, O. (1998) 'Towards a theory of the technology-based firm', *Research Policy*, 27, pp. 465–489.

Granstrand, O. and Oskarsson, C. (1994) 'Technological diversification in "multi-tech" corporations', *IEEE Transactions on Engineering Management*, 41, pp. 355–364.

Granstrand, O. and Sjölander, S. (1990) 'Managing innovation in multi-technology corporations', *Research Policy*, 19, pp. 35–60.

Granstrand, O., Bohlin, E., Oskarsson, C. and Sjöberg, N. (1992) 'External technology acquisition in large multi-technology corporations', *R&D Management*, 22 (2), pp. 111–133.

Granstrand, O., Patel, P. and Pavitt, K. (1997) 'Multi-technology corporations; why they have "distributed" rather than "distinctive core" competencies', *California Management Review*, 39, pp. 8–25.

Granstrand, O., Sjölander, S. and Alänge, S. (1989) 'Strategic technology issues in Japanese manufacturing industry', *Technology Analysis and Strategic Management*, 1 (3), pp. 259–272.

Hall, H.B. (1999) 'Innovation and market value', *NBER Working Paper 6984,* National Bureau of Economic Research, February, Cambridge, MA.

Hansen, G.S. and Hill, C.W.L. (1991) 'Are institutional investors myopic? A time series study of four technology-driven industries', *Strategic Management Journal*, 12, pp. 1–16.

Hart, P.E. (1971) 'Entropy and other measures of concentration', *Journal of the Royal Statistical Society*, pp. 73–85.

Henderson, R. and Cockburn, I. (1993) 'Scale, scope and spillovers: the determinants of research productivity in ethical drug discovery', *Working Paper No. 3629-93*, Sloan School of Management, MIT, Cambridge, MA.

Henderson, R.M. and Clark, K.B. (1990) 'Architectural innovation: the reconfiguration of existing product technologies and the failure of established firms', *Administrative Science Quarterly*, 35, pp. 9–30.

Hill, C.W.L. (1994) 'Diversification and economic performance: bringing structure and corporate management back into the picture', in Rumelt, R.P., Schendel, D.E. and Teece, D.J. (eds), *Fundamental Issues in Strategy. A Research Agenda*, Harvard Business School Press, Boston, pp. 297–321.

Hoskisson, R.O. and Johnson, R.D. (1992) 'Corporate restructuring and strategic change: the effect on diversification strategy and R&D intensity', *Strategic Management Journal*, 13, pp. 625–634.

Hoskisson, R.E., Hitt, M.A., Johnson, R.A. and Moesel, D.D. (1993) 'Construct validity of an objective (entropy) categorical measure of diversification strategy', *Strategic Management Journal*, 14, pp. 215–235.

Jacquemine, A.P. and Berry, C.H. (1979) 'Entropy measure of diversification and corporate growth', *Journal of Industrial Economics*, 27, pp. 359–369.

Jaffe, Adam B. (1989) 'Characterizing the "technological position" of firms, with application to quantifying technological opportunity and research spillovers', *Research Policy*, 18 (2), pp. 87–97.

Jantsch, E. (1967) *Technological Forecasting in Perspective*, OECD, Paris.

Jensen, M.C. (1986) 'Agency costs of free cash flow, corporate finance and takeovers', *American Economic Review Papers and Proceedings*, 76, pp. 323–329.

Jensen, M.C. and Meckling, W.H. (1976) 'Theory of the firm: managerial behaviour, agency costs and ownership structure', *Journal of Financial Economics*, October, pp. 305–360.

Kim, D.J. and Kogut, B. (1996) 'Technological platforms and diversification', *Organization Science*, 7 (3), May–June, pp. 283–301.

Kodama, F. (1986) 'Technological diversification of Japanese industry', *Science*, 18 (7), pp. 233, 291–296.

Kreps, D.M. (1990) *Game Theory and Economic Modelling*, Oxford University Press, Oxford.

Lancaster, K. (1990) 'The economics of product variety: a survey', *Marketing Science*, 9 (3), 189–206.

Lane, P.J., Cannella, A.A. and Lubatkin, M.H. (1999) 'Ownership structure and corporate strategy: one question viewed from different worlds', *Strategic Management Journal*, 20, pp. 1077–1086.

Lang, L.H.P. and Stulz, R.M. (1994) 'Tobin's q, corporate diversification, and firm performance', *Journal of Political Economy*, 102 (61), 1248–1280.

Lawrence, P.R. and Lorsch, J.W. (1967) *Organization and Environment*, Harvard Business School, Division of Research, Boston, MA.

Lichtenberg, F.R. (1992) 'Industrial de-diversification and its consequences for productivity', *Journal of Economic Behaviour and Organisation*, 18, pp. 427–438.

Lubatkin, M., Merchant, H. and Srinivasan, N. (1993) 'Construct validity of some unweighted product-count diversification measures', *Strategic Management Journal*, 14, pp. 433–449.

MacDonald, J.M. (1985) 'R&D and the directions of diversification', *Review of Economics and Statistics*, 67, pp. 583–590.

Markides, C.C. (1995) *Diversification, refocusing and economic performance*, MIT Press, Cambridge, MA.

Markowitz, H.M. (1959) *Portfolio Selection: Efficient Diversification of Investments*, Wiley & Sons, New York.

McGahan, A.M. and Porter, M. (1997) 'How much does industry matter, really?', *Strategic Management Journal*, 18, pp. 15–30.

Milgrom, P. and Roberts, J. (1990) 'The economics of modern manufacturing: technology, strategy, and organization', *American Economic Review*, 80 (3), pp. 511–528.

Mintzberg, H. (1983) *Structure in Fives: Designing Effective Organisations*, Prentice-Hall, Englewood Cliffs, NY.

Montgomery, C. (1982) 'The measurement of firm diversification: some new empirical evidence', *Academy of Management Journal*, 25, pp. 299–307.

Montgomery, C. (1994) 'Corporate diversification', *Journal of Economic Perspectives*, 6 (5), pp. 163–178.

Montgomery, C.A. and Wernerfelt, B. (1988) 'Diversification, ricardian rents, and Tobin's q', *Rand Journal of Economics*, 19, pp. 623–632.

Morck, R., Schleifer, A. and Vishny, R.W. (1990) 'Do managerial objectives drive bad acquisitions?,' *Journal of Finance*, 45, pp. 31–48.

Nelson, R.R. (1959) 'The simple economics of basic scientific research', *Journal of Political Economy*, 67, pp. 297–306.

Nelson, R.R. and Winter, S. (1982) *An Evolutionary Theory of Economic Change*, The Belknap Press of Harvard University Press, Cambridge, MA.

Oskarsson, C. (1993) *Technological Diversification – the Phenomenon, its Causes and Effects*, Chalmers University of Technology, Department of Industrial Management and Economics, PhD dissertation.

Palepu, K. (1985) 'Diversification strategy, profit performance, and the entropy measure', *Strategic Management Journal*, 6, pp. 239–255.

Panzar, J.C. and Willig, R.D. (1981) 'Economies of scope', *American Economic Review*, 71, pp. 268–272.

Patel, P. and Pavitt, K. (1994a) 'Technological competencies in the world's largest firms', *STEEP Discussion Paper*, 13, SPRU, University of Sussex, Brighton.

Patel, P. and Pavitt, K. (1994b) 'The continuing, widespread (and neglected) importance of improvements in mechanical technologies', *Research Policy*, 23, pp. 533–545.

Pavitt, K. (1998) 'Technologies, products and organisation in the innovating firm: what Adam Smith tells us and Joseph Schumpeter doesn't', *Industrial and Corporate Change*, 7, pp. 433–452.

Pavitt, K., Robson, M. and Townsend, J. (1989) 'Technological accumulation, diversification and organisation in UK companies, 1945–1983', *Management Science*, 35, pp. 81–99.

Penrose, E. (1959) *The Theory of the Growth of the Firm*, Basil Blackwell, Oxford.

Ramanujam, V. and Varadarajan, P. (1989) 'Research on corporate diversification: a synthesis', *Strategic Management Journal*, 10, pp. 523–551.

Ravenscraft, D.J. and Scherer, M. (1987) *Mergers, Sell-Offs, and Economic Efficiency*, The Brookings Institutions, Washington, DC.

Robbins, J. and Wiersema, M.F. (1995) 'A resource-based approach to the multi-business firm: empirical analysis of portfolio interrelationships and corporate financial performance', *Strategic Management Journal*, 16, pp. 277–299.

Roll, R. (1986) 'The Hubris hypothesis of corporate takeovers', *Journal of Business*, 59 (2), pp. 197–216.

Rosenberg, N. (1976) *Perspectives on Technology*, Cambridge University Press, Cambridge.

Rotemberg, J.J. and Saloner, G. (1994) 'Benefits of narrow business strategies', *The American Economic Review*, 4, pp. 1330–1349.

Rumelt, R.P. (1974) *Strategy, Structure and Economic Performance*, Harvard Business Press, Cambridge, MA (1986 edition).

Rumelt, R.P. (1982) 'Diversification strategy and profitability', *Strategic Management Journal*, 3, pp. 359–369.

Rumelt, R.P. (1991) 'How much does industry matter?', *Strategic Management Journal*, 12, pp. 167–185.

Scherer, F.M. (1965) 'Firm size, market structure and the output of patented inventions', *American Economic Review*, 55, pp. 1097–1125.

Schleifer, A. and Vishny, R.W. (1991) 'Takeovers in the '60s and '80s: evidence and implications', *Strategic Management Journal*, 12, pp. 51–59.

Schmalensee, R. (1985) 'Do markets differ much?', *American Economic Review*, 75, June, 341–351.

Scott, J.T. (1982) 'Multimarket contact and economic performance', *The Review of Economics and Statistics*, 64, pp. 368–375.

Scott, J.T. (1993) *Purposive Diversification and Economic Performance*, Cambridge University Press, New York.

Scott, J.T. and Pascoe, G. (1987) 'Purposive diversification of R&D in manufacturing', *The Journal of Industrial Economics*, 36, pp. 193–205.

Stimpert, J.L. and Duhaime, I.M. (1997) 'In the eyes of the beholder: conceptualisation of relatedness held by the managers of large diversified firms', *Strategic Management Journal*, 182 (2), pp. 111–125.

Sutton, J. (1996) 'Technology and market structure', *European Economic Review*, 40, pp. 511–530.

Suzuki, Y. (1980) 'The strategy and structure of top 100 Japanese industrial enterprises 1950–1970', *Strategic Management Journal*, 1, pp. 265–291.

Teece, D.J. (1980) 'Economies of scope and the scope of the enterprise', *Journal of Industrial Behavior and Organisation*, 1, pp. 223–247.

Teece, D.J., Rumelt, R., Dosi, G. and Winter, S. (1994) 'Understanding corporate coherence: theory and evidence', *Journal of Economic Behaviour and Organisation*, 23, pp. 1–30.

Torrisi, S. (1999) 'Firm specialisation and growth. A study of the European software industry' in Gambardella, A. and Malerba, F. (eds), *The Organisation of Economic Innovation in Europe*, Cambridge University Press, Cambridge, MA, pp. 239–268.

von Hippel, E. (1990) 'Task partitioning: an innovation process variable', *Research Policy*, 19, pp. 407–418.

Vonortas, N.S. (1999) 'How do participants in research joint ventures diversify?', *Review of Industrial Organization*, 15, pp. 263–281.

Williamson, O.E. (1970) *Conglomerate Control and Business Behavior: An Inquiry into the Effects of Organisation Form on Enterprise Behavior*, Prentice-Hall, New York.

Williamson, O.E. (1985) *The Economic Institutions of Capitalism*, Free Press, New York.

Winter, S.G. (1993) 'On coase, competence and the corporation', in Williamson, O.E. and Winter, S.G. (eds), *The Nature of the Firms*, Oxford University Press, New York, 179–195.

Wrigley, L. (1970) *Divisional Autonomy and Diversification*, unpublished doctoral dissertation, Harvard Business School, Boston, MA.

Yip, George S. (1982) 'Diversification entry: internal development versus acquisition', *Strategic Management Journal*, 3 (4), pp. 331–345.

3 The empirical assessment of firms' technological "coherence"

Data and methodology

Stefano Breschi, Francesco Lissoni and Franco Malerba

1 Introduction

A fairly common phenomenon in most industrial sectors is that firms are "technologically diversified", i.e. they master and innovate in more than one technology field. The literature on innovation and technical change has evidenced some robust stylised facts about firms' technological diversification.

First, technological diversification is usually greater than product diversification. In order to develop and produce new goods and services, innovative firms have to manage a wide number of technologies. Thus, most of them could be labelled multi-technology corporations, even if they are specialised in one line of business (Granstrand, 1997).

Second, technological diversification may often anticipate product and market diversification (Pavitt, 1998). This is so because technological exploration in a wide range of technologies is a prerequisite for production.

Third, firms' profile of technological diversification is rather stable, i.e. it changes slowly over time as a consequence of the inertia of specialisation, incremental changes in knowledge production and modifications in firms' competencies (Cantwell and Andersen, 1996).

Fourth, large firms exhibit different profiles of technological diversification, as a consequence of their history, market incentives and the specific institutional setting in which they operate. However, the profile of technological diversification of large firms dealing with the same products, particularly in high-tech and technology-based industries, is very similar (Patel and Pavitt, 1995a).

Based upon such evidence, a question that has recently gained the attention of several scholars in the field of industrial organisation and technical change concerns the nature and the determinants of firms' productive and technological diversification. On the one hand, there is emerging evidence that the range of firms' technological and productive activities is not chosen at random, but it follows some "purposiveness" (Scott, 1993). On the other hand, it has been shown that firms exhibit some "coherence" in the technological and productive activities they are engaged in (MacDonald, 1985; Teece *et al.*, 1994). However, much work has still to be done at the conceptual and empirical levels in order to define and measure concepts like coherence and purposiveness. This chapter develops some methodological reflections about the empirical treatment of "coherence" in firms' technological diversification. We will first address the conceptual question of defining what is meant by technological "coherence", and discuss why firms should diversify their technological activities in a "coherent" way (section 2). We will then present the main ingredients that are needed to build empirical tests of corporate technological coherence. In particular, we will focus upon the problem of measuring the degree of relatedness among technology fields, review some approaches that have been proposed in the most recent literature on the subject, and work out a new patent-based measure of "technological distance" (section 3). We will then compare the measure we propose with the existing ones, and explore the main differences and similarities, with respect to the main findings they lead to (section 4). The chapter closes with some suggestions for further research, and a short list of other research issues that may profit from further (methodological and empirical) work on technological distance.

2 On the notion of "coherence"

It is useful to start our discussion with a broad definition of what is meant by "coherence" in firms' technological diversification. A first (weak) definition is the following one: *a firm exhibits coherence when its technological activities are not allocated "randomly" across technology fields.* According to this definition, therefore, coherence in a firm's technological activities should be evaluated against what one would expect if this firm were choosing its portfolio of activities in a random way. A second (strong) definition of "coherence" is the following one: *a firm exhibits coherence when its technological activities are "related", in the sense that they share some common or complementary characteristics.* According to this definition, therefore, coherence should be evaluated on the basis of technological "relatedness".[1] Whereas the concept of business "relatedness" has been quite extensively studied in the managerial literature, the corresponding notion of technological "relatedness" has been only casually analysed and its empirical measurement has proved rather elusive.

On the one hand, technological relatedness may refer to production technology. In order to produce a certain good, firms may have to master more than one technology at the same time.[2] In this case, the relatedness among two or more technologies is due to their *complementarity* (Milgrom and Roberts, 1990; Scott, 1993). Moreover, when a complementary technology is used together with a wide range of other technologies for the development of several different products and processes, it may become a generic technology (Bresnahan and Trajtenberg, 1995). According to this view, a generic technology is a highly pervasive complementary technology.

On the other hand, technological relatedness may refer to the properties of the *knowledge base*. In this case, the relatedness among two or more technologies is due to their sharing of a common knowledge base, heuristics and scientific principles, such as the type of scientific inputs, search procedures (R&D, learning-by-doing, design activities) and knowledge sources (universities, public research institutes, users, suppliers).

There are two major theoretical reasons to expect firms to be active in knowledge-related fields in the sense given above. First, learning tends to be "local". Firms' innovative search takes place in the neighbourhood of the technologies currently developed and innovative activities proceed incrementally (Atkinson and Stiglitz, 1969; David, 1975; Malerba, 1992; Antonelli, 1995). According to this argument, because of uncertainty and change, firms are boundedly rational actors that focus on technological domains, which present similarity in problem solving and knowledge bases (Nelson and Winter, 1982; Dosi, 1997). Second, firms may be active in more than one technology field because the same type of knowledge is used in more than one technology. Therefore, firms have economies of scope in the "use of one piece of knowledge" (Penrose, 1959; Teece, 1982).

In what follows, we will not discriminate between knowledge relatedness as the outcome of a common knowledge base, and knowledge relatedness as the result of technical complementarity. However, as we will discuss in section 5, discriminating between the two sources of knowledge relatedness is a crucial research task, which requires further refinements of our methodology.

3 How to test corporate technological "coherence"? Methodological issues and a proposal

In this section, we discuss the main building blocks of an empirical test aimed at assessing the extent to which firms diversify their technological activities in coherent ways. In our view, there are four broad issues that must be dealt with:

a the choice of an *indicator of technological activity*, and the selection of a proper sample of technologically diversified firms, based upon such an indicator;

b the choice between a *weak* and a *strong* definition of firms' technological coherence;

c in the case of a strong definition of coherence, the choice of an *indicator of relatedness (or distance) among technologies* (Does this suggest to us that two technologies are related?), and of a proper measurement system (What metrics should we adopt for measuring relatedness?);

d following on from c), the choice of a proper *index for summarising and comparing the degree of coherence* of individual firms' (or firm classes') diversification patterns.

In the remainder of this section, we examine these issues in turn, and discuss our choices and methodology.

3.1 Indicators of technological activity and firm sampling

Different indicators of technological activity may lead to quite different assessments of the extent and coherence of firms' technological diversification.

Ideally, one would like to have firms' R&D expenditures broken down by technologies (or industries). In practice, R&D expenditures are rarely available at the firm level, least so broken down by technologies (or industries).[3] This explains why very few authors have proposed R&D-based tests of the coherence hypothesis so far.[4]

More consistent attempts at evaluating the coherence hypothesis have been carried out using survey data (Pavitt *et al.*, 1989; Pavitt, 1998). However, the main limitation of this approach is that one can hardly generalise survey results, which are often country-specific, and almost always do not provide time-series data. These weaknesses of R&D and survey data explain the relative success of US (USPO) or European (EPO) patents as indicators of firms' innovation activities, especially for studies on firms' technological diversification strategies (Patel and Pavitt, 1995b; Granstrand *et al.*, 1997). Compared to other indicators, in fact, patents have several advantages.

First and foremost, they are easily available at the firm level, provide quite a homogeneous indicator across countries, may refer to the results of non-formalised research effort, and are available for fairly long time series.

Second, they provide very detailed information on the technological contents of firms' innovation activities, thanks to their detailed classification systems and rich technical documentation. Thus, they make it possible to analyse innovation patterns at different levels of technical detail.

Third, patent applications are good indicators of firms' technological competencies: as long as a company applies for a patent to protect the output of its own research efforts, this means that such a company is very close to the technological frontier of the chosen field.[5]

Our study is based on the EP-CESPRI database, which contains all patent applications by firms from the United States, Italy, Germany, France, Japan and the United Kingdom, by priority date and IPC (International Patent Classification) 12-digit code, from 1978 to 1993 (for a total of more than half a million patents, and more then 48,000 firms).[6]

Considering the period from 1982 to 1993, patent documents have been classified into 30 different technological fields, based upon the original IPC 12-digit code (see Table 3.1).[7] According to this broad classification, techno-

Table 3.1 IPC-based technology classification for the EP-CESPRI database

1	Electrical Engineering	16	Chemical Engineering
2	Audiovisual Technology	17	Surface Technology
3	Telecommunications	18	Materials Processing
4	Information Technology	19	Thermal Processes
5	Semiconductors	20	Environmental Technology
6	Optics	21	Machine Tools
7	Control Technology	22	Engines
8	Medical Technology	23	Mechanical Elements
9	Organic Chemistry	24	Handling
10	Polymers	25	Food Processing
11	Pharmaceutics	26	Transport
12	Biotechnology	27	Nuclear Engineering
13	Materials	28	Space Technology
14	Food Chemistry	29	Consumer Goods
15	Basic Materials Chemistry	30	Civil Engineering

logically diversified firms (i.e. firms patenting in more than one technological field) represent no more than 30 per cent of all patenting firms. Moreover, their distribution over the number of technology fields in which they are active is highly skewed, with the large majority of them (around 70 per cent) patenting in only two different fields (see Figure 3.1).

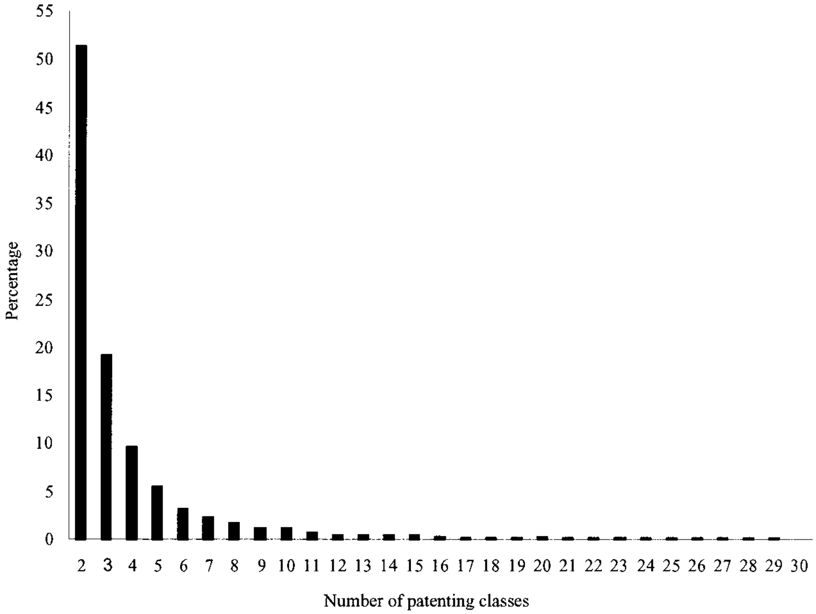


Figure 3.1 Distribution of technologically diversified firms, by number of patenting classes (percentage values, 1982–1993).

Source: EP-CESPRI database.

However, technologically diversified firms are also the biggest innovators. Overall, they account for more than 90 per cent of all EPO patent applications. In addition, *highly* diversified firms (such as those diversified in more than three fields) command nearly 88 per cent of all patents by diversified firms (Figure 3.2).

3.2 "Weak" vs "strong" technological coherence

One of the most influential approaches to the problem of testing firms' technological coherence was proposed by Teece *et al.* (1994), who extended to the issue of technological diversification some techniques they had already employed when dealing with firms' product diversification.[8]

The test they propose is based upon the following statistics:

$$S_{ij} = \frac{O_{ij} - \mu_{ij}}{\sigma_{ij}} \tag{1a}$$

where O_{ij} indicates the observed number of firms that are active (i.e. diversified) in both technology fields i and j, while μ_{ij} is the expected number of firms to be active in both technology fields i and j, if firms were

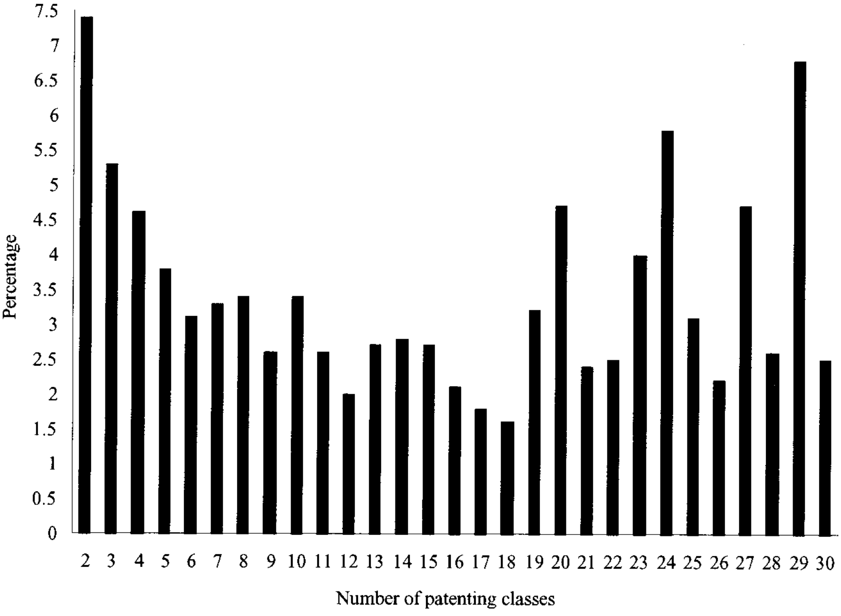


Figure 3.2 Distribution of *patents* by technologically diversified firms, by number of patenting classes (percentage values, 1982–1993).

Source: EP-CESPRI database.

assigned to technology fields on a random base. Therefore, S_{ij} measures the extent to which the observed association between two technology fields exceeds the level that would be expected if firms were assigned to technology fields randomly.[9] The greater number of S_{ij}s that are found to be significantly different from zero, the stronger the rejection of the random diversification hypothesis.

Both Teece *et al.* (1994) and other authors (e.g. Piscitello, 1999) get a positive answer from this testing exercise, which we have been able to replicate with the EP-CESPRI database (results are reported in Table 3.B1 in the Appendix).

However, according to the definitions we proposed in section 2, the S_{ij}-test tells us only about the existence of "weak" technological coherence, but cannot measure the *strength* of that coherence. That is, it tells us that the technological activities of the observed sample of firms follow *some logic* (since they are not distributed randomly across technology fields), but not *what kind of logic* they actually follow.

In order to get such information we need a *direct* measure of that distance, based upon leading technologists' and engineers' judgements, and independent from the behaviour of the sampled firms. A number of difficulties stand in the way of this effort, which we discuss and try to sort out in the next subsection.

3.3 Measuring technological distance

The ultimate goal of our measuring effort is to build a matrix of weights w_{ij}, where w_{ij} is the degree of relatedness between technologies i and j.

In recent times, there have been various attempts in the same direction. However, most of them were not motivated by the need to assess firms' technological diversification. Rather, they originated from an interest in inter-industry technology flows and the impact of inter-industry spillovers. Most of these approaches make use of patent data.[10]

A classical method, pioneered by Scherer (1982), is based upon classifying patents according to their industry of origin (branch of manufacturing activity of the firms that applied for the patents) and industry/industries of use (branches of manufacturing activity most likely to adopt the invented product or process). According to this method, therefore, two industries are considered *close* to each other if a rather high share of patents produced in one sector is actually used by the other one.

This method has been followed for constructing the so-called "Yale–Technology–Concordance" (YTC), based upon data from the Canadian Intellectual Property Office (CIPO). As a rule, CIPO examiners assign each individual patent document both one or more IPC technology codes (using the IPC), and a few SIC industry codes, distinguishing between "industry of manufacture" (IOM) and "industry of use" (IOU) codes.[11]

For our purposes, these user-producer methods of measuring technological relatedness present two main limitations.

The first limitation is conceptual. Since they are based on user-producer relationships and input–output flows, they are likely to capture only the *complementarity* aspect of technological relatedness. For example, technical knowledge contained in a patent on pesticides may be quite useful for innovative activities in other sectors, even though it is unlikely that the patent itself will be applied for outside the agricultural sector.[12] The second limitation is more practical. Following this approach requires a tremendous amount of manpower, thus forcing the researchers either to adopt a specific classification system (e.g. SIC) or to find quite complicated concordances between classification systems.

As an alternative, we propose *to measure the degree of relatedness between technologies by calculating the number of co-occurrences of the various IPC classification codes*, assigned by patent examiners to individual patent documents. Patent examiners, both at EPO and in other patent offices, are usually required to classify patents not just with one IPC code (the so-called *main* or *primary* code), but also with a number of further codes (*secondary* or *supplementary* codes). Whereas the primary code identifies the key technical area interested by the invention claim, the supplementary codes point at other technical areas to which the invention may contribute.

Thus, we assume that the frequency by which two classification codes are jointly assigned to the same patent document measures the strength of the technical relationship between the two, either in terms of knowledge base links or in terms of complementarity. That is, it represents an inverse measure of the technological distance between the two fields.

This basic intuition, however, can be exploited in a few different ways. On the one hand, Verspagen (1997) has recently suggested to distinguish between the *main* and the *supplementary* classes, by assuming that the former refers to the object of claimed and appropriable knowledge, while the latter refers to some non-appropriable additional knowledge, i.e. knowledge that is not new and upon which no discovery claim is made. Following this distinction, Verspagen (1997) assumes that the main classification code "*provides a good proxy of the producing sector of knowledge and that the listed supplementary IPC codes (taken as partially unintended 'by-products' of the main goal of the invention) give an indication for technology spillovers to other industrial sectors*".

Contrary to Verspagen we make no assumption about the meaning of the main classification codes as opposed to the supplementary ones. No EPO technical document suggests by any means that the two kinds of codes distinguish between knowledge-producing and knowledge-incorporating fields. In fact, although the main classification code describes the central characteristics of the main claim of the patent, the supplementary codes indicate further features of the main claim as well as of the remaining claims of the patent, i.e. they also refer to knowledge creation. Therefore, we do not attempt to distinguish between main and supplementary classification codes, and weigh them equally in all of our statistical exercises.

These exercises have started with the retrieval of *all* patent applications to the EPO over the period 1982–1993.[13] This yields around 721,260 observations. Then, for each patent document, we aggregated the primary and the secondary codes into the 30 technology fields, of the EP-CESPRI database classification scheme (see section 3.1 above). Finally, we built a symmetrical matrix $\mathbf{W}(30 \times 30)$, whose generic cell w_{ij} reports the number of patent applications classified in both technology fields i and j, which represents the fundamental input for our attempt of measuring knowledge relatedness.

Once the **W** matrix was built up, the key problem to be solved was the choice of a statistical index for summarising the degree of relatedness. Here we had several candidates (for a full list of them, see Engelsman and van Raan, 1991).

On the one hand, there are indexes that focus exclusively upon the frequency of the elements under consideration. The S_{ij} index we discussed in section 3.2 is one of those. By substituting the number of firms that are active in both technology fields i and j (O_{ij}) with the number of patents that are classified both in i and j (w_{ij}), we could reformulate it as:

$$S_{ij} = \frac{w_{ij} - \mu_{ij}}{\sigma_{ij}} \tag{1b}$$

(from now on, the S_{ij} index calculated as in equation (1a) will be referred to as $S_{ij}(O)$, as opposed to $S_{ij}(W)$ from equation (1b)).[14]

However, these kinds of indexes measure the distance between pairs of technologies in quite a crude way, since they ignore all the possible indirect associations between i and j, due to their co-occurrence with other technological classes.

The so-called *similarity* indexes measure the "profile likeness" of pairs of technologies, by taking into account not just their association on the same patent documents, but the distribution of all their associations with the remaining technological classes. If i and j are frequently found to be jointly assigned to patent documents with other classes, and those classes are the same for both i and j, then i and j are said to be similar, i.e. they are supposed to share a common knowledge base or to be complementary to the same set of other technologies.

One of the most widely used similarity indexes is the *cosine index*, defined as:

$$C_{ij} = \frac{\sum_{k=1}^{n} w_{ik} w_{jk}}{\sqrt{\sum_{k=1}^{n} w_{ik}^2 \sum_{k=1}^{n} w_{jk}^2}} \tag{2}$$

which we also have adopted to exploit our **W** matrix (we will refer to it as $C_{ij}(W)$).[15] This choice is motivated by our wish to use all the information contained in that matrix, and to go as near as possible to a knowledge-related measure of technological distance. Table 3.C1 in Appendix C reports all the $C_{ij}(W)$ values we calculated.

Once picked up a specific index of relatedness, a further problem that should be somehow evaluated concerns the metrics to be adopted. Both for S_{ij} and the C_{ij} index there is no a priori reason to assume the metrics to be linear, i.e. a linear mapping between the index and the "true" distance between the classes under scrutiny. However, this discussion goes beyond the limits of the present chapter, and we set it aside.

3.4 Measuring firms' technological coherence

On the basis of the technological distance measures we have proposed, one could calculate a large number of indexes measuring the degree of "strong" coherence in firms' diversification patterns.

Here we focus upon two indexes, both of them first suggested, once again, by Teece *et al.* (1994).

The first index measures the *weighted-average-relatedness* (WAR) of firm *k*'s technological activities outside a given class *i*, with the same firm's activities in that class. This is defined as:

$$\mathrm{WAR}_i^k = \frac{\sum\limits_{j \neq i} r_{ij} p_j}{\sum\limits_{j \neq i} p_j} \tag{3}$$

where *k* is the observed firm, r_{ij} is a measure of the relatedness between technologies *i* and *j*, and p_j measures the number of patents produced by firm *k* in each technology field *j*. Thus the index measures the degree to which technology field *i* is linked to all of the other activities of firm *k*.

For each firm, an average value of WAR_i can thus be calculated to get an index of global technological coherence. Further average values can be computed for specific firm categories, such as firms with the same size (in our case, size is given by the number of patents held by the firm), a similar diversification range (the number of technological fields in which the firm is found to be active), or active in the same technological field.

The main strength of the WAR index is its simplicity, while its main drawback is its dependence upon the individual firm's diversification range. In particular, one may suspect that the more technological fields the firm adds to its portfolio, the more "weak links" between those fields and field *i* (low r_{ij} values) will be added to the index, thus lowering its value.

In order to correct for this problem, Teece *et al.* propose a refinement, called *weighted-average-relatedness of neighbours* (WARN). This index is calculated as WAR, but it takes into account only those links that belong to the so-called *maximum spanning tree.*, i.e. those $(n-1)$ links which are strictly necessary for creating a connected graph between firm k's n technological activities, and at the same time show the largest r_{ij} values. Once the maximum spanning tree for each set of n technological fields has been calculated, this can be used to work out the WARN index for each activity i of firm k as:

$$\mathrm{WARN}_i^k = \frac{\sum_{j \neq i} r_{ij} \lambda_{ij} p_j}{\sum_{j \neq i} \lambda_{ij} p_j} \tag{4}$$

where $\lambda_{ij} = 1$ if the link between i and j belongs to the maximum spanning tree that relates firm k's activities, and $\lambda_{ij} = 0$ otherwise. Notice that, for firms patenting in two classes only, there is just one link to be included both in WAR and WARN, which therefore are the same.

Finally, besides choosing between WAR and WARN, we had to select a proper measure for r_{ij}. In the absence of better alternatives, Teece *et al.* (1994) fell back on the $S_{ij}(O)$ index, whose limitations we have discussed in the previous sections.[16] On the contrary, we can also rely on the **W** matrix, and the $C_{ij}(W)$ values based upon it. Therefore we have calculated, for each firm in our patent database, the whole range of its WAR_i and WARN_i indexes (one for each field in which the firm is active), and then used them to explore to what extent firms' diversification choices appear to be coherent not just in a "weak" sense (as discussed in section 3.2), but also in a strong one. In order to compare our results with those of Teece *et al.* (1994), we have also calculated, for each firm in the data set, the two sets of its $S_{ij}(O)$-based and $C_{ij}(W)$-based WAR_i and WARN_i indexes. Tables 3.C2 in Appendix C reports the cross-firm average values, by diversification range (i.e. number of technological activities), for both sets of indexes.

4 Applications and comparisons

4.1 WAR and WARN average values, by diversification range

A quick look at Table 3.C2 provides us with a few intuitions about the different properties of WAR and WARN indexes, at the firm level. In particular, they tell us that average WAR decreases along with the number of technological activities firms are involved in, while the opposite happens with average WARN. This result holds whatever distance index (S_{ij} or C_{ij}) we employ.

This confirms the suspect that WAR indexes underestimate the degree of firms' technological coherence, because they take into account a number of "redundant" links among the technological classes in which firms are active, i.e. links that do not belong to the maximum spanning tree. On the contrary, the technological distance covered by firms diversifying in classes *i*, *j* and *z* ought to be measured by taking into account just "the shortest way" between the three of them, rather than all the possible connections. Figures 3.1 and 3.2 summarise these results. They report the standardised (0–1) values of average WAR and WARN from Table 3.C2, and highlight even more clearly the decreasing trend of the former, and the increasing trend of the latter. In addition, they suggest that, both for WAR and WARN, the $S_{ij}(O)$-based and $C_{ij}(W)$-based indexes are highly correlated.

The latter result is confirmed by Table 3.2: the top-left cell in the matrix shows the high degree of correlation among the WAR indexes, as it does the bottom-right one for the WARN indexes.

The interpretation of the remaining cells in Table 3.2 is less intuitive: on the basis of the results for diversification range-based averages in Table 3.C2, we would expect a negative relationship between WARs and WARNs, no matter whether based on the same distance index or not. However, average values by diversification range cancel out similarities across technologies, i.e. the possibility that cross-technology patterns of WARs and WARNs will be the same (as they actually are; we will come back to this below).

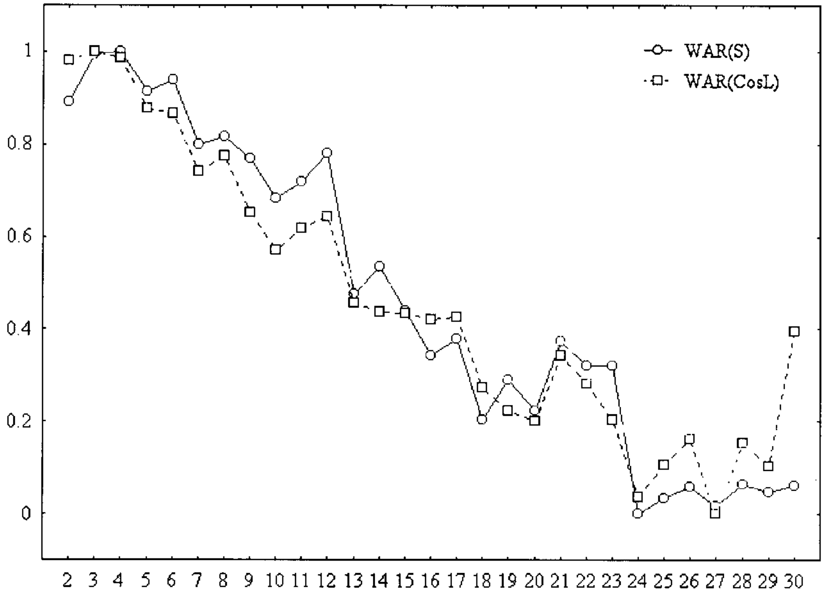


Figure 3.3 Average standardised WAR, by number of activities.

Source: elaboration on the EP-CESPRI database.

Table 3.2 Correlation between WAR and WARN indexes, for $S_{ij}(O)$ vs $C_{ij}(W)$ distance measures

	$WAR[S_{ij}(O)]$	$WAR[C_{ij}(W)]$	$WARN[S_{ij}(O)]$	$WARN[C_{ij}(W)]$
WAR[$S_{ij}(O)$]	–			
WAR[$C_{ij}(W)$]	0.781	–		
WARN[$S_{ij}(O)$]	0.797	0.628	–	
WARN[$C_{ij}(W)$]	0.648	0.853	0.748	–

Source: elaboration on the EP-CESPRI database.

One final comment on average WARN by firm's diversification range is that the pattern shown in Figure 3.4 clearly suggests that technological coherence increases, rather than decreases, with the number of technological classes in which the firm is active. However, this pattern is more evident when the number of classes increases from 2–3 to 4–7. This suggests that a large number of firms may occasionally patent outside their "core" class, but, when doing so, do not follow any clear-cut "technology strategy". This is especially true of firms with a limited number of patents.

On the contrary, as the volume of patenting and the number of classes increase, a technology strategy clearly emerges, as the technological links

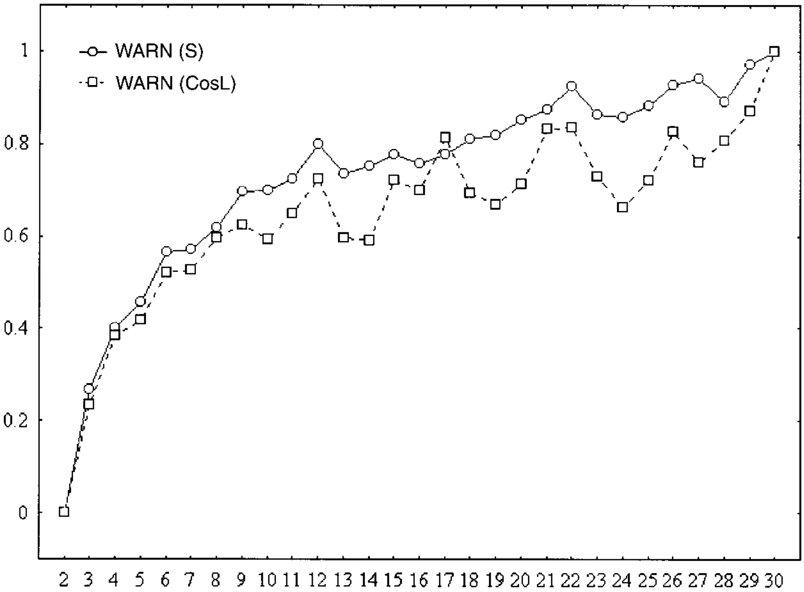


Figure 3.4 Average standardised WARN, by number of activities.

Source: elaboration on the EP-CESPRI database.

between the target activities show up through a dramatic increase of the average WARN index.

4.2 An examination by technological field: MDS analysis and firm mapping

Further hints on the similarities and differences across $S_{ij}(O)$-based and $C_{ij}(W)$-based WAR and WARN indexes come from an examination of technology-based average values (Figures 3.5 and 3.6).

We first notice that, for both distance measures, WAR and WARN averages follow a similar pattern, which help explain the correlation indexes of Table 3.2. In particular, $S_{ij}(O)$-based and $C_{ij}(W)$-based WAR and WARN averages follow a similar pattern for technological classes belonging to the chemical area, and reach extremely high values for Organic Chemistry (class 9), Pharmaceutics (class 11), and Biotechnology (class 12). These are tightly linked classes [i.e., they show very high values both for $S_{ij}(O)$-based and $C_{ij}(W)$-based], wherein pharmaceutical companies spread their patents in quite an homogeneous way, a combination that shows up in high values for WAR and WARN.

Looking at technological classes from 13 to 30, similarities of patterns for the $S_{ij}(O)$-based and the $C_{ij}(W)$-based indexes are confirmed. Moving from "horizontal" process technologies (such as Surface Technology,

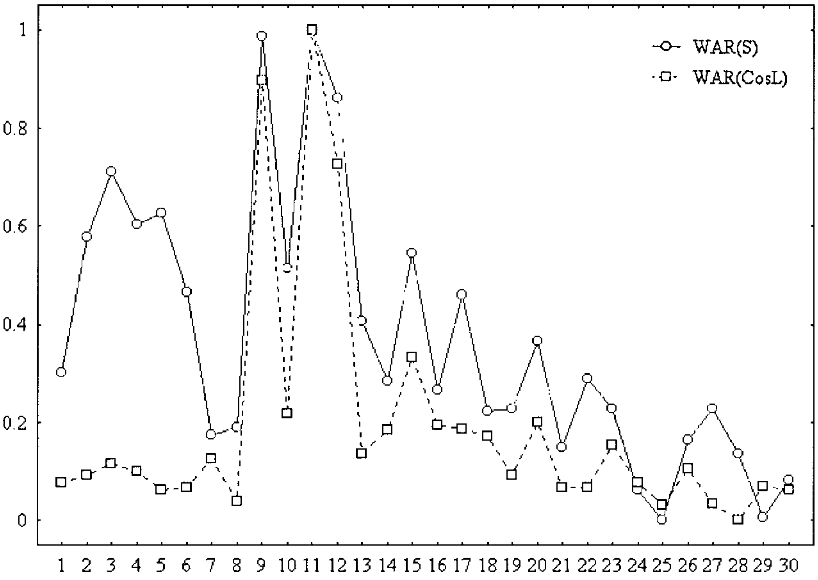


Figure 3.5 Average standardised WAR, by technological fields.

Source: elaboration on the EP-CESPRI database.

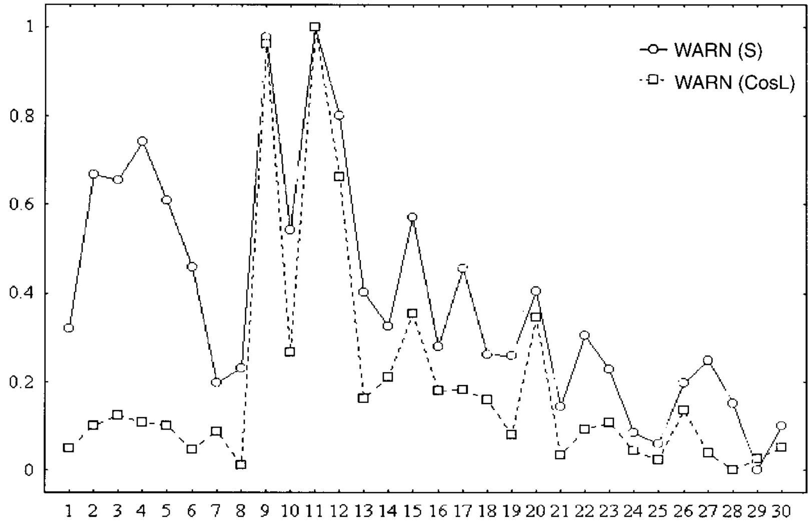


Figure 3.6 Average standardised WARN, by technological fields.

Source: elaboration on the EP-CESPRI database.

Materials Processing, Thermal Processes, and Environmental Technology (classes 17–20)) to mechanical classes (Machine Tools, Engines, Mechanical Elements, Handling, Food Processing, and Transport (classes 21–26)) we notice a decline of WAR and WARN, i.e. a decline of the overall technological coherence of firms active in those fields. This decline is presumably due to the different contents of the groups of technologies: classes from 17–20 host technologies which are necessary complements to a large number of other fields of invention, while classes 21–26 host a large number of patents that are not defined by their application field, but only by their design content.[17]

The most striking differences are those between $S_{ij}(O)$-based and $C_{ij}(W)$-based indexes for the electronics-related classes (Electrical Engineering, Audiovisual Technology, Telecommunications, Information Technology, Semiconductors (classes 1–5)), as well as for two more classes, whose applications also require complementary inputs from electronics (Optics and Control Technology (classes 6–7)). We notice that while $S_{ij}(O)$-based WAR and WARN indexes are extremely high (second only to the values observed for the chemical classes), the same does not hold for the $C_{ij}(W)$-based indexes, which show possibly the lowest values among the 30 classes.

These differences are not due to the choice of the distance index (S_{ij} vs C_{ij}), but to the different data matrixes upon which they are based (matrix **O** vs matrix **W**, as defined in section 3.3). That is, differences between the two sets of indicators are explained by differences between firms' behaviour (from which ex-post distance measures, such as those based on matrix **O**) and patent examiners' judgement (from which co-classification codes for patents, and matrix **W**). More precisely, we observe that while firms innovating in the electronics area tend to patent frequently in a number of classes within the area, as well as in Optics and Control Technology, patent examiners hardly classify those patents in as many classes, i.e. they hardly assign them a wide spectrum of IPC codes.

This is confirmed by comparing the same distance indexes calculated for both matrix **O** and matrix **W**, that is by calculating both the couple $C_{ij}(O)–C_{ij}(W)$ and the couple $S_{ij}(O)–S_{ij}(W)$. A synthesis of the results of this exercise is given by maps in Figures 3.7 and 3.8, both of them based upon the so-called Multi-Dimensional Scaling (MDS) analysis (see Engelsman and van Raan, 1991). Broadly speaking, the MDS maps summarise, by means of a by-dimensional representation, the overall set of 29 biunivocal distance indexes that link each of the 30 EP-CESPRI technological classes to the other classes.[18]

Each dot in a map corresponds to one of the 30 technological classes, dot size being proportional to the total number of EPO patents in that class.

The closer two dots (*i* and *j*) are, the greater is the cosine index C_{ij} that

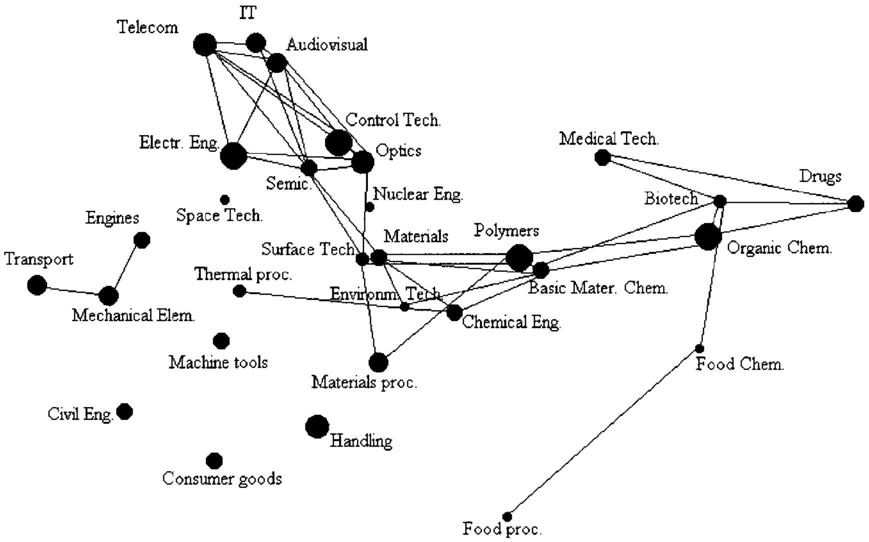


Figure 3.7 Technology map based on firms' diversification patterns (*O-based* MDS analysis).

Source: elaboration on the EP-CESPRI database.

Note
Stress index = 0.207.

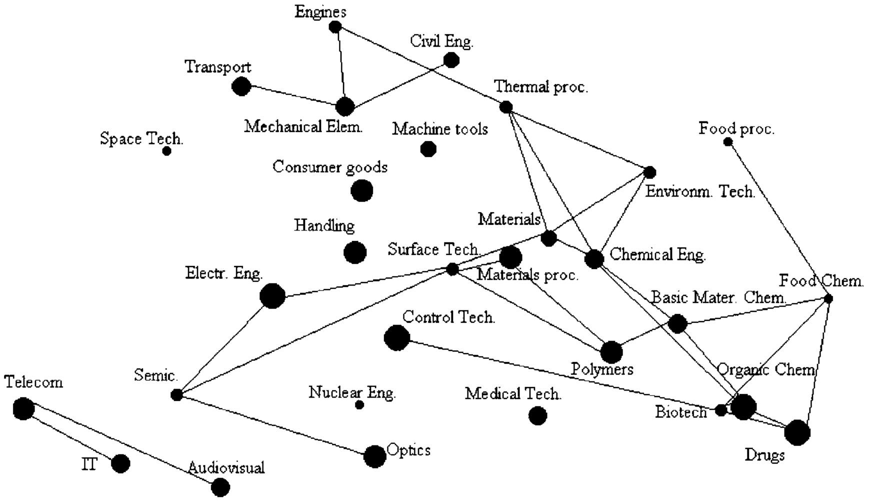


Figure 3.8 Technology map based on patents co-classification (*W-based* MDS analysis).

Source: elaboration on the EP-CESPRI database.

Note
Stress index = 0.130.

links them ($C_{ij}(O)$ in Figure 3.7, $C_{ij}(W)$ in Figure 3.8); that is, the relative position of two dots simulate the technological distance between them (no meaning, on the contrary, can be attached to their absolute position in the map, i.e. to their distance from the top/bottom or right/left ends of the map). The straight lines linking some pairs of dots signal above-average S_{ij} values.

One notices immediately that while both $C_{ij}(O)$ and $S_{ij}(O)$ suggest electronics-related technological classes to be "close" and "tightly linked" (in Figure 3.7, all dots for these classes cluster closely in the top-left region of the map, and are connected by a large number of lines), the same does not hold for $C_{ij}(W)$ and $S_{ij}(W)$ (the relevant dots are more scattered, and poorly linked; see the bottom-left corner of the map). On the contrary, the relative positions of dots and the number of links within the mechanical cluster (in particular: Engines, Mechanical Elements and Transport) and the pharmaceutical one (in particular: Organic Chemistry, Drugs and Biotechnology) do not differ much.

On the basis of our interpretation of **W**-based distance measures, these findings suggest that the knowledge-base links and/or the technical complementarities between electronics-related patents are not as far reaching as the leading innovators' strategies (as mirrored by the **O** matrix) seem to suggest.

This discrepancy may be explained by the existence, on the electronic firms' side, of some R&D and patenting strategies that go beyond the pursuit of technological spillovers and complementarities. Alternatively, the discrepancy between **O**-measures and **W**-measures may be due to different organisational arrangements, which lead the head-companies of electronic groups to centralise all the patenting activity of their groups (thus decreasing the overall technological coherence of their patents), as opposed to mechanical and pharmaceutical groups' strategy, which may turn out, at a closer look, to allow controlled firms to patent autonomously (so that each firm's set of patents turns out to be more technologically coherent than in the case of the electronics firms).

Testing these alternative explanations (and looking for other ones), will require many further research efforts, most of them directed at improving the distribution of EP-CESPRI patents *by firm* and at collecting information on individual companies' innovation strategies.[19] Here we can only propose a first step in that direction, which consists in a closer examination of the patenting activities of a selected number of large companies, namely the FORTUNE500 companies (from the Chemical, Pharmaceutical, Electronic, Computer and Photographic Equipment sectors) that we were able to trace back in the EP-CESPRI database.[20]

Figure 3.9 illustrates quite clearly the lower technological coherence of Electronic and Computer companies (bottom-left corner in Figure 3.9b) if compared to Chemical companies (centre/top-right corner in Figure 3.9b), and even more to Pharmaceutical companies (top-right corner in Figure 3.9a). In this case, the $C_{ij}(W)$-based and $S_{ij}(O)$-based average WARN indexes are highly correlated.

However, we also notice the existence of two outliers (Intel and Xerox in the bottom-right corner of Figure 3.9a), belonging respectively to the Electronic and Computer sectors, whose $C_{ij}(W)$-based average WARN indexes are comparatively much lower than the $S_{ij}(O)$-based ones. As for the Pharmaceuticals companies, these two outliers patent in a very limited number of fields, but differ from the latter in so far as they hold a very low number of patents.

As long as the technological fields in the electronic area of the EP-CESPRI database hosts many firms such as Intel and Xerox (as opposed to chemical and pharmaceutical fields, which are much more concentrated) this may suggest a first, tentative explanation of discrepancies between the two groups of fields. If the electronic area hosts many companies patenting simultaneously in a few technological classes belonging to it, and not outside it, this will show up in high values for all indexes based upon firm behaviour (i.e., indexes based upon matrix **O**, such as $S_{ij}(O)$ and the related WARN). At the same time, though, the technological classes in the electronic area may be, individually, more self-contained than those in the pharmaceutical area, so that patent examiners do not often need to refer simultaneously to more than one of them for defining the novelty

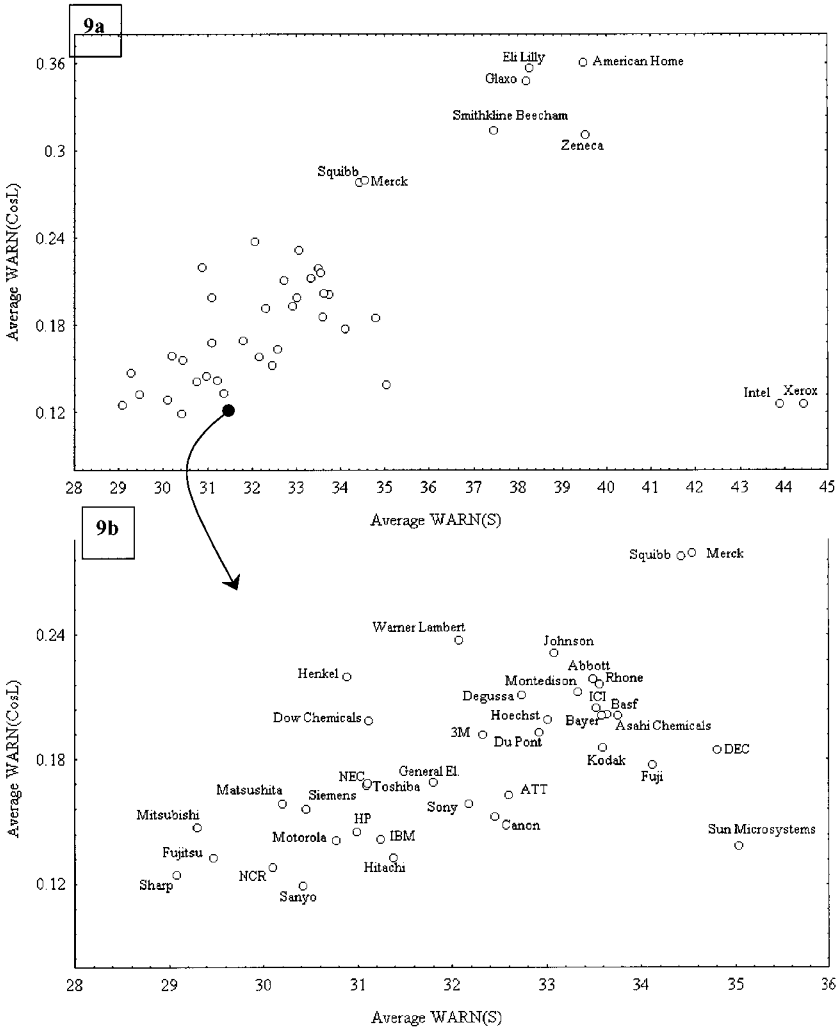


Figure 3.9 Average standardised WARN, by technological fields.

claim of the patent, as it happens with applications for new drugs and chemical products.[21] Thus, the two indexes may differ because of some problems in the EP-CESPRI classification, and not as a reflection of different innovation strategies in different industries. Once again, we need further enquiries to verify this.

5 Conclusions

International patents are a well-established indicator of technological activity. However, not all their information potential has been exploited so far. In particular, the most common econometric applications (such as those directed at estimating the knowledge production function, and other exercises on R&D productivity) tend to overlook the qualitative side of patent-based information. On the contrary, this is the main target of our methodological effort.

In particular, we have assumed that such a fine technological description of the patent content, as it is the multiple IPC classification assigned to each patent document, deserves much more attention than it has received so far. Other leading experts of bibliometric research share in this view.

We have shown that, after working out a limited number of technological classes from the original 12-digit IPC codes, it is possible to assign a large number of patents to more than class, and use these multiple assignments to derive a measure of the "technological distance" among the chosen classes.

We have then exploited such measures to explore the technological coherence of multi-technology innovating companies, thus providing a contribution to the study of corporate behaviour and the theory of the firm. This exercise has confirmed Teece *et al.*'s (1994) findings, by replicating them with our code-based measure of technological distance (as opposed to theirs, which was based on the application of the survivor principle to the observed firm behaviour).

At the same time, though, this exercise raised quite a big empirical puzzle about the behaviour of firms patenting in the electronic-related fields. Here, code-based indexes were significantly lower than firm-behaviour-based ones, but still more research has to be done in order to explain such differences.

More research is also required in order to find further applications for our measure of technological distance. In particular, the study of inter-firm and cross-sector technological spillovers should benefit greatly for more accurate distance measurement (Jaffe *et al.*, 2000; Henderson, 1999).

Finally, combining patent information with more updated and detailed information on the structure of manufacturing groups (including the distribution of their research activities across the various subsidiaries) would allow us to conduct some more sophisticated research effort on the innovation strategies of individual companies.

6 Appendices

6.1 Appendix A Description of the EP-CESPRI data set, and a methodological note on classification

6.1.1 Description of EP-CESPRI database

The EP-CESPRI dataset contains all patent applications to the European Patent Office (EPO) from 1978 (EPO's first year of activity) to 1993, by firms and institutions from the United States, Japan, France, Germany, Italy and the United Kingdom. It contains 17,394 patents and 4,802 firms for Italy, 124,626 patents and 10,459 firms for Germany, 39,582 patents and 7,121 firms for the UK, 51,690 patents and 6,835 firms for France, 164,790 patents and 14,395 firms for the US and 113,629 patents and 5,025 firms for Japan.

Firms that are part of business groups have been treated as individual companies.

In case of co-patenting, each co-patentee has been credited the patent.

Individual inventors have been excluded from the dataset. Since individual inventors are mostly self-employed and owners of small independent firms, their exclusion from the data set could underestimate the contribution of smaller companies to the innovative activities. However, the share of total patent applications held by private individuals in the dataset is rather small (generally, less than 3 per cent of total patent applications).

6.1.2 Classification issues

Each patent document in the EP-CESPRI dataset contains a (primary) classification code of the International Patent Classification (IPC), which has been assigned by patent examiners of the EPO and identify the technical area to which the invention refers. The IPC is an internationally agreed, non-overlapping and comprehensive patent classification system. Currently, the IPC refers to almost 60,000 individual codes (12-digit) and it may be used at different hierarchical levels (WIPO, 1994).

For practical purposes, the 12-digit IPC codes have to be aggregated in some way. In this chapter, we have adopted a technology-oriented classification that distinguishes 30 different technological fields. This classification has been elaborated jointly by *Fraunhofer Gesellschaft-ISI* (Karlsruhe), *Institut National de la Propriété Industrielle* (INPI, Paris) and *Observatoire des Sciences et des Techniques* (OST, Paris). The concordance between the 30 fields of technology and the original IPC codes is available from the authors.

6.2 Appendix B Test of randomness in firms' technological diversification

Let the universe being studied consist of T firms each active in two or more technology fields and assume there are in total n technology fields. A firm is considered to be active in a given technology field if it has autonomous research and development activities in that specific field. Let $G_{it} = 1$ if firm t is active in technology field i and $G_{it} = 0$ otherwise. The total number of firms being active in technology field i is therefore given by: $R_i = \Sigma_t G_{it}$. Using this notation, we can indicate the number of firms that are active, in both technology fields i and j as follows: $O_{ij} = \Sigma_t G_{it} G_{jt}$. By applying the latter to all possible pairs of technology fields we get a square $(n \times n)$ symmetrical matrix **O**, whose generic cell O_{ij} reports the number of firms that are active in both technology fields i and j.

A test of randomness can thus be performed by comparing the observed value of O_{ij} with the value that would be expected under the hypothesis that technological diversification is random. More particularly, let us assume that in a population of T innovative firms, a number R_i of firms possess the characteristic of being active in technology field i. This implies, of course, that $(T - R_i)$ firms do not possess such characteristics. Now, an independent sample (without replacement) of size R_j of firms is drawn from the population of T innovative firms and these firms are assigned activities in technology field j. Given this experiment, the probability of obtaining x firms that are active in both technology fields i and j is distributed according to a hypergeometric random variable, with population T, special members R_i, and sample size R_j:

$$P(X_{ij} = x) = \binom{R_i}{x}\binom{T - R_i}{R_i - x} \Big/ \binom{T}{R_i} \tag{1}$$

The mean and the variance of X_{ij} are respectively:

$$\mu_{ij} = E(X_{ij}) = R_i R_j / T \tag{2}$$

$$\sigma_{ij}^2 = \mu_{ij}\left(1 - \frac{R_i}{T}\right)\left(1 - \frac{R_i}{T}\right)\left(\frac{T}{T - 1}\right) \tag{3}$$

A test of randomness in firms' technological diversification can thus be based upon the following statistic:

$$r_{ij} = \frac{O_{ij} - \mu_{ij}}{\sigma_{ij}} \tag{4}$$

where O_{ij} is the value of the generic cell of matrix **O**; μ_{ij} and σ_{ij} are respectively the mean and variance of the hypergeometric distribution we would expect to obtain under the random hypothesis.

Table 3.B1 Test of non-randomness in firms' technological diversification, S_{ij} index

	Number of technology fields in which sample firms are active					
	Up to 2	*Up to 3*	*Up to 4*	*Up to 5*	*Up to 6*	*Up to 30*
T	6986	9507	10804	11548	11977	13460
I	30	30	30	30	30	30
O_{ij}*	435	435	435	435	435	435
O_{ij}	377	413	427	430	432	435
Percentage of O_{ij} with $\lvert S_{ij}\rvert > 2^a$	81.962	82.082	80.562	80.000	80.092	92.183
Sum S_{ij}	−1121.695	−1189.210	−1088.796	−917.143	−721.710	5059.644
Max S_{ij}	32.287	42.179	46.345	49.818	52.328	61.679
Min S_{ij}	−10.351	−12.773	−13.409	−13.436	−14.070	−11.143
Mean S_{ij}	−2.579	−2.734	−2.503	−2.108	−1.659	11.631
Std. Dev. S_{ij}	3.670	5.231	6.338	7.140	7.771	10.302
Var S_{ij}	13.466	27.362	40.170	50.985	60.395	106.132
Normality test for S_{ij}	−53.781	−57.018	−52.204	−43.974	−34.603	242.591

Legends
T: number of firms active in more than one technology
I: number of technologies where sample firms are active
O_{ij}*: all possible pairs of technological activities
O_{ij}: observed pairs of technological activities
Normality test for t is defined as: $t = \Sigma S_{ij}/\sqrt{I(I-1)/2}$, which under the assumption of independently distributed S_{ij} is expected to be distributed normally.

Note

a the distribution function of S_{ij}, under the assumption of a hypergeometric distribution, is normalised, i.e. the expected value of r_{ij} is 0 and its standard deviation is 1. This implies that for $\lvert S_{ij}\rvert > 2$ one has a possibility of 75 per cent (at least) that the indicated relation is real.

6.3 *Appendix C Further tables on* $\mathbf{C_{ij}}$ *(W), WAR, and WARN*

Table 3.C1 Knowledge similarity index C_{ij} (W) for 30 technology fields, 1982–1993

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
1 Electrical Engineering	1												
2 Audiovisual Technology	0.056	1											
3 Telecommunications	0.060	0.154	1										
4 Information Technology	0.033	0.094	0.143	1									
5 Semiconductors	0.116	0.038	0.037	0.054	1								
6 Optics	0.068	0.098	0.067	0.038	0.102	1							
7 Control Technology	0.083	0.050	0.087	0.112	0.043	0.062	1						
8 Medical Technology	0.022	0.016	0.011	0.024	0.008	0.037	0.080	1					
9 Organic Chemistry	0.010	0.008	0.003	0.004	0.006	0.048	0.101	0.030	1				
10 Polymers	0.057	0.019	0.004	0.003	0.024	0.095	0.018	0.053	0.148	1			
11 Pharmaceutics	0.005	0.004	0.002	0.004	0.003	0.018	0.097	0.068	0.755	0.089	1		
12 Biotechnology	0.010	0.007	0.009	0.014	0.006	0.018	0.257	0.042	0.477	0.059	0.479	1	
13 Materials	0.101	0.016	0.005	0.004	0.079	0.040	0.023	0.021	0.043	0.086	0.026	0.019	1
14 Food Chemistry	0.009	0.002	0.001	0.003	0.003	0.008	0.025	0.030	0.141	0.043	0.161	0.232	0.017
15 Basic Materials Chemistry	0.027	0.015	0.002	0.003	0.012	0.071	0.033	0.032	0.411	0.187	0.214	0.173	0.092
16 Chemical Engineering	0.031	0.008	0.006	0.013	0.018	0.022	0.095	0.061	0.152	0.083	0.073	0.082	0.165
17 Surface Technology	0.120	0.027	0.009	0.007	0.128	0.062	0.031	0.035	0.034	0.159	0.016	0.015	0.191
18 Materials Processing	0.045	0.021	0.004	0.007	0.018	0.053	0.030	0.050	0.036	0.268	0.018	0.021	0.097
19 Thermal Processes	0.078	0.006	0.008	0.007	0.019	0.010	0.060	0.019	0.009	0.012	0.004	0.012	0.124
20 Environmental Technology	0.019	0.003	0.002	0.003	0.010	0.011	0.026	0.025	0.045	0.048	0.021	0.038	0.151
21 Machine Tools	0.053	0.008	0.005	0.009	0.029	0.026	0.049	0.024	0.007	0.024	0.004	0.008	0.083
22 Engines	0.047	0.005	0.008	0.007	0.009	0.006	0.052	0.019	0.004	0.005	0.003	0.008	0.028
23 Mechanical Elements	0.057	0.012	0.008	0.009	0.010	0.013	0.055	0.034	0.004	0.018	0.002	0.007	0.031
24 Handling	0.035	0.027	0.015	0.034	0.021	0.056	0.060	0.036	0.012	0.038	0.007	0.011	0.021
25 Food Processing	0.012	0.005	0.003	0.006	0.004	0.006	0.036	0.021	0.021	0.015	0.022	0.050	0.012
26 Transport	0.051	0.011	0.015	0.010	0.007	0.013	0.055	0.014	0.003	0.019	0.002	0.006	0.013
27 Nuclear Engineering	0.092	0.025	0.019	0.019	0.030	0.045	0.082	0.063	0.012	0.014	0.009	0.018	0.064
28 Space Technology	0.019	0.008	0.018	0.011	0.009	0.023	0.075	0.007	0.010	0.013	0.006	0.014	0.020
29 Consumer Goods	0.035	0.034	0.011	0.022	0.011	0.021	0.056	0.073	0.007	0.030	0.007	0.009	0.020
30 Civil Engineering	0.026	0.011	0.009	0.007	0.007	0.008	0.041	0.010	0.007	0.025	0.003	0.008	0.045

Table 3.C1 Continued

	14	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*
1 Electrical Engineering																
2 Audiovisual Technology																
3 Telecommunications																
4 Information Technology																
5 Semiconductors																
6 Optics																
7 Control Technology																
8 Medical Technology																
9 Organic Chemistry																
10 Polymers																
11 Pharmaceutics																
12 Biotechnology																
13 Materials																
14 Food Chemistry	1															
15 Basic Materials Chemistry	0.119	1														
16 Chemical Engineering	0.081	0.171	1													
17 Surface Technology	0.020	0.068	0.102	1												
18 Materials Processing	0.023	0.113	0.098	0.189	1											
19 Thermal Processes	0.017	0.033	0.104	0.037	0.036	1										
20 Environmental Technology	0.034	0.097	0.373	0.067	0.048	0.133	1									
21 Machine Tools	0.012	0.024	0.043	0.072	0.090	0.042	0.021	1								
22 Engines	0.003	0.011	0.042	0.019	0.013	0.084	0.058	0.028	1							
23 Mechanical Elements	0.006	0.012	0.040	0.047	0.069	0.067	0.036	0.089	0.149	1						
24 Handling	0.037	0.023	0.066	0.102	0.116	0.026	0.022	0.073	0.015	0.067	1					
25 Food Processing	0.144	0.038	0.062	0.018	0.026	0.026	0.031	0.035	0.012	0.034	0.057	1				
26 Transport	0.003	0.005	0.015	0.031	0.038	0.037	0.021	0.026	0.066	0.207	0.044	0.020	1			
27 Nuclear Engineering	0.007	0.038	0.045	0.046	0.016	0.040	0.040	0.038	0.015	0.030	0.023	0.007	0.010	1		
28 Space Technology	0.004	0.011	0.025	0.030	0.021	0.019	0.013	0.020	0.028	0.039	0.022	0.008	0.054	0.010	1	
29 Consumer Goods	0.030	0.016	0.045	0.077	0.084	0.058	0.026	0.072	0.017	0.075	0.089	0.037	0.054	0.014	0.028	1
30 Civil Engineering	0.005	0.022	0.041	0.053	0.049	0.042	0.044	0.045	0.025	0.135	0.042	0.038	0.070	0.015	0.026	0.072

Source: elaboration on all EPO patents, 1982–1993.

Table 3.C2 Weighted average relatedness (WAR) index; firm average values, by number of patenting classes (1982–1993)

No. of classes	*No. of firms*	*No. of patents*	*WAR[$S_{ij}(O)$]*	*WAR[$C_{ij}(W)$]*	*WARN[$S_{ij}(O)$]*	*WARN[$C_{ij}(W)$]*
2	6896		18.015	0.104	18.015	0.104
3	2611		18.580	0.105	22.020	0.126
4	1297		18.606	0.104	24.027	0.140
5	744		18.135	0.098	24.891	0.143
6	429		18.272	0.098	26.496	0.153
7	326		17.509	0.091	26.606	0.154
8	232		17.605	0.092	27.286	0.160
9	164		17.345	0.086	28.480	0.163
10	139		16.875	0.081	28.497	0.160
11	94		17.068	0.084	28.894	0.166
12	66		17.407	0.085	30.023	0.173
13	67		15.756	0.075	29.036	0.161
14	54		16.076	0.074	29.311	0.160
15	55		15.551	0.073	29.691	0.172
16	45		15.028	0.073	29.394	0.170
17	31		15.224	0.073	29.687	0.181
18	25		14.269	0.064	30.172	0.170
19	33		14.737	0.062	30.287	0.167
20	35		14.372	0.060	30.820	0.172
21	15		15.192	0.068	31.120	0.183
22	22		14.910	0.065	31.895	0.183
23	16		14.905	0.061	30.975	0.173
24	14		13.159	0.051	30.907	0.167
25	17		13.345	0.055	31.285	0.172
26	10		13.479	0.058	31.936	0.182
27	8		13.247	0.049	32.135	0.176
28	7		13.511	0.058	31.406	0.180
29	7		13.423	0.055	32.601	0.187
30	1		13.500	0.071	33.022	0.199

Source: elaboration on the EP-CESPRI database.

Notes

1 Indeed, the terms "coherence" and "relatedness" are often used interchangeably in the literature dealing with the argument.

2 For example, a company engaged in the food industry needs to master at least some chemical technologies and some mechanical engineering technologies.

3 In addition, as it is well known, R&D expenditures fail to capture a large part of small- and medium-sized firms' innovative efforts.

4 A possible exception is Harhoff (2000). However, this author is more concerned with assessing the effects on productivity of inter-industry spillovers, than on the problem of evaluating coherence in the patterns of firms' R&D expenditures.

5 In a limited number of cases, it may happen that the applicant company is a user of the innovation, which has provided only a financial contribution to the research effort. In a few more cases, it may be that a parent company, which

holds no direct competencies in a given field, applies for a patent to protect the innovation output of a subsidiary, especially if that output is considered strategically relevant. However, both cases seem too rare for diminishing the reliability of patents as indicators of individual firms' own technological competencies.

6 A more detailed description of the EP-CESPRI dataset, as well as more information on the classification system can be found in Appendix A.

7 This classification was elaborated jointly by the *Fraunhofer Gesellschaft-ISI* (Karlsruhe), the *Institut National de la Propriété Industrielle* (INPI, Paris) and the *Observatoire des Sciences et des Techniques* (OST, Paris) in 1995 (see Hinze *et al.*, 1997).

8 The methodological issues related to the extension of this test from product to technological diversification are discussed by Piscitello (1999). A full description of the test is provided in the Appendix.

9 If the actual number of firms diversified in technology fields i and j (i.e. O_{ij}) greatly exceeds the expected number μ_{ij}, then there must be a strong (non random) relationship between the two technological fields. If, on the contrary, S_{ij} takes a negative value, this means that O_{ij} is even lower than the number we would observe if firms were to choose their technological fields randomly.

10 Possible exceptions are Harhoff (2000) and Goto and Suzuki (1989).

11 For a fuller description of the YTC see the May 1997 issue of *Economic Systems Research.*

12 For a discussion along these lines, see Verspagen (1997). In addition to the problem reported in the text, Verspagen also claims that user-producer methods of measuring relatedness are likely to capture rent-spillovers, more than knowledge-spillovers among sectors.

13 That is, we retrieved not only the patents also contained in the six-country EP-CESPRI database, but the whole lot of patent applications to EPO, from any country.

14 Note however that the use of an hypergeometric distribution as a benchmark case for building up the $S_{ij}(O)$ index is entirely plausible, while it is certainly not true for the $S_{ij}(W)$ index: while firms, in line of principle, could choose their activities in a random fashion, it is impossible that patent examiners assign classification codes in casual ways.

15 As with S_{ij}, we can distinguish between $C_{ij}(O)$ and $C_{ij}(W)$, the former being the cosine index based upon the matrix of co-occurrences of technical fields in firms' diversification patterns, the latter exploiting the **W** matrix.

16 They justified this choice by invoking a "survivor principle", according to which a sufficient degree of economic competition ought to lead to the disappearance of relatively inefficient technological diversification patterns (such as those involving unrelated technologies), and leave unscathed only the efficient ones (such as those strictly based upon related technologies). This allowed them to go on and assume the $S_{ij}(O)$ index to reflect the (unmeasured) degree of technological relatedness across fields. Inevitably, the suspect that of a tautology to be hidden in this line of reasoning arises immediately, which will be able to dispel only partially, both in this section and in section 4.

17 Classes from 27 to 30 are harder to comment upon. All of them are highly heterogenous, and they escape a clearly technologically oriented logical structure. Two of them, Nuclear Engineering and Space Technology, are very small, and were built to isolate and identify different countries' patents in two military-related strategic fields. Consumer Goods and Civil Engineering are, by and large, residual classes that collect IPC codes, which could hardly be associated to any of the previous classes.

18 MDS analysis is a statistical technique for representing the mutual relationships amongst N elements (in our case the 30 technological classes) in a space with a

lower number of dimensions (possibly two dimensions), according to the criterion that similar units must be located, on a map, closer than others, and vice versa. The MDS procedure operates by minimising an appropriate index called *stress* index. See also Engelsman and van Raan (1991) and Grupp (1996).

19 At present, the dataset does not attribute all patents of one group to a single unit, but keep them distributed across all individual firms, regardless of their group affiliation; nor does it check for differences between the patent applicant's and the patent inventor's addresses, which could reveal that some patents, although applied for by one company in a group, were actually developed elsewhere in the group itself, if not outside it.

20 It is useful to remind the reader that the data set contains data for six countries only (see section 3 and Appendix A), and that many companies listed therein since 1982 may have gone through many changes of properties, changes of names and restructuring processes. This makes it hard to match closely the EP-CESPRI database to frequently updated company directories such as FORTUNE500, unless a dedicated additional effort of data scrutiny is provided, which goes beyond the purposes of this chapter, which are mainly illustrative.

21 The novelty claim of electronic and mechanical patents can refer only to the design of a component or process, while patents in the pharmaceutical area may be assigned to new applications for well-known (although possibly modified) compounds, which makes it more likely that a proper definition of the patent content of the patent will require quite "distant" different IPC codes to be quoted.

References

Antonelli, C. (1995) *The Economics of Localised Technological Change and Industrial Dynamics*, Dordrecht, Kluwer.

Atkinson, A.B. and Stiglitz, J.E. (1969) "A new view of technical change", *Economic Journal*, 79, 573–578.

Bresnahan, T.F. and Trajtenberg, M. (1995) "General purpose technologies 'Engines of growth'?", *Journal of Econometrics*, 65, 83–108.

Cantwell, J. and Andersen, B. (1996) "A statistical analysis of corporate technological leadership historically", *Economics of Innovation and New Technologies*, 4, 211–234.

David, P.A. (1975) *Technical Choice, Innovation and Economic Growth*, Cambridge, Cambridge University Press.

Dosi, G. (1997) "Opportunities, incentives and collective patterns of technological change", *Economic Journal*, 107, 1530–1547.

Engelsman, E.C. and van Raan, A.F.J. (1991) *Mapping of Technology*, Policy Studies on Technology and Economy (BTE), no. 15, The Hague.

Goto, A. and Suzuki, K. (1989) "R&D capital, rate of return on R&D. Investment and spillover of R&D in Japanese manufacturing industries", *The Review of Economics and Statistics*, 71 (4 November), 555–564.

Granstrand, O. (1997) "Towards a theory of the technology-based firm", *Research Policy*, 27 (5), 465–479.

Granstrand, O., Patel, P. and Pavitt, K. (1997) "Multi-technology corporations: why they have distributed rather than distinctive core competencies", *California Management Review*, 39 (4), 8–25.

Grupp, A. (1996) "Spillover effects and the science base of innovations reconsidered: an empirical approach", *Journal of Evolutionary Economics*, 6, 175–197.

Harhoff, D. (2000) "R&D spillovers, technological proximity, and productivity growth – evidence from German panel data", *Schmalenbach Business Review*, July, 238–260.

Henderson, V. (1999) "Marshall's scale economies", *NBER Working Paper 7358.*

Hinze, S., Reiss, T. and Schmoch, U. (1997) "Statistical analysis on the distance between fields of technology", *Innovation Systems and European Integration (ISE),* Targeted Socio-Economic Research Program, 4th Framework Program of the European Commission (DGXII).

Jaffe, A.B., Trajtenberg, M. and Fogarty, M.S. (2000) "The meaning of patent citations: report on the NBER/Case-Western Reserve Survey of Patentees", *NBER Working Paper 7631.*

MacDonald, J.M. (1985) "R&D and the directions of diversification", *The Review of Economics and Statistics*, 67, 583–590.

Malerba, F. (1992) "Learning by firms and incremental technical change", *Economic Journal*, 102, 845–859.

Milgrom, P. and Roberts, J. (1990) "Modern manufacturing: technology, strategy and organisation", *American Economic Review*, 80 (3), 511–528.

Nelson, R. and Winter, S. (1982) *An Evolutionary Theory of Economic Change*, Cambridge, Mass., Harvard University Press.

Patel, P. and Pavitt, K. (1995a) "Technological competencies in the world's largest firms: characteristics, constraints and scope for managerial choice", WP-95-66, IIAASA, Laxenburg.

Patel, P. and Pavitt, K. (1995b) "Patterns of technological activity: their measurement and interpretation, in: P. Stoneman (ed.), *Handbook of the Economics of Innovation and Technological Change*, Oxford, Blackwell.

Pavitt, K. (1998) "Technologies, products and organisation in the innovating firm: what Adam Smith tells us and Joseph Schumpeter doesn't", *Industrial and Corporate Change*, 7, 433–452.

Pavitt, K., Robson, M. and Townsend, J. (1989) "Technological accumulation, diversification and organisation in UK companies, 1945–1983", *Management Science*, 35 (1), 81–99.

Penrose, E. (1959) *The Theory of the Growth of the Firm*, Oxford, Basil Blackwell.

Piscitello, L. (1999) *Coherence in Technological and Product Diversification of the World's Largest Firms*, mimeo, Politecnico Milan.

Scott, J.T. (1993) *Purposive Diversification and Economic Performance*, New York, Cambridge University Press.

Scherer, F.M. (1982) "Inter-industry technology flows and productivity growth", *The Review of Economics and Statistics*, 64 (4 November), 627–634.

Teece, D.J. (1982) "Toward an economic theory of the multiproduct firm", *Journal of Economic Behavior and Organisation*, 3, 39–63.

Teece, D.J., Rumelt, R., Dosi, G. and Winter, S.G. (1994) "Understanding corporate coherence: theory and evidence", *Journal of Economic Behaviour and Organisation*, 23, 1–30.

Verspagen, B. (1997) "Measuring inter-sectoral technology spillovers: estimates from the European and US patent office databases", *Economic Systems Research*, 9 (1), 49–67.

WIPO (1994) *International Patent Classification, 6th edition (1994),* volume 9 Guide, survey of classes and summary of main groups, World Intellectual Property Organisation, Geneva.

Part II

Technological diversification, internationalisation and alliances

4 The relationships between technological diversification and internationalisation

John Cantwell and Lucia Piscitello

1 Introduction and theoretical framework

The relationship between strategies for growth that the industrial enterprise can adopt – which traditionally refers both to product or industrial diversification, and to geographical diversification, or internationalisation – has been the subject of systematic research by economists and strategic management researchers for more than 30 years. However, diversification and internationalisation have often been considered and analysed separately as two distinct phenomena or alternative routes to growth, in the analytical framework derived from the theory of the growth of the firm that originated from Penrose (1959). The traditional perspective concerned essentially the firm's expansion into new markets; moving into new product markets at home (diversification), or creating new markets abroad through exports and then foreign direct investment were viewed as means of exploiting the firm's potential for growth or its competitive advantages. Diversification and internationalisation were viewed as being directly interrelated, in that Penrose (1959) and others suggested that the firm had a strategic choice between these two means of exploiting the firm's growth potential. In recent years, a new perspective has emerged on internationalisation and diversification as means of extending the growth potential or competence itself of the firm. In this event, corporate internationalisation and diversification may also be directly connected, as mutually interrelated ways of spreading the competence base of the firm, and of acquiring new technological assets, or sources of competitive advantage. This had led to a new focus on the internationalisation and diversification of corporate technology, as a reflection of the development of the underlying capability of firms. In the internationalisation field, new theoretical and empirical models have been devised of the process by which multinational companies access locationally dispersed technological assets, through their own international operations and through alliances with other firms (Cantwell, 1989; Kogut and Chang, 1991; Dunning, 1995; Almeida, 1996; Frost, 1996; Kuemmerle, 1996; Pugel *et al.*, 1996; Cantwell and Barrera, 1998; Cantwell and Piscitello, 2000).

In the diversification field, the notion of technological diversification has been conceptualised as a means by which firms extend their technological base and capabilities, and it has attracted the attention of researchers. Some authors have shown that an increase in technological diversification at the firm level, defined as a rise in the breadth of corporate technological effort across a wider range, was an increasingly prevalent phenomenon in Japan (Kodama, 1986), in the UK (Pavitt *et al.*, 1989), and in Sweden (Granstrand and Sjölander, 1990; Oskarsson, 1993). Various authors have proposed ideas which suggest the existence of a relationship between technological diversification and the internationalisation of technological activity. Nonetheless, the early literature investigating the nature of this linkage had suggested that it is essentially a direct one.

According to our previous research results (Cantwell and Piscitello, 2000), we argue that the relationship between technological diversification and internationalisation is by no means direct and that, at least until very recently, it is an indirect one. In fact, the corporate internationalisation and diversification of technological activity are both ways of spreading the competence base of the firm, and of acquiring new technological assets, or sources of technological advantage. This has led to a new focus on the internationalisation and diversification of corporate technology, as a reflection of the development of the underlying capability of firms, rather than (as in the past) simply a means of supporting the better exploitation of established competence in new markets. In particular, when controlling for the existing level of competence, for the absolute and the proportional growth of rate of competence accumulation, as well as for the firm's technological size, we found that little direct relationship between internationalisation and diversification themselves remain.

To sum up, empirical studies in this field have operated on the (sometimes implicit) premise of a direct relationship between a firm's technological diversification and the internationalisation of its technological activity. This contribution starts instead from the already documented idea of an indirect relationship and goes further to analyse the net overall association between them (that is, once the effect on each of other variables has been allowed for). In particular, does the broadening of the firm's technological base lead to a greater internationalisation of technological activities, does the geographical spread of technological activity lead to a greater technological diversification, or do both occur? We investigate the net interrelationship between technological diversification and the internationalisation of technological activities by using the concept of sequential or Granger causality. Namely, we examined whether the relationship between these two phenomena is mutually sequential through a technique developed by Holtz-Eakin *et al.* (1988) that is based on the estimation of the vector autoregression coefficients in short panel data.

The sample considered is a large cross-firm panel of technological activity over time, proxied by the corporate patenting in the US of 140 of the largest European and American industrial firms over the period 1930–1995. The use of a longitudinal data set is particularly appropriate since the nature of the interaction over time between technological diversification and internationalisation is not uniform across firms, but it depends upon the characteristics of the firm and on its changing external environment (Granstrand, 1998). We apply an extension of a model of bivariate vector autoregressions for panel data proposed by Holtz-Eakin *et al.* (1988) and Colombo and Garrone (1996). The econometric results are consistent with the view that these two corporate growth processes are mutually interdependent, and therefore they have to be jointly modelled when studying their determinants and the factors that influence each of them.

The organisation of the chapter is as follows. The next section describes the data employed, while the proxies used to measure corporate technological diversification and internationalisation are discussed in section 3. The fourth section describes the model constructed to test for the existence of causality between technological diversification and internationalisation, while section 5 reports the results and certain other test statistics. The last section contains some concluding comments and suggestions for future research.

2 The data

The study was based upon a database on the patenting activity in the US of the largest US and European companies over the period 1901–1995,[1] developed at the University of Reading (see Cantwell, 1995, and Chapter 10, this volume). The firms included in the database were identified in one of three ways. The first group consisted of those firms which have accounted for the highest level of US patenting after 1969; the second group comprised other US, German or British firms which were historically among the largest 200 industrial corporations in each of these countries (Chandler, 1990); and the third group was made up of other companies which featured prominently in the US patent records of earlier years. In each case, patents were counted as belonging to a common corporate group where they were assigned to affiliates of a parent company.[2] The location of the original research facility that gave rise to each patent (the country of residence of the original inventor) is recorded in the data. The location of the parent company is another important dimension of the analysis, as this is treated as the home country or the country of origin of the corporate group. By consolidating patents attributable to international corporate groups, it is then feasible to examine the geographical distribution of the technological activity of these firms (Cantwell, 1995). In addition, the primary field of technological activity of each patent can be derived from the US patent class system, which provides a measure of corporate technological diversification.

In all, the historical path was traced of the US patenting activity from the beginning of the century of 857 companies or affiliates that together comprise 283 corporate groups.[3] In particular, we considered cumulated stocks of patents data for individual years spaced at five-year intervals. Starting with the 1930 cumulated stock we have 14 (1930, 1935, . . ., 1995) observations for each firm.

The group of companies used in the econometric analysis of whether the relationship between technological diversification and internationalisation is simultaneous, consists of 140 firms. In order to be able to apply the bivariate autoregressive techniques generally used in causality analysis, we excluded from the original 283 firms all those for which complete time series relating to the period under examination were not available. However, as shown in Tables 4.1 and 4.2 the group obtained can be regarded as quite representative of the world's largest firms in terms of technological development as measured by patenting, and it shows many of the same statistical characteristics as the overall database.[4]

Table 4.1 Data characteristics by industry[5]

	283 firms		*140 firms*	
	No.	*%*	*No.*	*%*
Chemicals	82	29.0	36	25.5
Electrical	44	15.5	21	14.9
Mechanical	108	38.2	51	36.9
Transport	49	17.3	32	22.7
Total	283	100.0	140	100.0

Table 4.2 Data characteristics by country

	283 firms		*140 firms*	
	No.	*%*	*No.*	*%*
The USA	92	32.5	63	44.8
Germany	40	14.1	20	14.2
The UK	65	22.9	24	17.0
Italy	7	2.5	4	2.8
France	29	10.2	13	9.9
The Netherlands	2	0.7	1	0.7
Belgium	1	0.4	1	0.7
Switzerland	9	3.2	5	3.5
Sweden	38	13.4	9	6.4
Total	283	100.0	140	100.0

3 The measures of technological diversification and internationalisation

A number of proxies have been proposed of a firm's technological diversification, understood as the extent of the spread of its technological activity across fields. Some authors have considered the number of technological fields in which the firm is active (e.g. Patel and Pavitt, 1994) or the use of the Herfindhal index and the entropy index to measure the degree of dispersion across fields (e.g. Oskarsson, 1993). Our proxy is based on the consideration that technological diversification is inversely related to the extent of the concentration of the firm's technological specialisation in favoured sectors. The firm's specialisation can be measured by an index of its revealed technological advantage (*RTA*) which for each particular sector of technological activity is defined by the firm's share in that sector of US patents granted to companies in the same industry, relative to the firm's overall share of all US patents assigned to firms in the industry in question. Specifically, denoting as P_{ij} the number of US patents granted in sector or activity j to firm i in a particular industry, then the *RTA* index is defined as follows:

$$RTA_{ij} = \left(P_{ij} \Big/ \sum_{i} P_{ij} \right) \Big/ \left(\sum_{j} P_{ij} \Big/ \sum_{ij} P_{ij} \right)$$

The index varies around unity, such that values greater than one suggest that a firm is comparatively advantaged in the sector of activity in question relative to other firms in the same industry, while values less than one are indicative of a position of comparative disadvantage. Importantly, the use of *RTA* index allows us to control for inter-sectoral and inter-firm differences in the propensity to patent (Cantwell, 1993, 1995). The degree of technological diversification of the firm is measured by the reciprocal of the coefficient of variation (*CV*) of the *RTA* index across all the relevant sectors for the firm.[6] Therefore, for firm i in each period considered, DIV_i will be proxied by the reciprocal of the *CV*:

$$DIV_i = 1/CV_i = \mu_{RTA_i}/\sigma_{RTA_i}$$

where σ_{RTA_i} is the standard deviation and μ_{RTA_i} is the mean value of the *RTA* distribution for the firm i.

A brief clarification of this measure may not be out of place here. When CV_i is low, the cross-sectoral distribution of RTA_i is widely dispersed, that is the profile of the comparative technological advantage of firm i, is highly diversified across fields, and not highly concentrated in some activities rather than others. On the other hand, when CV_i is high, the *RTA* distribution is highly concentrated in certain fields and the degree of diversification of the firm will be low. Thus, CV_i constitutes a direct

Table 4.3 Statistical properties of the DIV and INT (140 firms)

Variables	*Mean*	*Std Error*	*Minimum*	*Maximum*
DIV30	0.54	0.29	0.20	1.81
DIV35	0.55	0.30	0.19	1.92
DIV40	0.56	0.27	0.19	1.70
DIV45	0.57	0.28	0.19	1.57
DIV50	0.58	0.29	0.18	1.54
DIV55	0.61	0.30	0.18	1.56
DIV60	0.61	0.30	0.18	1.80
DIV65	0.61	0.30	0.17	1.65
DIV70	0.63	0.29	0.17	1.63
DIV75	0.64	0.29	0.17	1.89
DIV80	0.66	0.29	0.17	1.91
DIV85	0.66	0.31	0.17	2.09
DIV90	0.65	0.30	0.17	1.84
DIV95	0.65	0.30	0.17	1.79
INT30	7.35	18.52	0.00	100.00
INT35	8.72	20.24	0.00	100.00
INT40	8.95	21.09	0.00	100.00
INT45	9.26	21.06	0.00	99.33
INT50	8.90	19.90	0.00	99.51
INT55	9.88	20.48	0.00	99.66
INT60	10.63	21.37	0.00	98.87
INT65	11.27	21.50	0.00	94.33
INT70	12.75	21.71	0.00	94.16
INT75	13.47	21.12	0.00	93.47
INT80	14.01	20.80	0.00	92.22
INT85	14.57	20.50	0.00	91.87
INT90	15.93	20.80	0.00	92.50
INT95	17.77	21.85	0.00	95.60

measure of concentration but an inverse measure of technological diversification.[7]

With regard to the firm's degree of internationalisation, we took the foreign share of activity, which is the proxy almost universally used in empirical studies (e.g. Pearce, 1989, 1993). For firm *i*, the proxy INT_i is defined as the share of patenting that is attributable to research located outside its home country in each period considered.[8] The statistical properties of the proxies considered for technological diversification and internationalisation, *DIV* and *INT*, are illustrated in Table 4.3.

4 The model for the study of the relationship between technological diversification and internationalisation

4.1 The causality analysis

In examining the relationship between two variables, it is useful to recall the concept of causality. Indeed, causality, of whatever kind, is always a relationship, a relationship between facts or variables (Hicks, 1979). Specifically, the present work investigates whether the technological diversification and internationalisation of firms are mutually interrelated (even if only indirectly). In fact, the direct contemporaneous association studied previously (Cantwell and Piscitello, 2000) still leaves open the issue of whether there is any indirect association between the two, having isolated their direct relationship from the mutual direct effect of other variables. Such an indirect association is then a consequence of the mutual impact of other variables, and it may run in either direction sequentially. Therefore, we used the concept of sequential or Granger causality, but in a mutual way. In other words, we tested whether the two phenomena considered show a reciprocal influence in either direction.

From a methodological perspective, the analysis has been traditionally conducted in an interactive framework. Nevertheless, the approaches used most frequently are essentially cross-sectional or pure times-series analyses and these might lead to biased results. In this context, a panel data approach may be better able to identify and measure effects that are simply not detectable in pure times-series, which do not allow the researcher to control for individual heterogeneity; or in pure cross-section analysis at a given point in time, which does not allow for the dynamics of adjustment.[9]

In order to investigate the nature and the evolution of the relationship between technological diversification and internationalisation, we apply a model developed to test for Granger causality in short panel data. In particular, we follow the approach developed by Holtz-Eakin *et al.* (1988) to explore Granger causality between variables when using a panel data set in place of a single time series.[10] When considering a panel data set, it is necessary to take account of individual heterogeneity. For this reason, the model allows for an "individual effect" which takes into account firm heterogeneity in the level of the two variables, and allows for cross-sectional heteroskedasticity of the error terms.

Consider 140 cross-sectional units observed over 14 periods (that is 1930, 1935,..., 1985, 1990, 1995). Let subscript $i = 1,\ldots, 140$ denote the cross-sectional observations and $t = 1930,\ldots, 1995$ the time periods. The following model then allows us to study whether *INT* causes *DIV*:

$$DIV_{it} = \alpha_{0t} + \sum_{l=1}^{6} \alpha_{lt} DIV_{i,t-1} + \sum_{l=1}^{6} \beta_{lt} INT_{i,t-1} + \phi_t f_i + \epsilon_{it} \qquad (1)$$

where f_i is an observed individual effect, and the lag length has been arbitrarily assumed to be up to $m = 6$.[11]

The symmetrical model has been defined to study whether *DIV* causes *INT*:

$$INT_{it} = \gamma_{0t} + \sum_{l=1}^{6} \gamma_{lt} INT_{i,t-1} + \sum_{l=1}^{6} \delta_{lt} DIV_{i,t-1} + \phi_t f_i + \xi_{it} \tag{2}$$

In order to identify the parameters of the equations, we should deal with the presence of the unobserved individual effect f_i. Since it is well known that in models with lagged dependent variables it is inappropriate to treat the unobserved individual effects f_i as constants to be estimated, we transform equation (1) to eliminate the individual effect. Let $r_t = \phi_t / \phi_{t-1}$ and consider multiplying equation (1) for time $t-1$ by r_t and then subtracting the result from the equation for period t. Collecting all *DIV* and *INT* terms dated $t-1$ or before on the right-hand side yields:

$$DIV_{it} = \alpha_{0t} + \sum_{l=1}^{7} a_{lt} DIV_{i,t-1} + \sum_{l=1}^{7} b_{lt} INT_{i,t-1} + u_{it} \tag{1a}$$

where u_{it}, a_{0t}, a_{lt} and b_{lt} represent a combination of ϵ_{it}, α_{0t}, α_{lt}, β_{lt} and ϕ_t from the previous equation. It should be noted that now the equations obtained are simultaneous, as u_{it} is correlated with $INT_{i,t-1}$ and $DIV_{i,t-1}$ through $\epsilon_{i,t-1}$.

More generally, this transformation is a quasi-differencing transformation suggested by Chamberlain (1983). Importantly, there is no need to recover the original parameters to test the hypothesis that *INT* does not (Granger) cause *DIV*, conditional on the individual effect. Since this would imply that $b_{lt} = 0$ for each l and t, testing the non-causality hypothesis amounts to a test for zero coefficients on the lagged *INT* variables in the transformed equation. More specifically, the linear tests associated with the null hypothesis that *INT* does not (Granger) cause *DIV* are:

$$H_0\colon b_{lt} = 0 \,\forall l \in [1, \ldots, 8], \forall t \in [1970, 1975, 1980, 1985, 1990, 1995]$$

Analogously, to test the symmetrical null hypothesis that *DIV* does not (Granger) cause *INT*, the equation is:

$$INT_{it} = c_{0t} + \sum_{l=1}^{7} c_{lt} INT_{i,t-1} + \sum_{l=1}^{7} d_{lt} DIV_{i,t-1} + \nu_{it} \tag{2a}$$

and the linear tests associated with the null hypothesis are:

$$H_0\colon d_{lt} = 0 \,\forall l \in [1, \ldots, 8], \forall t \in [1970, 1975, 1980, 1985, 1990, 1995]$$

If the absence of Granger causality is rejected these variables actually share some interactions, and neither of them can be treated as strongly exogenous in the estimation of the parameters of the other (Cantwell and Piscitello, 1997).

4.2 The changing direction of sequential causality

The estimation of the models has been run in two stages by applying 2SLS and GLS to the simultaneous equations systems (1a) and (2a).[12] The structure of the model allows us to impose and test linear constraints through a procedure by which restricted and unrestricted models are compared by examining the difference of the sum of squared residuals $L = Q_R - Q$, which conforms to a chi-squared distribution. Therefore, we tested both the hypothesis of non-causality and the hypothesis of parameter stationarity over time, which provides a preliminary perception of the nature of the relationship between the two corporate strategies under consideration. Tables 4.4 and 4.5 show the results of the tests for models (1a) and (2a) respectively. In particular, the tables report the null hypotheses, the values of the Q and L statistics, and the critical values of $\chi^2_{0.05}(n)$.

As regards the first model (see Table 4.4), the results of the test that *INT* does not cause *DIV* show that absence of causality is rejected with $p < 0.05$, as is the hypothesis of parameter stationarity. The particular hypothesis of parameter stationarity in the bivariate part of the equation is also strongly rejected, thus confirming that the influence of internationalisation upon technological diversification is not constant but evolves and changes over the period considered. The results of the analysis of causality in the other direction are shown in Table 4.5. Again, the null hypothesis that *DIV* does not cause *INT* is rejected with $p < 0.05$, as are the hypotheses of parameter stationarity. To sum up, the results of this first step in the

Table 4.4 Exogeneity of *DIV*

	Q	L	$\chi^2_{0.05}(n)$
Unrestricted model	22.7	–	–
H_0: *INT* does not cause *DIV*	69.2	46.5	24.9
$b_{lt} = 0$			
$\forall t \in [1995,\ldots,1970], \forall l \in [1,\ldots,8]$			
H_0: Stationarity of parameters	1491.3	1468.6	55.8
$a_{0t} =$ constant			
$a_{lt} =$ constant			
$b_{lt} =$ constant			
$\forall t \in [1995,\ldots,1970], \forall l \in [1,\ldots,8]$			
H_0: Stationarity of bivariate parameters	153.1	130.4	22.4
$b_{lt} =$ constant			
$\forall t \in [1995,\ldots,1970], \forall l \in [1,\ldots,8]$			

Table 4.5 Exogeneity of *INT*

	Q	L	$\chi^2_{0.05}(n)$
Unrestricted model	16.1	–	–
H_0: *DIV* does not cause *INT*	55.7	39.6	24.9
$d_{lt} = 0$			
$\forall t \in [1995, \dots, 1970], \forall l \in [1, \dots, 8]$			
H_0: Stationarity of parameters	677.3	661.2	55.8
$c_{0t} =$ constant			
$c_{lt} =$ constant			
$d_{lt} =$ constant			
$\forall t \in [1995, \dots, 1970], \forall l \in [1, \dots, 8]$			
H_0: Stationarity of bivariate parameters	88.3	72.2	22.4
$d_{lt} =$ constant			
$\forall t \in [1995, \dots, 1970], \forall l \in [1, \dots, 8]$			

analysis suggests that the existence of a mutual sequential relationship between *DIV* and *INT* cannot be rejected.

The second important result is that the structure of the coefficients cannot be assumed to be fixed, but it varies over time. In fact, looking at the coefficients obtained (see Table 4.6), it emerges that the underlying structural relationship between technological diversification and internationalisation has tended to shift from a negative to a positive one, although it is not a stable relationship. In particular, the shift to a positive effect of internationalisation on diversification appears to have led the more recent emergence of a positive effect of diversification on internationalisation. The former was significantly positive as early as 1965, while the latter only became significantly positive in 1990 and 1995, and they were jointly significantly positive for the first time in 1995. We have argued that while the early negative relationship represented a choice over the direction of use of scarce technological and managerial resources in the early stages of large firm growth as discussed by Penrose, the more recent emergence of a positive interrelationship can be understood as attributable to the evolution of interconnected international networks for innovation in the leading multinational companies (Cantwell and Piscitello, 2000). The process began when international network formation started to have a positive potential impact upon the scope of technological capabilities of the firm.

5 Conclusions

This chapter has attempted to shed light on the relationship between technological diversification and internationalisation, particularly with respect to its sequential nature. In fact, we acknowledge that the corporate internationalisation and diversification of technological activity are both ways of spreading the competence base of the firm, and of acquiring new

Table 4.6 Estimated coefficients

	INT on DIV	*DIV on INT*
1935	−0.28 (−1.22)	−0.01 (−1.20)
1940	−0.00 (~0)	−0.001 (−0.02)
1945	−0.22* (−1.84)	−0.01 (−1.57)
1950	−0.03 (−0.28)	−0.01 (−0.18)
1955	0.19 (1.36)	−0.02** (−1.98)
1960	−0.02 (−0.11)	−0.01** (−1.98)
1965	0.30** (2.06)	−0.01 (0.30)
1970	0.23 (1.37)	−0.01 (−0.16)
1975	−0.16 (−1.05)	−0.01 (−1.46)
1980	−0.10 (1.03)	−0.01** (−2.12)
1985	0.23*** (2.63)	0.001 (0.09)
1990	0.04 (0.47)	0.01** (2.00)
1995	0.10* (1.81)	0.02* (1.79)

Notes
* Significant at the 10 per cent level.
** Significant at the 5 per cent level.
*** Significant at the 1 per cent level.

technological assets, or sources of technological advantage, and that their relationship is by no means direct but is instead generally indirect. In order to test the composite form of the indirect relationship, we have used a longitudinal data set that allows us to take into account cross-section characteristics, that is individual heterogeneity as well as variations over time. Our results suggest that, once allowing for the mediation of other variables, these two corporate growth strategies are indirectly mutually associated.

The capacity to develop internationally derives from a position of technological strength in the firm's domestic base, which may lead to similar lines of technological development being established abroad; while, in its turn, foreign innovation provides a further source of capability that can be exploited to broaden the technological base of the MNC. In other words, MNCs undertake international expansion in part to exploit their existing technological advantage by increasing the scale and the geographical scope of their operations; but at the same time, MNCs use foreign expansion in part to develop international networks to create advantages by drawing upon the locationally differentiated competitive advantages.

Importantly, our empirical evidence suggests also the rejection of the stationarity of coefficients, thus indicating that the underlying structure of the relationship may have changed over time. In fact, a deeper investigation revealed that the relationship between technological diversification and internationalisation is negative historically while it becomes positive in the most recent periods, although it is not highly stable. In particular, our results show that the relationship is negative until the most recent period and it becomes significatively positive only in 1985–1995.

Arguably, an increase in technological interrelatedness (Pavitt *et al.*, 1989) and the emergence and rise of the internationally integrated MNC (Dunning, 1993, 1994), both of which facilitate a more positive linkage between the sectoral diversification and geographical dispersion of corporate technological efforts, are both comparatively recent phenomena in historical terms. In the past, foreign technological activity exploited domestic strengths abroad, it was located in response to local demand conditions and its role ranged from the adaptation of products to suit local tastes through to the establishment of new local industries. The capacity to develop internationally derived from a position of technological strength in the firm's domestic base and led to similar lines of technological development being established abroad. Today, foreign technological activity increasingly aims to tap into local fields of expertise and to provide a further source of new technology that can be utilised internationally. MNCs are increasingly committed to the development of international networks in order to exploit the locationally differentiated potential of foreign centres of excellence.

Notes

1 The pros and cons of using US patents as indicator of technological activity are well known and quite widely discussed in the literature (e.g. Schmookler, 1950, 1966; Pavitt, 1985, 1988).

2 Affiliate names were normally taken from individual company histories.

3 Births, deaths, mergers and acquisitions as well as the occasional movement of firms between industries (sometimes associated with historical change in ownership) have been taken into account.

4 The differences are mainly attributable to the fact that US firms were rather under-represented in the original data (since we included all US firms granted

at least 30 patents per year historically, but all European companies granted at least 5 patents per annum), while Swedish firms over-represented (owing to a particular search conducted on behalf of some Swedish colleagues, see Zander, 1994, 1997).

5 Firms have been allocated to an industry on the basis of their primary field of production/market, and subsequently these industries have been combined into four major industrial groups on the basis of the types of technology that have been mainly developed by the firms in question. In particular, for the four industries we have:

Chemical (C): where the sub-industries included are chemicals, pharmaceuticals, textiles and clothing, coal and petroleum products.

Electrical (E): electrical equipment, office equipment.

Mechanical (M): food, drinks, metals, mechanical engineering, paper and paper products, printing and publishing, non-metallic mineral products, professional and scientific instruments, other manufacturing.

Transport (T): motor vehicles, aircraft, other transport equipment, rubber and plastic products.

6 The choice of the relevant sectors is particularly important to define the range over which the *RTA* distribution is to be considered. We analysed two alternative measures. The first one is the coefficient of variation of the *RTA* distribution across all sectors in which firms in the relevant industry had a stock of at least 100 patents at some point during the period 1930–1995. In this case the number of sectors considered is the same for all firms in an industry, and it is fixed over time. The other one is the coefficient of variation of the *RTA* distribution across a variable number of sectors, according to the constraint that firms in an industry group collectively have an accumulated stock of at least 100 patents in each year considered separately. Although the two measures are strongly correlated, the latter performs better in the following models and therefore has been preferred.

7 This measure has often been used as well in the analysis of business concentration across firms within an industry, as opposed to concentration or dispersion across sectors within a firm (see Hart and Prais, 1956). It is worth noticing that for a given number of firms (N), there is a strict relationship between the Herfindhal index (H) and the coefficient of variation (CV) (Hart, 1971). The relationship is: $H = (CV^2 + 1)/N$.

8 Using the same procedure applied to build the proxy *DIV*, we considered a second proxy defined as the coefficient of variation across national shares of patenting for the firm. However, this is strongly correlated with the foreign share measure and therefore we preferred the proxy more commonly used in the literature.

9 For examples on causality with panel data, see Finkel (1995).

10 For a similar empirical approach, applied to the causality relationship between a firm's infra-muros R&D and co-operative technological agreements, see Colombo and Garrone (1996).

11 It should be noted that it is desirable to specify an arbitrarily long maximum initial lag length in order to ensure that ϵ_t is a white noise error term (Holtz-Eakin *et al.*, 1988, p. 1386).

12 For technicalities concerning the estimation, see Holtz-Eakin *et al.* (1988).

References

Almeida, Paul. 1996. Knowledge sourcing by foreign multinationals: patent citation analysis in the US semiconductor industry. *Strategic Management Journal*, 17: 155–165.

Cantwell, John A. 1989. *Technological Innovation and Multinational Corporations.* Oxford: Basil Blackwell.

——. 1993. Corporate technological specialisation in international industries. In M.C. Casson and J. Creedy, editors, *Industrial Concentration and Economic Inequality,* Aldershot: Edward Elgar.

——. 1995. The globalisation of technology: what remains of the product cycle model? *Cambridge Journal of Economics,* 19: 155–174.

—— and Pilar Barrera. 1998. The localisation of corporate technological trajectories in the interwar cartels: cooperative learning versus an exchange of knowledge. *Economics of Innovation and New Technology,* 6: 257–290.

—— and Lucia Piscitello. 1997. A Note on the Causality Between Technological Diversification and Internationalisation. Discussion Papers in Quantitative Economics and Computing. Series E, Vol VI, No. 52, University of Reading.

——. 2000. Accumulating technological competence – its changing impact on corporate diversification and internationalisation. *Industrial and Corporate Change,* 9, 21–51.

Chamberlain, Gary. 1983. Panel data. In Z. Griliches and M. Intrilligator, editors, *Handbook of Econometrics,* Volume II. Amsterdam: North-Holland Publishing Company.

Chandler, Alfred D. 1990. *Scale and Scope. The Dynamics of Industrial Capitalism.* Cambridge, MA: Belknap Press.

Colombo, Massimo G. and Paola, Garrone. 1996. Technological cooperative agreements and firms' R&D intensity. An analysis of causality relation. *Research Policy,* 25: 923–932.

Dunning, John H. 1993. *Multinational Enterprise and the Global Economy,* Reading: Addison Wesley.

——. 1994 Multinational enterprise and the globalisation of innovatory capacity. *Research Policy,* 23: 67–88.

——. 1995. Reappraising the eclectic paradigm in an age of alliance capitalism. *Journal of International Business Studies,* 26: 461–491.

Finkel, Steven E. 1995. Causal analysis with panel data. *Sage University Paper Series: Quantitative Applications in the Social Sciences,* no. 105, London and New Delhi: Sage Publications.

Frost, Tony S. 1996. From exploitation to exploration: the geographic sources of subsidiary innovations and the evolutionary theory of the multinational enterprise. Mimeo, University of Western Ontario.

Granstrand, Ove. 1998. Towards a theory of the technology based firm. *Research Policy,* 27: 465–489.

Granstrand, Ove and Sören Sjölander. 1990. Managing innovation in multi-technology corporations. *Research Policy,* 19: 35–60.

Hart, Peter E. 1971. Entropy and other measures of concentration. *Journal of the Royal Statistic Society,* Series A, 134: 73–85.

Hart, Peter E. and Sigmund J. Prais. 1956. The analysis of business concentration: a statistical approach. *Journal of the Royal Statistical Society,* Series A, 119, 150–191.

Hicks, John R. 1979. *Causality in Economics.* Oxford: Basil Blackwell.

Holtz-Eakin, Douglas, Whitney Newey and Harvey S. Rosen. 1988. Estimating vector autoregressions with panel data. *Econometrica,* 56 (6), 1371–1395.

Kodama, Fumio. 1986. Technological diversification of Japanese industry. *Science,* 233, 291–296.

Kogut, Bruce and See Jin Chang. 1991. Technological capabilities and Japanese foreign direct investment in the United States. *Review of Economics and Statistics*, 73: 401–413.

Kuemmerle, Walter. 1996. The drivers of foreign direct investment into research and development – an empirical investigation. *Harvard Business School Working Paper*, no. 96-062.

Oskarsson, Christer. 1993. *Technological Diversification – The Phenomenon, Its Causes and Effects. A Study of Swedish Industry*. Department of Industrial Management and Economics. Göteborg: Chalmers University of Technology.

Patel, Pari and Keith L.R. Pavitt. 1994. *Technological competencies in the world's largest firms: characteristics, constraints and scope for managerial choice*. University of Sussex: Working Paper, Science Policy Research Unit.

Pavitt, Keith L.R. 1985. Patents statistics as indicators of innovative activities: possibilities and problems. *Scientometrics*, Vol. 7, 1–2, January.

——. 1988. Uses and abuses of patent statistics. In A.F.J. van Raan (ed.) *Handbook of Quantitative Studies of Science and Technology*. Elsevier Science Publishers.

Pavitt, Keith L.R., Michael Robson and Joe Townsend. 1989. Technological accumulation, diversification and organisation in UK companies 1945–1983. *Management Science*, 35 (1), 81–99.

Pearce, Robert D. 1989. *The Internationalisation of Research and Development by Multinational Enterprises*. London: MacMillan.

——. 1993. *The Growth and Evolution of Multinational Enterprise*. Aldershot: Edward Elgar.

Penrose, Edith T. 1959. *The Theory of the Growth of the Firm*. Oxford: Oxford University Press.

Pugel, Thomas A., Erik S. Kragas and Yui Kimura. 1996. Further evidence on Japanese direct investment in US manufacturing. *Review of Economics and Statistics*, 78, 208–213.

Schmookler, Joseph. 1950. The interpretation of patent statistics. *Journal of the Patent Office Society*, 32 (2), 123–146.

——. 1966. *Inventions and Economic Growth*. Cambridge, MA: Harvard University Press.

Zander, Ivo. 1994. *The Tortoise Evolution of the Multinational Corporation – Foreign Technological Activity in Swedish Multinational Firms, 1890–1990*. Published PhD thesis, Stockholm School of Economics.

——. 1997. Technological diversification in the multinational corporation. Historical evolution and future prospects. *Research Policy*, 26, 209–228.

5 Technological diversification and strategic alliances

Paola Giuri, John Hagedoorn and Myriam Mariani

1 Introduction

Over the 1980s firms and industries have experienced a process of "technological convergence" or "technology fusion" (Rosenberg, 1976; Kodama, 1986, 1992). Due to the complexity and multi-technology nature of products, different firms and industries came to share similar and wider technological bases (Granstrand and Sjölander, 1990; Granstrand and Oskarsson, 1994; Granstrand *et al.*, 1997; Patel and Pavitt, 1997). In many cases these wider technological bases are achieved through firms' technological diversification.

Unlike technological diversification, product diversification decreased over time through the processes of restructuring and refocusing of large diversified firms (Scott, 1993; Hoskisson and Hitt, 1994; Markides, 1995a). Empirical work witnessed the difference between technological diversification and product diversification (Granstrand, 1997; Granstrand *et al.*, 1997) suggesting that while in principle multi-technology firms can develop a wide range of different products, there are severe limitations to the acquisitions of the downstream assets needed to produce and commercialise products in a high number of different markets (Gambardella and Torrisi, 1998).

One way to get access to competencies that firms lack internally is by developing linkages with other companies. During the past two decades a number of studies in the economic and managerial literature have focused on the extent, motivations and characteristics of strategic alliances (Kogut, 1988; Contractor and Lorange, 1988; Hagedoorn, 1993; Dunning, 1993, 1995). There is also empirical evidence showing that the increasing technological diversification of firms is frequently associated with the use of strategic alliances (Mowery *et al.*, 1998).

Based on these literature, our chapter explores empirically the relationship between firms' internal technological profile – *internal* technological diversification – and diversification through strategic alliances – *external* diversification – in Europe, the USA and Japan. It examines some stylised facts highlighted in the literature about technological diversification, market diversification and strategic alliances, and explores the relationship between diversification strategies and firms' performances. More specifically, this work looks at three issues.

It first describes the extent of firms' internal technological diversification versus external technological diversification. We believe that firms invest internally in developing a wider range of technological competencies compared to external agreements. This is because the internalisation of knowledge aims at both enhancing firms' core-competencies, and at creating absorptive capacities to acquire technologies developed by others.

Second, it shows that technological diversification is more pronounced than product and market diversification. Although firms develop competencies in several technological fields they may find it difficult to access production and commercialisation assets for entering different businesses.

Finally, the chapter studies the relationship between firms' economic performance, internal technological diversification and external technological diversification. Most of the literature focuses on the impact of related and unrelated product diversification on firm performance. The results indicate that related diversifiers outperform unrelated diversifiers (Robins and Wiersema, 1995; Berger and Ofek, 1995; Markides and Williamson, 1994; Varadarajan and Ramanujam, 1987; Dubofsky and Varadarajan, 1987), and that refocusing has a positive effect on firms' performance (Markides, 1995a; Comment and Jarrell, 1995). We expect technological diversification to be positively correlated with firms' performance in specific sectors like transportation equipment where product development requires the integration of a wider range of different technologies compared to sectors like the ICTs.

To analyse these issues we combine firm level data on technological diversification, strategic alliances and economic performance in 13 industrial sectors from 1990 to 1997. The empirical analysis is based on a worldwide sample of 219 industrial firms selected from the largest 500 companies (Fortune 500, 1998–1999). For each company we collected information about the internal technological profile (*internal diversification*) and external alliances (*external diversification*). We assume that internal technological competencies of firms are reflected in the relative number of patents granted in each sector. Therefore, patents granted to our 219 companies are used to define their internal technological configuration. Strategic alliances are used to trace their external strategies in technology and production related operations. Firm level data are drawn from three datasets.

USPTO patent data in the period 1990–1997 are used to measure firms' internal technological diversification (Techline, 1999). These patents are classified in 27 technological classes.

Data on strategic alliances are drawn from the SDC database (Securities Data Company). These data are used to measure technological diversification by external operations, and diversification in production and marketing activities. The SDC database on joint-ventures, strategic alliances and licensing provides information on about 115,000 agreements. We selected 12,342 alliances signed by our sample companies during the period 1990–1997, and collected information on several of the agreements. By using the SIC codes of the alliance we classified each operation by business sector. We then developed a concordance table between the 27 technological classes in which patents are classified and the SIC codes of the alliances in the manufacturing sectors. Alliances in the service sectors, with the exception of telecommunication (SIC 4800) and software (SIC 7370), are excluded from the analysis. According to their content, alliances were also classified as *technological alliances* and *production and marketing alliances*.

Finally, the Compustat database provides information on firms' economic performance.

The chapter is organised as follows. Section 2 presents the background literature on technological diversification and strategic alliances. It focuses on the issues that will be explored in the empirical sections. Section 3 describes the data. Section 4 compares internal and external technological diversification to the diversification through production and marketing alliances during 1990–1997. Section 5 develops a multiple correlation analysis to study the relationship between internal and external diversification, and economic performance. Section 6 concludes.

2 On technological diversification and strategic alliances.

A number of contributions explore firms' technological and business diversification. As far as technological diversification is concerned, these studies show that during the past decades the complexity and multi-technology nature of products and processes led firms to broaden their technological base in order to develop new products and processes (Granstrand and Sjölander, 1990; Patel and Pavitt, 1994; Granstrand and Oskarsson, 1994; Granstrand *et al.*, 1997). The literature suggests that firms might develop technologies that are different but highly interdependent with their distinctive capabilities. They can also invest in complementary fields in order to be able to adopt and integrate technologies developed by external suppliers. Moreover, firms may want to develop some knowledge in non-core technologies in order to have a window on emerging technological opportunities. Or, still, they can internalise some "general purpose technologies" which are used in different products and processes. Some authors, however, point out that firms' technological profiles are difficult to change. They tend to be stable over time and evolve in a path-dependent fashion according to strong inter-sectoral differences. Furthermore, firms that successfully diversify technologically maintain a certain coherence between existing and new fields (Patel and Pavitt, 1997; Teece *et al.*, 1994; Breschi *et al.*, 1998).

Unlike technological diversification, product diversification decreased over time due to the process of restructuring and refocusing of large diversified firms (Scott, 1993; Hoskisson and Hitt, 1994; Markides, 1995a). Hence, firms broaden their technological knowledge, but they do not use all their competence to enter new businesses. Empirical studies witness the difference between technological diversification and product diversification (Granstrand, 1997; Granstrand *et al.*, 1997). Some of them point out that while in principle multi-technology firms can develop a wide range of different products, there are severe limitations to the acquisitions of the downstream assets needed to produce and commercialise these products in many different markets (Gambardella and Torrisi, 1998). Other studies focus on the impact of related and unrelated product diversification on firm performance. The results indicate that related diversifiers outperform unrelated diversifiers (Robins and Wiersema, 1995; Berger and Ofek, 1995; Markides and Williamson, 1994; Varadarajan and Ramanujam, 1987; Dubofsky and Varadarajan, 1987), and that refocusing has a positive effect on firms' performance (Markides, 1995a; Comment and Jarrell, 1995).

A branch of the literature on technological diversification focuses on the strategies that firms adopt to build up technological competencies internally. The distribution of patents across technological classes is used to measure the extent to which firms diversify technologically. In-house R&D investment, however, is not the only means that firms can use to enlarge their technological base. External collaborations help acquire competencies that are more "exogenous" to the firm (Hagedoorn and Duysters, 2002). They are a means to strengthen firms' critical technological competencies, to acquire general-purpose technologies that companies do not develop internally, to get access to frontier technologies produced by firms in other sectors, and to expand knowledge in complementary or more marginal fields. Some contributions explore the trade-off between the internal development and the "outsourcing" of technologies. Richardson (1972) suggests that similar and complementary activities should be maintained within the firm, while activities that are complementary but dissimilar can be accessed externally. Prahalad and Hamel (1990) claim that firms should invest internally in related areas or in core technologies, and use external alliances to acquire technological competencies in unrelated areas or in non core technologies. In addition, firms can use strategic alliances to get access to new and complementary technologies (Teece, 1986), to speed up firms' learning processes, to share the costs and risks of R&D activities, to exploit economies of scale and scope in research, to access new markets or production facilities, or to monitor the evolution of non core technologies (Hagedoorn, 1993). These issues have been studied intensively during the past two decades, when there has been a steep increase in the use of collaborative agreements between domestic firms in related markets and foreign companies in global markets (von Tunzelmann, 1995; Freeman and Hagedoorn, 1995; Hagedoorn and Schakenraad, 1994; Chesnais, 1988).

This chapter focuses on strategic alliances as a means to exchange technological knowledge and other downstream assets. The "competence-based" theories of the firm provide a valid support to the study of this issue. The basic idea is that economic institutions have different abilities to support the acquisition and development of knowledge or other assets. These abilities are firm-specific, they are cumulative, and determine firms' competitive advantages. Inter-firm linkages can help combine these firm-specific assets that require time to build up and that are hard to reproduce. Moreover, since the shared assets can be accessed without separating them from the developer firm, the problem of tradability is also bypassed (see, for example, Richardson, 1972; Kogut and Zander, 1992).

The empirical evidence suggests that various factors influence the choice between different types of external agreements, such as the pace of technological change, the complexity and the objectives of the transaction. Pisano (1991) and Teece (1992) demonstrate that when technological change proceeds fast, companies prefer flexible forms of organisation – i.e. strategic alliances versus mergers and acquisitions. Other contributions show that in industries characterised by rapid technological change, the scope for learning, the organisational change and the quick strategic response require flexible forms of organisation (Hagedoorn, 1993; Eisenhardt and Schoonhoven, 1996). By contrast, when transactions are complex, hierarchical organisations have superior monitoring and incentive aligning properties. Some contributions also show that the larger the number of partners, the broader the product and/or technology scope, and the wider the functional activities covered by an alliance, the higher the likelihood of the alliance being a joint venture or, more generally, an equity arrangement (Pisano, 1989; Garcia Canal, 1996; Oxley, 1997). Even though the empirical evidence on the relationship between the technological content and the organisational form of the alliances are mixed (Osborn and Baughn, 1990; Gulati, 1995) the preference for more hierarchical arrangements is more likely also when firms develop or transfer tacit know-how.

To conclude, in recent years there has been a trend towards the increasing technological diversification of firms and the intensification in the use of strategic technological alliances. Although the relationship between technological diversification and firms' performances deserves further attention, so far the empirical results suggest that there is a positive correlation between the two. The same positive relationship holds for strategic technological alliances and firms' performances, although the results are not clear across sectors (Hagedoorn and Schakenraad, 1994). By contrast, firms' performances are positively affected by the process of refocusing and restructuring of production and marketing activities (among others Markides, 1995a, 1995b; Montgomery and Wernerfelt, 1988; Amit and Livnat, 1988; Hitt and Ireland, 1986).

This work adds empirical evidence to some of these issues. It investigates the relationship between *internal* technological diversification and diversification through strategic alliances, and highlights differences across countries and sectors. It also explores the relationship between internal and external technological diversification and firms' economic performances. More specifically, we explore the following issues.

First, the chapter compares firms' *internal technological diversification* with *external technological diversification.* We expect the former to be more pronounced than the latter. Firms develop in-house critical technologies and try to maintain a frontier position in these fields. However, the multi-technology nature of products and processes leads companies to internalise knowledge in a wider range of technological fields. Competencies developed internally are also needed to evaluate, understand and assimilate outside technologies (Cohen and Levinthal, 1989, 1990; Rosenberg, 1990), and allow firms to guide the evolution of external collaborations by avoiding that the partners entirely shape the scope of the relationships.

Second, this work compares firms' *internal technological diversification* with *external market diversification* (see also Granstrand, 1997; Patel and Pavitt, 1994, 1997; Granstrand *et al.*, 1997). The expectation is that internal technological diversification is more pronounced than external market diversification. Although firms develop competencies in several technological fields, they may find it difficult to get access to production and commercialisation assets for entering different markets (Gambardella and Torrisi, 1998). The internalisation of a wide range of technologies does not imply the presence in "all potential" markets in which these technologies can be applied. Entry in different markets requires investments in downstream assets, some of which are extremely specific.

Third, by means of multiple correlation analysis, this chapter describes the relationship between firms' performances, internal technological diversification, and diversification through strategic alliances. We expect the results to be sector-specific, with some sectors like transportation equipment displaying a positive correlation between firms' performances and technological diversification. This is because, compared to industries like the ICTs, the transportation equipment sector requires the integration of a wider range of different technologies to develop the products.

3 Data

The empirical analysis focuses on a sample of 219 manufacturing firms. We drew 265 industrial firms from the Fortune Global 500 (1998–1999). From this sample we selected the 219 firms for which we have information on patents and alliances. Fifty firms are European, 121 are American, 48 are Japanese, four are from South Korea and two from Canada. We used the company primary SIC code (Standard Industrial Classification) to classify each firm in one of the 13 industrial sectors as shown in the Appendix (Table 5.A1).

For each company we collected information about the internal technological profile – *internal diversification* – and external alliances – *external diversification*. We assume that internal technological competencies of firms are reflected in the relative number of patents granted in different sectors.[1] Therefore, patents granted to our sample companies are used to define their internal technological configuration. We use strategic alliances to trace their external strategies in technology and production related operations.[2]

The empirical analysis is based on three sources of data.

Patent data are drawn from the Techline database that provides data on patents issued by the American Patent Office in 1990–1999. The total number of patents issued to our 219 sample companies from 1990 to 1997 is 309,574. The distribution of patents by region and sector is shown in the Appendix (Table 5.A2). The technologies in which firms' patent are classified according to 27 technological classes are described in Table 5.A3 of the Appendix.

Data on strategic alliances are drawn from the SDC database (Securities Data Company, 1999). The SDC database on joint-ventures, strategic alliances and licensing provides information on about 115,000 agreements. We selected 12,342 agreements signed by our sample companies from 1990 to 1997, and collected information about the primary SIC code of the participants, the activity developed within the alliance, the location of the participants, the technological content of the alliance, the direction of the technology flow, and all SIC codes in which the alliance is classified. By using the SIC codes of the alliance we also classified each operation by industrial sector and by one of the 27 technological classes in which patents are codified. The Appendix (Table 5.A3) shows the concordance table between technological fields – in which patents are classified – and the SIC codes of the alliances in the manufacturing sectors, as indicated by the SDC database. Alliances in the service sectors, with the exception of telecommunications (SIC 4800) and software (SIC 7370) are excluded from the analysis.

Alliances are then distinguished into:

- ***production and marketing alliances***: alliances aimed at obtaining downstream assets in marketing and production activities – i.e. Joint Marketing and Joint Manufacturing operations. The total number of market alliances is 5,840.
- ***technological alliances***: alliances in which some technological knowledge is exchanged trough technology transfer or joint innovative projects – i.e. Licensing Agreements and Joint Research Agreements. The number of technological alliances is 6,502. Technological alliances are divided into alliances through which firms acquire technological

> knowledge and alliances through which firms transfer their knowledge to third parties. To differentiate between these two types of alliances we use the information on the direction of the technological flow involved in the alliance. The analysis below will focus only on the alliances used to acquire knowledge.

The distribution of technological and production alliances is shown in Tables 5.A4 and 5.A5 in the Appendix.

One problem in comparing firms' internal and external diversification concerns the use of different measures for the two strategies. We use patents to measure internal technological diversification, and strategic alliances to describe external technological and market diversification. The problem is that these two proxies measure different "objects", and that one patent is something smaller and technologically more specific than one alliance. Symmetrically, an alliance includes a wider range of activities and technologies compared to a patent. This means that the comparison between the number of sectors in which firms patent and the number of sectors in which they develop alliances could be biased because we are not comparing similar objects as it could be by comparing the patents produced by in-house R&D, and those generated by developing technological alliances. In other words, one would need data on the number and classes of patents developed internally, and the number and classes of patents developed by using external agreements. Unfortunately, these data are not available.

To mitigate this problem, a possible solution is to use the information provided by SDC on all technologies and sectors involved in each alliance. For each operation we have the number and the sectoral classification of the different technological "components". By using the SIC codes of these "components" we disaggregate each operation in different technologies, from 1 to 11 sectoral classes. This allows us to compare the number and classes of patents with the number and classes of alliances of the 219 companies in the sample.

4 Technological diversification and alliances

This section compares firms' internal technological profile with their propensity to engage in external alliances. We use Herfindhal indexes as indicators of diversification. The internal technological diversification (ITD) is proxied by the Herfindhal index of the number of patents of each firm in the 27 technological classes shown in the Appendix (Table 5.A3). The external technological diversification (ETD) is measured by the Herfindhal index of the number of technological alliances in the same 27 technological classes. Finally, the external diversification in production and marketing activities (EPMD) is measured by the Herfindhal index of the number of production and marketing alliances in the 27 classes. The index ranges between 0 and 1. A value close to 1 indicates that firms concentrate patents or alliances in few technological classes or only in one technological class when the index is equal to 1. The lower the index, the higher the degree of diversification.

Table 5.1 shows the average Herfindhal indexes by sector for the period 1990–1997.[3] On average, firms are less diversified externally than internally. The Herfindhal index for ITD is 0.24 compared to 0.46 and 0.50 for ETD and EPMD. In other words, firms produce patents in a wider range of sectors than those in which they develop external technological and production and marketing agreements. We will explore further the relationship between internal and external diversification later in this section. There are cross-sectoral differences in the level of diversification. Firms in the ICTs and chemical and pharmaceutical industries are more focused internally (ITD) than companies in the transportation equipment, metal, machinery and electrical equipment sectors. The same applies for ETD. As far as EPMD is concerned, chemical and pharmaceutical firms are more diversified than the sample average, while firms in the transportation equipment sector are more focused than the average.

Table 5.2 shows the Herfindhal indexes by macro-regions. The differences across regions are less marked than those across sectors. Japanese firms are more diversified technologically (ITD and ETD) than the European and the American ones, while European and Japanese firms are more diversified in production and marketing alliances (EPMD) than American firms. However, these patterns may reflect sectoral differences. The multiple correlation analysis performed in section 5 will better highlight sectoral and country differences.

We now turn to the relationship between firms' internal and external technological diversification (ITD and ETD). Table 5.3 shows the Pearson correlation coefficients among the three indexes of diversification calculated at the firm level. They are all positive and significant, suggesting that firms that diversify technologically, also diversify in marketing and production activities, and that internal technological diversification is associated with external technological diversification at the firm level.

Figures 5.1 to 5.3 show the position of each firm in terms of ITD, ETD and EMPD. Figure 5.1 shows the scatter diagram of internal and external technological diversification of firms. With the exception of a few companies, most firms are located below the diagonal of the graph, meaning that the Herfindhal indexes for patents (ITD) are lower than the Herfindhal indexes for technological alliances (ETD). This suggests that large firms have, on average, a more diversified internal than external technological profile. This is consistent with the multi-technology view of products and processes that leads firms to internalise knowledge in different fields in order to develop new products and processes. It is also consistent with the idea that firms invest internally to improve knowledge in different fields, both "core" and marginal ones, and to absorb technologies acquired externally. The few firms above the diagonal in Figure 5.1

Table 5.1 Herfindhal indexes by sector, 1990–1997

	ITD: Herfindhal index – average by sector	*No. of firms*	*ETD: Herfindhal index – average by sector*	*No. of firms*	*EPMD: Herfindhal index – average by sector*	*No. of firms*
Chemicals and Pharmaceuticals	0.26 (0.09)	50	0.51 (0.23)	49	0.44 (0.19)	50
Electrical Equipment	0.18 (0.12)	11	0.39 (0.31)	11	0.27 (0.14)	11
Electronics	0.22 (0.13)	28	0.41 (0.23)	27	0.43 (0.26)	26
ICT	0.39 (0.19)	41	0.58 (0.20)	39	0.68 (0.22)	37
Machinery	0.17 (0.06)	17	0.45 (0.22)	12	0.46 (0.24)	16
Metal	0.13 (0.04)	17	0.33 (0.14)	15	0.33 (0.22)	17
Other Manufacturing	0.24 (0.12)	18	0.57 (0.26)	15	0.71 (0.25)	17
Transport	0.19 (0.10)	37	0.33 (0.20)	35	0.51 (0.28)	37
Total	*0.24 (0.14)*	*21 9*	*0.46 (0.24)*	*20 3*	*0.50 (0.26)*	*21 1*

Source: Techline (1999) and SDC (1999).

Note
*Standard deviations in parenthesis.

Table 5.2 Herfindhal indexes by country, 1990–1997

	ITD: Herfindhal index – average by region	*No. of firms*	*ETD: Herfindhal index – average by region*	*No. of firms*	*EPMD: Herfindhal index – average by region*	*No. of firms*
Canada	0.25 (0.00)	2	0.45 (0.00)	1	0.65 (0.00)	1
EU	0.22 (0.10)	50	0.43 (0.22)	46	0.40 (0.22)	49
Japan	0.20 (0.09)	42	0.38 (0.24)	41	0.42 (0.24)	41
Korea (South)	0.18 (0.01)	4	0.51 (0.38)	4	0.33 (0.16)	3
The United States	0.27 (0.17)	121	0.50 (0.23)	111	0.57 (0.26)	117
Total	0.24 (0.14)	*219*	0.46 (0.24)	*203*	0.50 (0.26)	*211*

Source: Techline (1999) and SDC (1999).

Note
*Standard deviations in parenthesis.

Table 5.3 Pearson correlation of Herfindhal indexes (firm-level elaborations), 1990–1997

	ITD	*ETD*	*EMPD*
ITD	1.000 (219)		
ETD	0.338 (203)	1.000 (203)	
EMPD	0.434 (211)	0.472 (198)	1.000 (219)

Source: Techline (1999) and SDC (1999).

Note
*Correlation is significant at the 0.01 level (2-tailed). Number of observations in parenthesis.

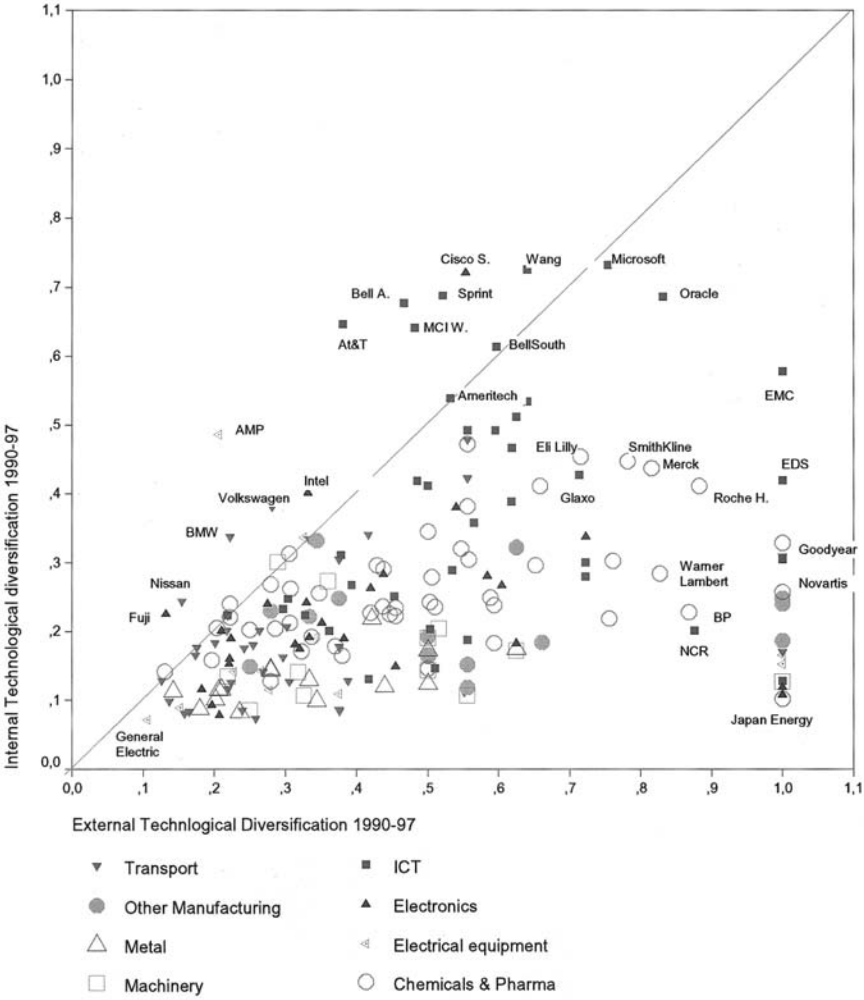


Figure 5.1 ITD vs ETD, 1990–1997.

are less diversified internally than externally. Some of them, like AT&T, Bell Atlantic, MCI WorldCom, Cisco System in the ICT and electronic sectors are very focused internally and much more diversified in terms of technological alliances. Finally, the Herfindhal index for ETD is 1 for a small group of firms. However, since the total number of alliances of these firms ranges between 1 and 8, the value of the Herfindhal does not necessarily reflect a strategy of technology focusing. Some of these firms are also very diversified internally.

Figure 5.1 also highlights the cross-sectoral differences shown in Table 5.1. The less diversified firms, both internally and externally, are in the ICT sectors and in the software industry (e.g. Microsoft and Oracle). In the chemical and pharmaceutical sectors there are both diversified and focused companies. Specifically, pharmaceutical companies are less diversified than those in chemicals and petrochemicals. The most diversified firms are in the electrical equipment sector (e.g. General Electric) and in the transportation equipment, metal and machinery industries.

Figure 5.2 confirms that internal technological diversification is more pronounced than external market diversification. The difference between the Herfindhal index for patents and the Herfindhal index for production and market alliances is almost always negative. This suggests that large companies are, on average, more diversified in developing internal technological competencies than in engaging in external market alliances. The sectoral differences are less marked.

Figure 5.3 compares firms' diversification in technological alliances and market alliances. It confirms the positive correlation between the two Herfindhal indexes as many companies are located around the diagonal. There are, however, cross-sectoral differences. Pharmaceutical and petrochemical companies diversify in production and marketing alliances more than in technological alliances. Firms in the ICTs and in the automotive and aerospace sectors are more diversified in developing technological alliances than in market alliances. Since strategic alliances might be a strategy to integrate or strengthen firms' internal competencies, these large firms broaden their technological competencies more than they do with their business portfolio. This is consistent with the idea that, even though a multi-technology firm might develop a wide range of products, it would find it extremely difficult to acquire the downstream competencies needed to enter different markets. Gambardella and Torrisi (1998) reach similar results in the electronics industry. They find that technological convergence in the computer, telecommunications, electronic and electrical equipment industries is not followed by a similar degree of diversification in downstream activities.

To sum up, there is a positive correlation between internal and external technological diversification, and between technological diversification and diversification in production and marketing activities. However, some questions remain unanswered on the goals that firms pursue when they

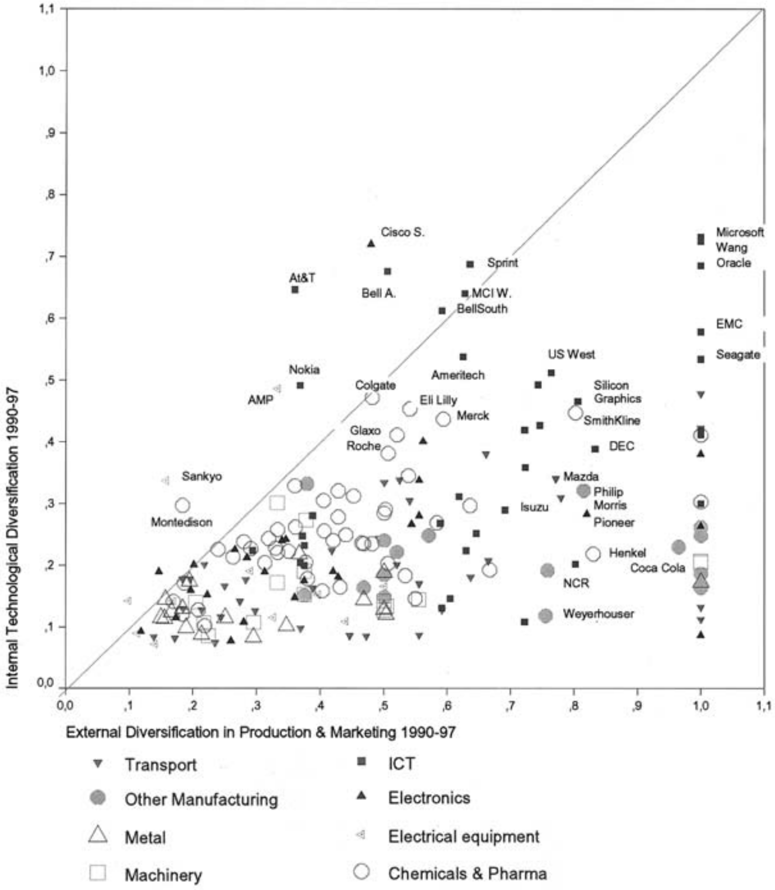


Figure 5.2 ITD vs EPMD, 1990–1997.

engage in external collaborations. For example, do firms invest externally in complementary or "non core" technologies that are not developed internally? Do firms invest internally in building up the absorptive capacity for acquiring technologies through external agreements? Do firms invest both internally and externally in critical technologies? In which sectors do firms use alliances for accessing production and marketing assets?

A deeper inspection in our data, and specifically a look into the set of technologies in which each firm patents and develops alliances helps answer these questions. For each company in the sample we identified the technological class with the largest number of patents, technological alliances and production and marketing alliances. We then computed the correlation coefficient among these top classes in the two sub-periods 1990–1993 and 1994–1997.

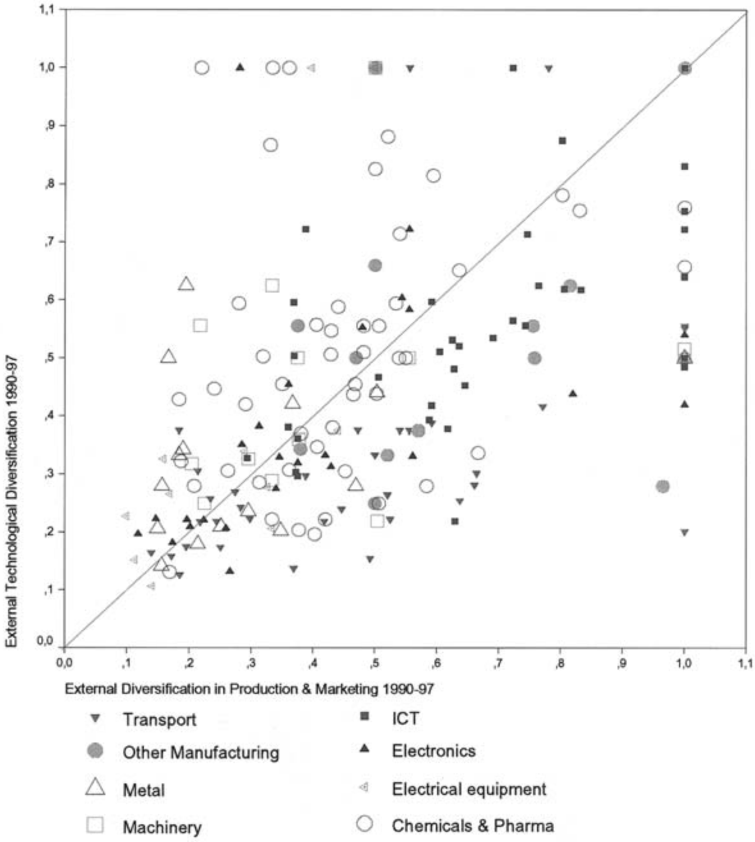


Figure 5.3 ETD vs. EPMD, 1990–1997.

The correlation coefficients between the top technological classes in which the 219 companies produce patents and engage in external collaborations are all positive and significant, suggesting that in many cases large firms concentrate patents and alliances in the same technological classes. However, these correlation coefficients decrease substantially from 1990–1993 to 1994–1997. While in 1990–1993 firms engaged in technological alliances in the same fields in which they patented, in 1994–1997 firms developed technological alliances in more diversified and complementary technologies compared to their core technologies.

There are, however, cross-sectoral differences. In the aerospace, electrical equipment, machinery, metal and petrochemical sectors, the top classes in which firms patent are the same as those in which they engage in alliances in a lower number of cases compared to firms in the chemical, pharmaceutical, computer and telecommunications sectors.

Table 5.4 Spearman correlation between top technological classes in ITD, ETD, EMPD (firm-level elaboration), 1990–1993 and 1994–1997

	ITD	*ETD*	*EMPD*
1990–1993			
ITD	1.000 (219)		
ETD	0.831 (219)	1.000 (219)	
EMPD	0.626 (190)	0.597 (190)	1.000 (190)
1994–1997			
ITD	1.000 (219)		
ETD	0.583 (192)	1.000 (192)	
EMPD	0.680 (201)	0.620 (179)	1.000 (201)

Source: Techline (1999) and SDC (1999).

Note
*Correlation is significant at the 0.01 level (2-tailed). Number of observations in parenthesis.

We can go a step forward in this analysis by comparing the top three technological classes in which each firm patents and develops technological alliances. In the ICT and electronic sectors – which includes computer, semiconductor, telecommunications, electrical equipment and other electronics – patents and technological alliances are concentrated in the same three technological classes. These classes are computers, telecommunications and semiconductors. Moreover, firms from all sectors in the *electrical-electronic filiere* develop a large share of external alliances among them. This process leads to a sort of technological convergence among the electrical-electronic companies. Only firms in the electrical equipment sector behave differently. They receive a large share of technologies from all the ICT sectors, but they are rarely the source of technologies to firms from the other sectors. Finally, alliances in other fields are very rare for the ICT firms, while companies in the electrical equipment and electronic sectors develop a high share of alliances in the chemical, pharmaceutical, automotive, aerospace, machinery and metal sectors.

Patents and alliances in chemical technologies show up in the top three positions for most of the firms in petrochemicals, chemicals and pharmaceuticals – the *chemical filiere.* This suggests that chemical technologies provide general and basic knowledge that cut across the three sectors in the *filiere.*

Second, in the pharmaceutical sector the top three technological classes in which firms patent are the same in which firms develop technological agreements. By contrast, in chemicals and petrochemicals, only one technological class is both in the top ranking for patents and technological alliances. This suggests that while pharmaceutical companies concentrate their innovative efforts in the same fields in which they also develop external technological agreements, petrochemical and chemical firms do differently. They focus internally on some technologies (i.e. chemicals, oil and plastics for petrochemical firms; chemicals, plastics and office equipment for chemical firms), and develop external linkages in other fields (chemicals, glass and pharmaceuticals in the case of petrochemical firms; pharmaceuticals, chemicals and computers in the case of chemical firms). Hence, the "convergence" between internal and external diversification strategies in these two industries is lower than in the pharmaceutical sector.

A third remark concerns the pattern toward the "downward specialisation" in the chemical and petrochemical sectors. By "downward specialisation" we mean that firms in the petrochemical sector enter the chemical sector, and that firms in the chemical sector move downward into the pharmaceutical sector. Both patents and alliances confirm this pattern. This is consistent with the history of the chemical industry in the past decades. Due to increased competition, firms' profitability in the chemical industry started to decline in the early 1960s. In the 1970s and 1980s, the oil shocks, the entry of competitors from the developing countries, the slower demand growth, the diminishing opportunities for product innovation made the profitability decline become a severe problem. Firms in a large number of chemical markets, especially basic intermediates, experienced excess-capacity. To solve their problems, firms started a process of restructuring. A number of companies in the US and Europe exited from the commodity chemical businesses, and moved into downstream sectors. In their place, many oil companies took over existing commodity chemical firms. This process led firms to specialise either on commodity chemicals, or on more downstream specialty sectors. The restructuring process occurred through a large number of inter-firm alliances and acquisitions, both in production and R&D (Arora and Gambardella, 1998).

A different example is given by the transportation equipment sectors, in which patents and alliances occur in different technological classes. Aerospace is a typical sector integrator of technologies for the realisation of a final complex product-system (i.e. aircraft, engine, missile). Firms in the aerospace sector internally develop process technologies, industrial machinery, industrial process equipment and electronic equipment. External technological alliances occur for the joint development of aircraft technologies, motivated by the exceptionally high costs of R&D projects and for the acquisition of other technologies to be integrated (i.e. computing, electronics). The technical classes in which firms concentrate the largest share of patents are different across firms in the aerospace sector, while in most cases firms develop technological and production and marketing alliances in the aerospace and parts technologies. By contrast, in the automotive industry, firms develop a larger share of alliances in the same sector in which they patent (motor vehicle technologies). A small number of alliances are used to get access to technologies and market assets in electronics, telecommunications, computers, semiconductors, electrical equipment, machinery and metal.

Firms in the machinery industry show a pattern similar to that in the automotive industry. However, the motivation that leads firms to establish a high number of collaborations with firms in other sectors are different from those that command the pattern of alliances in the automotive and aerospace sectors. The aerospace and aircraft sectors are integrators of technologies developed by others. They develop technological, production and market alliances to acquire knowledge that has to be integrated into the final products or processes. By contrast, the machinery sector is a transversal sector where firms develop alliances with firms in other sectors that are "users" of their products.

A final point concerns the pervasiveness and the general-purpose nature of the information technologies (Bresnahan and Trajtenberg, 1995). It is interesting that in non-IT sectors – such as the automotive, aerospace, machinery and chemical sectors – computer technologies and software show up in the top positions of technological alliances.

5 Diversification and economic performance

This section performs a multiple correlation exercise by means of OLS regressions. The purpose of these regressions is to describe the relationship between firms' performance and diversification strategies. We use a panel composed of 219 companies over 8 years during the period 1990–1997. From the Compustat database we collected various measures of performance. In order to check for the robustness of our results we performed five OLS regressions that use different measures of performance as dependent variables. Specifically, the regressions use as dependent variables on the return on invested capital, the return on total equity, the return on total assets, the gross profit margin, and the "Tobin's q" given by the ratio between the firm's market value and its book value. The regressors are our measures of internal and external diversification, the number of firms' patents and alliances in each year, the sales of the firms as controls for their size, and country, sectoral and time dummies.[4] Table 5.5 lists the variables of the regressions. All these variables are expressed in logs. The results of the econometric estimates are shown in Table 5.6.

Table 5.6 shows that our three measures of diversification – Herf ITD, Herf ETD, Herf EMPD – are positively correlated with firms' performances, meaning that firms that focus have also better economic results. However, only the coefficients of Herf ITD in the last three specifications and the coefficient of Herf ETD in all five specifications are significant. This suggests that not only do companies that focus internally have better performances, but also firms that engage in external technological agreements in few sectors have higher performances than companies that develop technological alliances in a large number of sectors.

Table 5.5 List of variables

Return on Invested Capital	Income Before Extraordinary Items divided by Invested Capital multiplied by 100 – 1990–1997
Return on Total Equity	Income Before Extraordinary Items divided by the average of the most recent two years of Shareholders' Equity – Total multiplied by 100 – 1990–1997
Return on Total Assets	Income Before Extraordinary Items divided by the average of the most recent two years of Assets – Total. This result is multiplied by 100 – 1990–1997
Gross Profit Margin	Total Revenue minus Cost of Goods Sold divided by Total Revenue* 100 – 1990–1997
Tobin's q	Market Value (Monthly Close Price multiplied by Common Shares Outstanding) divided by Book value – 1990–1997
Herf ITD	Internal technological diversification (ITD) proxied by the Herfindhal index of the annual number of patents assigned to each firm in the 27 technological classes shown in the Appendix (Table 5.3A) – 1990–1997
Herf ETD	External technological diversification (ETD) measured by the Herfindhal index of the annual number of firms' technological alliances in the 27 technological classes shown in the Appendix 1 (Table 5.3A) – 1990–1997
Herf EMPD	External diversification in production and marketing activities (EPMD) measured by the Herfindhal index of the annual number of production and marketing alliances in the 27 classes shown in the Appendix (Table 5.3A) – 1990–1997
No. of Patents	Number of annual patents assigned to each firm in 1990–1997
No. of Technological alliances	Number of annual technological alliances engaged by each firm in 1990–1997
No. of Production and Marketing alliances	Number of annual alliances in production and marketing engaged by each firm in 1990–1997
Sales-turnover	Gross sales reduced by cash discounts, trade discounts, returned sales, excise taxes, value-added taxes and allowances for which credit is given to customers – 1990–1997

Source: Compustat (1998).

Table 5.6 Estimates of the OLS regressions

	Dependent variables				
	Return on invested capital	*Return on total equity*	*Return on total assets*	*Gross profit margins*	*Tobin's q*
Constant	3.841*** (0.466)	3.644*** (0.450)	2.878*** (0.517)	5.975*** (0.258)	0.714 (0.879)
Herf ITD	0.087 (0.075)	−0.015 (0.073)	0.187** (0.078)	0.157*** (0.042)	0.367*** (0.076)
Herf ETD	0.188** (0.083)	0.158** (0.080)	0.216** (0.086)	0.133*** (0.046)	0.338*** (0.081)
Herf EMPD	0.000 (0.079)	0.016 (0.076)	0.048 (0.082)	−0.007 (0.043)	−0.074 (0.078)
No. of Patents	0.027 (0.029)	−0.030 (0.028)	0.030 (0.030)	0.048*** (0.017)	0.042 (0.030)
No. of Technological alliances	0.179*** (0.046)	0.151*** (0.044)	0.186*** (0.048)	0.176*** (0.026)	0.243*** (0.047)
No. of Production and Marketing alliances	−0.035 (0.052)	−0.020 (0.050)	−0.018 (0.054)	−0.012 (0.028)	−0.031 (0.051)
Sales-turnover	−0.099*** (0.036)	−0.014 (0.035)	−0.145*** (0.037)	−0.119*** (0.020)	−0.277*** (0.038)
Country dummies	Yes	Yes	Yes	Yes	Yes
Sector dummies	Yes	Yes	Yes	Yes	Yes
Time dummies	Yes	Yes	Yes	Yes	Yes
Number of observations	767	766	765	773	813
Adj. R-squared	0.401	0.382	0.465	0.570	0.534

Source: Compustat (1998), Techline (1999), SDC (1999).

Notes

**$p < 0.05$, ***$p < 0.01$.

Standard errors in parenthesis.

Also the number of technological alliances is positively correlated with firms' performances. The coefficient of the number of technological alliances is positive and significant across all five specifications. Therefore, technological partnership is an effective means to get access to external knowledge that firms probably internalise and upon which the firm builds up internal competencies as suggested by the results in Table 5.4. This is particularly so if companies concentrate their efforts in few technological fields.

The coefficient of the number of patents over firms' performances is positive in four regressions, but it is significant only in one of them. This may reflect differences among sectors in the importance of technology over economic performance. To explore this issue, we run our regressions for each of the eight broad sectors shown in the Appendix. Apart from a few exceptions, the sectoral results (not shown here) are consistent with the estimates shown in Table 5.6. The coefficient of the number of patents is positive and significant in the chemical and pharmaceutical sector and in the electrical equipment sector.

As far as the internal technological diversification (Herf ITD) is concerned, the coefficient of Herf ITD is negative and significant only in the transportation equipment sector. In the other sectors, it is either positive and significant (in chemicals and pharmaceuticals and in the ICTs) or negative but not-significant (in the other five sectors). The coefficient of Herf ETD is positive and significant in the chemical and pharmaceutical sector. It is negative and significant in the electrical equipment industry. In the other sectors the coefficient of Herf ETD is not significant. The coefficient of Herf EPMD takes the positive sign in 5 sectors, but it is significant only in the metal sector. In the other industries the coefficient of this variable is not significant. Finally, the number of technological alliances is positive and significant in chemicals and pharmaceuticals, in the ICT sector and in transports. The number of alliances in production and marketing activities is negative and significant in chemicals and pharmaceuticals and in the "other manufacturing sectors".

These results are also consistent with another set of regressions (not shown here), in which we tested the correlation between the change in the degree of diversification from 1990 to 1997 and firms' economic performances. The results confirm that technological refocusing is positively associated with economic performances.

To sum up, when we run multiple correlation analysis to examine the relationship between firms' performance and the extent to which firms diversify internally and externally, the results indicate that:

1 internal technological focusing is positively correlated with firms' performances;
2 the external technological focusing is positively correlated with firms' performances;

3 the number of technological alliances is positively associated with firms' economic results.

The estimates are also robust across different specifications that use different indicators of firms' performances. It is worth noting that these results do not suggest that large firms refocus technologically. Rather, they say that less technologically diversified companies have also higher returns on invested capital, higher returns on total equity, higher returns on total assets, greater gross profit margins, and higher ratios of market value over book value. Better performances and technological focusing is also associated with a large number of cooperative agreements to get access to technological knowledge in a restricted number of sectors. Hence, firms that go in depth rather than in breadth in technological collaborations achieve better economic results.

A final comment on the estimates in Table 5.6 concerns the "relatedness" in firms' diversification strategies. Given the level of aggregation of technological classes on which we computed the Herfindhal indexes, these results may also suggest that only in very diversified sectors like the aerospace and the electrical equipment, internal and external technological diversification is positively associated with economic performance, as firms must invest in very different technologies to develop their products. In other sectors, our measure of technology focusing may indicate strategies of related diversification in several technological sub-fields. In this respect, our results may be consistent with the literature on relatedness and coherence in diversification. With respect to the effects of strategic alliances, this study suggests that the number of technological alliances is positively correlated with economic performances, when alliances are concentrated in the firms' core technologies. This is also consistent with other studies showing that mergers and acquisitions in unrelated sectors negatively affect company performances and lead to divestiture within a few years after the acquisition (Porter, 1987; Singh and Montgomery, 1987).

6 Conclusions

The aim of this chapter was to use added empirical evidence on the diversification strategies of large firms in different sectors. The chapter described the relationship between:

1 internal technological diversification and external technological diversification;
2 internal technological diversification and external market diversification;
3 firms' performances and the extent to which they diversify internally and externally.

To explore these issues, we compared the Herfindhal index of firms' patenting activity across 27 technological classes, with the Herfindhal index of technological alliances across the same technological classes. The results show that large firms from all sectors have, on average, a more diversified internal than external technological profile. This is consistent with the multi-technology view of the firm.

The comparison between firms' Herfindhal index in market alliances and the Herfindhal index in patents and technological alliances suggests that firms, on average, diversify more in technological alliances than in market alliances – even though there are some inter-sectoral differences. In general these results are consistent with existing literature showing that multi-technology firms might find it difficult to acquire the downstream competencies needed to enter different markets.

By simply comparing the top positions in which firms patent and develop technological alliances we also described the extent to which firms use strategic alliances to strengthen their internal competencies, or to enter different and complementary sectors. This comparison showed that in most cases large firms concentrate patents in the same technological classes in which they engage in strategic alliances. However, this pattern is more pronounced in sectors like the ICTs, chemicals and pharmaceuticals than in the others. In more diversified sectors, such as the aerospace, electrical equipment and machinery, firms develop a large share of technological and market alliances in complementary and non core technologies.

Finally, the multiple correlation analysis suggested that technological refocusing, both through internal and external strategies, is positively associated with firms' economic performances. The number of technological alliances is also positively related with economic performances. Further empirical investigation at a more disaggregated technological level may better explore the relationship between relatedness in technological diversification and economic performances. This would provide a support to the competence based theories of the firm, to the results on coherent diversification and diversification in product and market operations.

7 Appendix Sample descriptive statistics and industrial and technological classifications

Table 5.A1 Number of firms by sector and region

Broad sector	*Sector*	*Canada*	*Europe*	*Japan*	*South Korea*	*United States*	*Total*
Chemicals and Pharmaceuticals	Chemicals		9	3		5	*17*
Chemicals and Pharmaceuticals	Petrochemicals		9	2		9	*20*
Chemicals and Pharmaceuticals	Pharmaceuticals		5			8	*13*
Electrical Equipment	Electrical Equipment		2	4	1	4	*11*
Electronics	Other electronics		2	10	1	15	*28*
ICT	Computers		1	3		20	*24*
ICT	Telecommunications	2	3			12	*17*
Machinery	Machinery			3		14	*17*
Metal	Metal		7	5		5	*17*
Other Manufacturing	Food and tobacco		2	2		5	*9*
Other Manufacturing	Wood and paper					9	*9*
Transportation Equipment	Aerospace		2	1	1	10	*14*
Transportation Equipment	Automotive		8	9	1	5	*23*
		2	*50*	*42*	*4*	*121*	*219*

Source: elaborations from SDC (1999) and Techline (1999).

Table 5.A2 Number of patents by sector and region

Broad sector	*Sector*	*Canada*	*Europe*	*Japan*	*South Korea*	*United States*	*Total*
Chemicals and Pharmaceuticals	Chemicals		15,037	1,776		9,734	*26,547*
Chemicals and Pharmaceuticals	Petrochemicals		6,136	851		7,902	*14,889*
Chemicals and Pharmaceuticals	Pharmaceuticals		10,542			10,260	*20,802*
Electrical Equipment	Electrical Equipment		2,186	21,023	3,512	10,347	*37,068*
Electronics	Other electronics		10,071	31,236	3,274	27,246	*71,827*
ICT	Computers		91	12,228		22,542	*34,861*
ICT	Telecommunications	1,516	1,812			14,528	*17,856*
Machinery	Machinery			8,525		11,670	*20,195*
Metal	Metal		4,468	4,121		2,354	*10,943*
Other Manufacturing	Food and tobacco		2,016	270		1,366	*3,652*
Other Manufacturing	Wood and paper					2,522	*2,522*
Transportation Equipment	Aerospace		892	633	416	21,118	*23,059*
Transportation Equipment	Automotive		6,638	10,330	925	7,460	*25,353*
		1,516	*59,889*	*90,993*	*8,127*	*149,049*	*309,574*

Source: elaborations from Techline (1999).

Table 5.A3 List of technological classes, and concordance with industrial sectors of alliances

	Technological class	
1	Agriculture	Agriculture; Forestry and fishing
2	Oil and Gas Mining	Metal mining; Coal mining; Petrochemicals (extraction)
3	Power Generation and Distribution	Electric distribution equipment; Electrical industrial apparatus
4	Food and Tobacco	Tobacco; Beverages; Fats and oils; Cane sugar, except refining; Grain mill and bakery products; Preservated fruits and vegetables; Dairy products; Meat products; Other food
5	Textile and Apparel	Textile mills; Apparel and other textile products; Leather
6	Wood and Paper	Lumber and wood; Furniture and fixtures; Paper
7	Chemicals	Chemicals
8	Pharmaceuticals and Biotechnology	Pharmaceuticals and biotechnology
9	Medical Equipment and Medical Electronics	Measurement and control
10	Plastics, Polymers and Rubber	Rubber and plastic
11	Glass, Clay and Cement	Petrochemicals; Stone, clay and glass products
12	Primary Metals	Metal – primary
13	Fabricated Metals	Metal – products
14	Industrial Machinery and Tools	Construction and related machinery; Engines and turbines; Farm and garden machinery; Machinery
15	Industrial Process Equipment and Miscellaneous Machinery	Other industrial and process equipment machinery
16	Office Equipment and Cameras	Photographic equipments
17	Heating, Ventilation and Refrigeration	Other machinery
18	Computers and Peripherals	Computer and data processing and services; Computers and office equipment
19	Telecommunications	Telecommunication equipment; Household audio and video equipment; Telecommunication services
20	Semiconductors and Electronics	Semiconductors; Other electronics
21	Measurement and Control Equipment	Measurement and control
22	Electrical Appliances and Components	Electric lighting and wiring equipment; Household appliances; Miscellaneous electrical equipment and supplies
23	Motor Vehicles and Parts	Automotive; Motor vehicles and passenger car bodies; Motor vehicles parts and accessories; Motorcycles, bicycles and parts; truck and bus bodies
24	Aerospace and Parts	Aircraft; Aircraft engines; Aircraft parts and auxiliary equipment; Guided missiles, space vehicles, parts
25	Other transport	Other transport; Railroads; Water transportation
26	Miscellaneous Manufacturing	General building contractors; Heavy construction, except building; Miscellaneous manufacturing; Non metallic minerals, except fuel; Special trade contractors
27	Others	Printing, publishing and allied industries

Source: elaborations from Techline (1999) and SIC classification.

Table 5.A4 Number of technological alliances by sector and region

Broad sector	*Sector*	*Canada*	*Europe*	*Japan*	*South Korea*	*United States*	*Total*
Chemicals and Pharmaceuticals	Chemicals		233	30		177	*440*
Chemicals and Pharmaceuticals	Petrochemicals		86	8		97	*191*
Chemicals and Pharmaceuticals	Pharmaceuticals		218			373	*591*
Electrical Equipment	Electrical Equipment		31	307	1	108	*447*
Electronics	Other electronics		274	295	4	529	*1,102*
ICT	Computers		6	327		1,531	*1,864*
ICT	Telecommunications	76	77			615	*768*
Machinery	Machinery			90		53	*143*
Metal	Metal		50	73		18	*141*
Other Manufacturing	Food and tobacco		10	11		16	*37*
Other Manufacturing	Wood and paper					23	*23*
Transportation Equipment	Aerospace		36	16	20	216	*288*
Transportation Equipment	Automotive		171	75	16	205	*467*
		76	*1,192*	*1,232*	*41*	*3,961*	*6,502*

Source: elaborations from SDC (1999).

Table 5.A5 Number of production and marketing alliances by sector and region

Broad sector	*Sector*	*Canada*	*Europe*	*Japan*	*South Korea*	*United States*	*Total*
Chemicals and Pharmaceuticals	Chemicals		332	30		179	*541*
Chemicals and Pharmaceuticals	Petrochemicals		467	18		438	*923*
Chemicals and Pharmaceuticals	Pharmaceuticals		66			73	*139*
Electrical Equipment	Electrical Equipment		94	158	2	157	*411*
Electronics	Other electronics		239	198	0	183	*620*
ICT	Computers		7	116		585	*708*
ICT	Telecommunications	67	64			434	*565*
Machinery	Machinery			68		93	*161*
Metal	Metal		160	135		56	*351*
Other Manufacturing	Food and tobacco		59	4		92	*155*
Other Manufacturing	Wood and paper					32	*32*
Transportation Equipment	Aerospace		59	27	111	176	*373*
Transportation Equipment	Automotive		353	242	38	228	*861*
		67	*1,900*	*996*	*151*	*2,726*	*5,840*

Source: elaborations from SDC (1999).

Table 5.A6 Herfindhal indexes of sample firms, 1990–1997

Sector	*Company*	*ITD 1990–1997*	*ETD 1990–1997*	*EPMD 1990–1997*
Aerospace	AlliedSignal Inc	0.081	0.16	0.17
Aerospace	BF Goodrich Co	0.128	0.39	0.59
Aerospace	Boeing Co, The	0.084	0.38	0.47
Aerospace	British Aerospace PLC	0.127	0.31	0.21
Aerospace	Daewoo Electronics Co Ltd	0.177	0.18	0.2
Aerospace	General Dynamics Corp	0.166	0.17	0.25
Aerospace	Lockheed Martin Corp	0.074	0.26	0.23
Aerospace	McDonnell Douglas Corp	0.086	0.24	0.45
Aerospace	Mitsubishi Heavy Industries Inc	0.084	0.16	0.14
Aerospace	Northrop Grumman Corp	0.086	0.38	0.56
Aerospace	Rockwell International Corp	0.098	0.14	0.37
Aerospace	Rolls-Royce PLC	0.201	0.26	0.52
Aerospace	Textron Inc	0.112	0.55	1
Aerospace	United Technologies Corp	0.116	0.22	0.24
Chemicals	Akzo Nobel NV	0.165	0.38	0.43
Chemicals	Asahi Chemical Industry Co Ltd	0.158	0.2	0.4
Chemicals	BASF Group	0.236	0.44	0.46
Chemicals	Bridgestone Corp	0.203	0.25	0.51
Chemicals	BTR PLC	0.121	–	0.18
Chemicals	Colgate Palmolive Co	0.472	0.56	0.48
Chemicals	Degussa AG	0.213	0.31	0.26
Chemicals	Dow Chemical Co	0.204	0.29	0.31
Chemicals	E I DuPont de Nemours & Co	0.142	0.13	0.17
Chemicals	Goodyear Tire & Rubber Co	0.329	1	0.36
Chemicals	Henkel KGAA	0.219	0.76	0.83
Chemicals	Hoechst AG	0.256	0.35	0.41
Chemicals	Imperial Chemical Industries PLC	0.193	0.34	0.67
Chemicals	Mitsubishi Gas Chemical Co	0.235	0.51	0.48
Chemicals	Montedison SpA	0.296	0.43	0.18
Chemicals	Procter & Gamble Co, The	0.178	0.37	0.38
Chemicals	Rhone Poulenc SA	0.235	0.45	0.47
Computers	3COM Corp	0.419	0.49	1
Computers	Apple Computer Inc.	0.427	0.71	0.75
Computers	Compaq Computer Corp	0.359	0.56	0.72
Computers	Dell Computer Corp	0.3	0.72	1
Computers	Digital Equipment Corp	0.389	0.62	0.83
Computers	Electronic Data Sys Corp	0.42	1	0.72
Computers	EMC Corp	0.578	1	1
Computers	Fujitsu Ltd	0.204	0.5	0.37
Computers	Harris Corp	0.232	0.3	0.38
Computers	Hewlett-Packard Co	0.146	0.51	0.6
Computers	IBM	0.289	0.53	0.69
Computers	Lexmark Int'l Inc	0.305	1	–
Computers	Microsoft Corp	0.732	0.75	1
Computers	NCR Corp	0.202	0.88	0.8
Computers	NEC Corp	0.224	0.33	0.29
Computers	OKI Electric Industry Co Ltd	0.2	0.36	0.38
Computers	Oracle Corp	0.686	0.83	1

Table 5.A6 continued

Sector	*Company*	*ITD 1990–1997*	*ETD 1990–1997*	*EPMD 1990–1997*
Computers	Pitney Bowes Incorporated	0.187	0.56	–
Computers	Racal Electronics PLC	0.28	0.72	0.39
Computers	Seagate Technology	0.534	0.64	1
Computers	Silicon Graphics Inc	0.466	0.62	0.81
Computers	Sun Microsystems Inc	0.493	0.56	0.74
Computers	Unisys Corp	0.311	0.38	0.62
Computers	Wang Laboratories Inc	0.725	0.64	1
Electrical equipment	ABB Asea Brown Boveri	0.09	0.15	0.11
Electrical equipment	AMP Incorporated	0.486	0.21	0.33
Electrical equipment	Electrolux AB	0.115	0.28	0.33
Electrical equipment	Emerson Electric Co	0.11	0.38	0.44
Electrical equipment	General Electric Co	0.072	0.11	0.14
Electrical equipment	Hitachi Ltd	0.142	0.23	0.1
Electrical equipment	Samsung Group	0.166	1	0.5
Electrical equipment	Sankyo Co Ltd	0.337	0.33	0.16
Electrical equipment	Sharp Corp	0.191	0.34	0.29
Electrical equipment	Toshiba Corp	0.142	0.27	0.17
Electrical equipment	Whirlpool Corp	0.153	1	0.4
Food and tobacco	Coca Cola Co, The	0.23	0.28	0.96
Food and tobacco	Conagra, Inc.	0.248	0.38	0.57
Food and tobacco	Japan Tobacco Inc	0.184	0.66	0.5
Food and tobacco	Nabisco Group Holdings Corp	0.652	–	–
Food and tobacco	Nestle SA	0.192	0.5	0.76
Food and tobacco	Philip Morris Companies Inc	0.322	0.63	0.82
Food and tobacco	Sara Lee Corp	0.222	0.33	0.52
Food and tobacco	Snow Brand Milk Products Co Ltd	0.24	1	0.5
Food and tobacco	Unilever NV	0.332	0.34	0.38
Machinery	American Standard Cos Inc DE	0.133	–	0.5
Machinery	Applied Materials Inc	0.204	0.52	1
Machinery	Baker Hughes Inc	0.19	0.5	0.38
Machinery	Black & Decker Corp, The	0.127	1	0.5
Machinery	Brunswick Corp	0.172	0.63	0.33
Machinery	Caterpillar Inc	0.134	0.22	0.5
Machinery	Cummins Engine Company Inc	0.301	0.29	0.33
Machinery	Deere & Company	0.208	–	1
Machinery	Dover Corp	0.142	–	0.5
Machinery	FMC Corp	0.107	0.56	0.22
Machinery	Halliburton Co	0.273	0.36	0.38
Machinery	Ingersoll-Rand Co	0.144	0.5	0.56
Machinery	Kawasaki Heavy Industries Ltd	0.086	0.25	0.22
Machinery	Komatsu Ltd	0.107	0.33	0.3
Machinery	Mitsubishi Electric Corp	0.14	0.32	0.2
Machinery	Parker-Hannifin Corp	0.153	–	0.38
Machinery	Tyco International Ltd	0.222	–	–
Metal	Alcatel	0.219	0.42	0.37
Metal	Aluminum Company of America	0.121	0.44	0.5
Metal	Ball Corp	0.144	0.28	0.47

Table 5.A6 continued

Sector	*Company*	*ITD 1990–1997*	*ETD 1990–1997*	*EPMD 1990–1997*
Metal	Gillette Co, The	0.125	0.5	0.17
Metal	Illinois Tool Works Inc	0.173	0.5	1
Metal	Kobe Steel Ltd	0.083	0.24	0.29
Metal	Mannesmann AG	0.146	0.28	0.16
Metal	Metallgesellschaft AG	0.116	0.21	0.25
Metal	Nippon Steel Corp	0.088	0.18	0.21
Metal	NKK Corp	0.102	0.2	0.35
Metal	Pechiney SA	0.129	–	0.5
Metal	Reynolds Metals Co	0.174	0.63	0.19
Metal	Sumitomo Electric Industries Ltd	0.099	0.34	0.19
Metal	Sumitomo Metals Industries Ltd	0.113	0.14	0.16
Metal	Thyssen AG	0.115	0.21	0.15
Metal	Usinor Sacilor	0.188	–	0.5
Metal	Viag AG	0.13	0.33	0.18
Other electronics	Allegheny Technologies Inc	0.086	–	1
Other electronics	Alps Electric Company Ltd	0.182	0.31	0.43
Other electronics	Canon Inc	0.191	0.33	0.42
Other electronics	Cisco Systems Inc	0.721	0.55	0.48
Other electronics	Eastman Kodak Co	0.19	0.22	0.15
Other electronics	Fuji Photo Film Co Ltd	0.226	0.13	0.27
Other electronics	Honeywell Inc	0.078	0.21	0.26
Other electronics	Intel Corp	0.401	0.33	0.56
Other electronics	Kyocera Corp	0.119	1	–
Other electronics	Litton Industries Inc	0.189	0.38	0.31
Other electronics	Matsushita Electric Industrial Co Ltd	0.152	0.22	0.22
Other electronics	Micron Technology Inc	0.281	0.58	0.56
Other electronics	Omron Corp	0.149	0.45	0.36
Other electronics	Philips Electronics NV	0.16	0.22	0.2
Other electronics	Pioneer Electronic Corp	0.283	0.44	0.82
Other electronics	Raytheon Co	0.116	0.18	0.17
Other electronics	Ricoh Co Ltd	0.24	0.28	0.34
Other electronics	Samsung Electronics Co Ltd	0.182	0.63	–
Other electronics	Siemens AG	0.093	0.2	0.12
Other electronics	Sony Corp	0.242	0.33	0.35
Other electronics	Tandy Corp	0.338	0.72	0.56
Other electronics	TDK Corp	0.175	0.32	0.38
Other electronics	Texas Instruments Incorporated	0.212	0.35	0.28
Other electronics	Thermo Electron Corp	0.108	1	0.28
Other electronics	TRW Incorporated	0.201	0.21	0.2
Other electronics	Western Digital Corp	0.264	0.42	1
Other electronics	Xerox Corp	0.267	0.6	0.54
Other electronics	Zenith Electronics Corp	0.381	0.54	1
Petrochemicals	Amoco Corp	0.205	0.2	0.38
Petrochemicals	Atlantic Richfield Co	0.183	0.59	0.53
Petrochemicals	British Petroleum Co PLC	0.228	0.87	0.33
Petrochemicals	Chevron Corp	0.313	0.31	0.45
Petrochemicals	ENI-Ente Nazionale Idrocarburi	0.238	0.59	0.28
Petrochemicals	Exxon Corp	0.223	0.46	0.35

Table 5.A6 continued

Sector	*Company*	*ITD 1990–1997*	*ETD 1990–1997*	*EPMD 1990–1997*
Petrochemicals	Idemitsu Kosan KK	0.24	0.22	0.42
Petrochemicals	Japan Energy Corp	0.102	1	0.22
Petrochemicals	Mobil Corp	0.279	0.51	0.43
Petrochemicals	Norsk Hydro A/S	0.128	0.28	0.21
Petrochemicals	Occidental Petroleum Corp	0.382	0.56	0.51
Petrochemicals	Petrofina SA	0.345	0.5	0.54
Petrochemicals	Phillips Petroleum Co	0.291	0.44	0.5
Petrochemicals	Royal Dutch Petroleum Co	0.243	0.5	0.32
Petrochemicals	Schlumberger Ltd	0.226	0.45	0.24
Petrochemicals	Soc Nationale Elf Aquitaine	0.227	0.42	0.29
Petrochemicals	Texaco Inc	0.269	0.28	0.58
Petrochemicals	Total S.A.	0.146	0.5	0.55
Petrochemicals	USX Corp	0.221	0.22	0.33
Petrochemicals	Veba AG	0.171	0.32	0.19
Pharmaceuticals	Abbott Laboratories	0.25	0.59	0.44
Pharmaceuticals	American Home Products Corp	0.303	0.76	1
Pharmaceuticals	Bayer AG	0.262	0.31	0.36
Pharmaceuticals	Bristol-Myers Squibb Co	0.296	0.65	0.64
Pharmaceuticals	Eli Lilly and Co	0.453	0.71	0.54
Pharmaceuticals	Glaxo Wellcome PLC	0.411	0.66	1
Pharmaceuticals	Johnson & Johnson	0.305	0.56	0.41
Pharmaceuticals	Merck & Co Inc	0.437	0.82	0.59
Pharmaceuticals	Novartis AG	0.258	1	0.33
Pharmaceuticals	Pfizer Inc	0.321	0.55	0.43
Pharmaceuticals	Roche Holding Ltd	0.411	0.88	0.52
Pharmaceuticals	SmithKline Beecham Group PLC	0.447	0.78	0.8
Pharmaceuticals	Warner-Lambert Co	0.285	0.83	0.5
Telecommunications	AT&T Corp	0.646	0.38	0.36
Telecommunications	Ameritech Corp	0.538	0.53	0.63
Telecommunications	BCE Incorporated	0.251	0.45	0.65
Telecommunications	Bell Atlantic Corp	0.677	0.47	0.51
Telecommunications	BellSouth Corp	0.613	0.6	0.59
Telecommunications	British Telecommunications PLC	0.268	0.39	0.59
Telecommunications	CBS Corp	0.108	–	0.72
Telecommunications	General Elec Co PLC, The	0.128	1	–
Telecommunications	GTE Corp	0.131	0.42	0.59
Telecommunications	Lucent Technologies	0.224	0.22	0.63
Telecommunications	MCI Worldcom Inc	0.64	0.48	0.63
Telecommunications	Motorola Inc	0.247	0.3	0.37
Telecommunications	Nokia Group	0.492	0.6	0.37
Telecommunications	Northern Telecom Ltd	0.253	–	–
Telecommunications	SBC Communications Inc	0.412	0.5	1
Telecommunications	Sprint Corp	0.687	0.52	0.64
Telecommunications	US West Communications Inc	0.512	0.63	0.76
Transportation equipments	Bayerische Motoren Werke Ag	0.338	0.22	0.52
Transportation equipments	Chrysler Corp	0.184	0.2	1
Transportation equipments	Daimler-Benz Ag	0.129	0.13	0.18

Table 5.A6 continued

Sector	*Company*	*ITD 1990–1997*	*ETD 1990–1997*	*EPMD 1990–1997*
Transportation equipments	Dana Corp	0.305	0.38	0.54
Transportation equipments	Denso Corp	0.132	–	1
Transportation equipments	Fiat S.P.A.	0.141	0.27	0.27
Transportation equipments	Ford Motor Co	0.163	0.3	0.39
Transportation equipments	Fuji Heavy Industries Co Ltd	0.334	0.33	0.5
Transportation equipments	General Motors Corp	0.126	0.22	0.3
Transportation equipments	Honda Giken Kogyo KK	0.207	0.3	0.66
Transportation equipments	Hyundai Corp	0.176	0.24	0.28
Transportation equipments	Isuzu Motors Ltd	0.31	1	0.78
Transportation equipments	Lear Corp	0.171	1	0.56
Transportation equipments	Man AG	0.178	0.38	0.18
Transportation equipments	Mazda Motor Corp	0.341	0.42	0.77
Transportation equipments	Mitsubishi Motors Corp	0.422	0.56	1
Transportation equipments	Nissan Motor Co Ltd	0.244	0.15	0.49
Transportation equipments	Renault, Regie National Des Usines	0.173	–	1
Transportation equipments	Robert Bosch GmbH	0.201	0.22	0.22
Transportation equipments	Suzuki Motor Corp	0.478	0.56	1
Transportation equipments	Toyota Motor Corp	0.224	0.22	0.42
Transportation equipments	Volkswagen AG	0.381	0.28	0.66
Transportation equipments	Volvo AB	0.18	0.25	0.64
Wood and paper	Avery Dennison Corp	0.149	0.25	0.5
Wood and paper	Boise Cascade Corp	0.262	–	1
Wood and paper	Georgia-Pacific Corp	0.187	1	1
Wood and paper	International Paper Company	0.152	0.56	0.38
Wood and paper	Kimberly-Clark Corp	0.164	0.5	0.47
Wood and paper	Mead Corp	0.248	1	1
Wood and paper	Union Camp Corp	0.163	–	1
Wood and paper	Westvaco Corp	0.165	0.5	1
Wood and paper	Weyerhaeuser Company	0.119	0.56	0.76

Source: elaborations from SDC (1999) and Techline (1999).

Acknowledgements

The help of Scuola Superiore Sant'Anna is warmly acknowledged for allowing us access to the Techline database. We also thank the TSER (European Targeted Socio-Economic Research) project *From Science to Products: A Green Paper on Innovation for the European Chemical Industry* (Contract No SOE1-CT97-1059) for allowing us to use the SDC data. Myriam Mariani also acknowledges support by the European Commission TMR "Marie Curie Fellowship" (Grant No, HPMF-CT-2000-00694).

Notes

1 We are aware of the limitations of patent-based proxies for measuring firms' innovative activity, and for comparing sectors and countries' innovative output. For a review see Griliches (1990).

2 Company-level aggregation of subsidiaries was performed before selecting the data.

3 We also calculated the Concentration Ratio for patents and alliances by firms and sectors. The results are consistent with the Herfindhal indexes.

4 We also run the OLS regressions by using different controls for the size of the companies. The results in Table 5.6 do not change significantly.

References

Amit, R. and Livnat, J., 1988, Diversification strategies, business cycles and economic performance, *Strategic Management Journal*, 9, 99–110.

Arora, A. and Gambardella, A., 1998, Evolution of Industry Structure in the Chemical Industry, in Arora, A., Landau, R. and Rosenberg, N. (eds), *Chemicals and Long-term Economic Growth: Insights from the Chemical Industry*, John Wiley & Sons, New York.

Berger, P.G. and Ofek, E., 1995, Diversification's effect on firm value, *Journal of Financial Economics*, 37, 39–65.

Breschi, S., Lissoni, F. and Malerba, F., 1998, Technological diversification and knowledge proximity, mimeo CESPRI.

Bresnahan, T. and Trajtenberg, M., 1995, General purpose technologies: engines of growth?, *Journal of Econometrics*, 65 (1), 83–108.

Chesnais, F., 1988, Technical cooperation agreements between firms, STI Review, 4, December, OECD, Paris, 57–119.

Cohen, W. and Levinthal, D., 1989, Innovation and learning: the two faces of R&D, *The Economic Journal*, 99, 569–596.

Cohen, W.M. and Levinthal, D.A., 1990, Absorptive capacity: a new perspective on learning and innovation, *Administrative Science Quarterly*, 35, 128–152.

Comment, R. and Jarrell, G.A., 1995, Corporate focus and stock returns, *Journal of Financial Economics*, 37, 67–87.

Contractor, F.J. and Lorange, P., 1988, *Cooperative strategies in international business*, D.C. Heath, Lexington, MA.

Dubofsky, P. and Varadarajan, P.R., 1987, Diversification and measures of performance: additional empirical evidence, *Academy of Management Journal*, 30, 597–608.

Dunning, J.H. 1993, *Multinational Enterprise and the Global Economy*, Addison Wesley, Wokingham, England.

Dunning, J.H, 1995, Reappraising the eclectic paradigm in an age of alliance capitalism, *Journal of International Business Studies*, 461, 191.

Eisenhardt, K.M. and Schoonhoven, C.B., 1996, Resource-based view of strategic alliance formation: strategic and social effects in entrepreneurial firms, *Organisation Science*, 7, 136–150.

Freeman, C. and Hagedoorn, J., 1995, Convergence and divergence in the internationalization of technology, in Hagedoorn, J. (ed.), *Technical change and the world economy – Convergence and divergence in technology strategies*, Edward Elgar, Aldershot, 34–57.

Gambardella, A. and Torrisi, S., 1998, Does technological convergence imply convergence in markets? Evidence from the information technology industry, *Research Policy*, 27, 445–463.

Garcia Canal, 1996, Contractual form in domestic and international strategic alliances, *Organization Studies*, 17, 773–794.

Granstrand, O., 1997, Towards a theory of the technology-based firm, *Research Policy*, 27, 465–489.

Granstrand, O. and Oskarsson, C., 1994, Technological diversification in MUL-TECH Corporations, *IEEE Transactions on Engineering Management*, 41, 355–364.

Granstrand, O. and Sjölander, S., 1990, Managing innovation in multi-technology corporations, *Research Policy* 19, 35–60.

Granstrand, O., Patel, P. and Pavitt, K., 1997, Multi-technology corporations: why they have distributed rather than distinctive core competences, *California Management Review*, 39, 8–25.

Griliches, Z., 1990, Patent statistics as economic indicators, *Journal of Economic Literature*, 18, 1661–1707.

Gulati, R., 1995, Does familiarity breed trust? The implications of repeated ties for contractual choice in alliances, *Academy of Management Journal*, 38, 85–112.

Hagedoorn, J., 1993, Understanding the rationale of strategic technology partnering: interorganisational modes of cooperation and sectional differences, *Strategic Management Journal*, 15, 371–385.

Hagedoorn, J. and Duysters, G., 2002, External sources of innovative capabilities: the preference for strategic alliances or M&As, *Journal of Management Studies*, 39, 167–188.

Hagedoorn, J. and Schakenraad, J., 1994, The effect of strategic technology alliances on company performance, *Strategic Management Journal*, 15, 291–309.

Hitt, M.A. and Ireland, R.D., 1986, Relationship among corporate level distinctive competencies, diversification strategy, corporate structure and performance, *Journal of Management Studies*, 23, 401–416.

Hoskisson, R.E. and Hitt, M.A., 1994, *Downscoping. How to Tame the Diversified Firm*, Oxford University Press, New York.

Kodama, F., 1986, Technological diversification of Japanese industry, *Science*, 233, 291–296.

Kodama, F., 1992, *Emerging Patterns of Innovation. Sources of Japan's Technological Edge*, Harvard Business School Press, Boston, MA.

Kogut, B., 1988, Joint ventures: theoretical and empirical perspectives, *Strategic Management Journal*, 9, 319–333.

Kogut, B. and Zander, I., 1992, Knowledge of the firm, combinative capabilities, and the replication of technology", *Organization Science*, 3, 383–397.

Markides, C.C., 1995a, *Diversification, Refocusing and Economic Performance*, MIT, Cambridge, MA.

Markides, C.C., 1995b, Diversification, restructuring and economic performance, *Strategic Management Journal*, 16, 101–118.

Markides, C.C. and Williamson, P.J., 1994, Related diversification, core competencies and corporate performance, *Strategic Management Journal*, 15, 149–165.

Montgomery, C.A. and Wernerfelt, B., 1988, Diversification, Ricardian rents and Tobin's *q*, *Rand Journal of Economics*, 19, 623–632.

Mowery, D.C., Oxley, J.E. and Silverman, B.S., 1988, Technological overlap and interfirm cooperation: implications for the resource-based view of the firm, *Research Policy*, 27, 507–523.

Osborn, R.N. and Baughn, C., 1990, Forms of interorganisational governance for multinational alliances, *Academy of Management Journal*, 33, 503–519.

Oxley, J.E., 1997, Appropriability hazards and governance in strategic alliances: a transaction cost approach, *Journal of Law, Economics, and Organization*, 13, 387–409.

Patel, P. and Pavitt, K., 1994, Technological competencies in the world's largest firms: characteristics, constraints and scope for managerial choice, WP-95-66, IIASA, Laxenburg.

Patel, P. and Pavitt, K., 1997, The technological competencies of the world's largest firms: complex and path-dependent, but not much variety, *Research Policy*, 26, 141–156.

Pisano, G.P., 1989, Using equity participation to support exchange: evidence from the biotechnology industry, *Journal of Law, Economics, and Organization*, 5, 109–126.

Pisano, G.P., 1991, The governance of innovation: vertical integration and collaborative arrangements in the biotechnology industry, *Research Policy*, 20, 237–249.

Porter, M.E., 1987, From competitive advantage to corporate strategy, *Harvard Business Review*, May–June, 43–59.

Prahalad, C.K. and Hamel, G., 1990, The core competence of the corporation, *Harvard Business Review*, May–June, 79–91.

Richardson, G.B., 1972, The organisation of industry, *Economic Journal*, 82, 883–896.

Robins, J. and Wiersema, M.F., 1995, A resource-based approach to the multibusiness firm: empirical analysis of portfolio interrelationships and corporate financial performance, *Strategic Management Journal*, 16, 277–299.

Rosenberg, N., 1976, *Perspectives on Technology*, Cambridge University Press, Cambridge, MA.

Rosenberg, N., 1990, Why do firms do basic research (with their own money)?, *Research Policy*, 19, 165–174.

Scott, J.T., 1993, *Purposive Diversification and Economic Performance*, Cambridge University Press, Cambridge and New York.

Singh, H. and Montgomery, C., 1987, Corporate acquisition strategies and economic performance, *Strategic Management Journal*, 8, 377–386.

Teece, D.J., 1986, Profiting from technological innovation: implications for integration, collaboration, licencing and public policy, *Research Policy*, 15, 285–305.

Teece, D.J., 1992, Competition, cooperation and innovation: organisational arrangements for regimes of rapid technological progress, *Journal of Economic Behaviour and Organisation*, 18, 44–70.

Teece, D.J., Rumelt, R., Dosi, G. and Winter, S.G., 1994, Understanding corporate coherence: theory and evidence, *Journal of Economic Behavior and Organisation*, 23, 1–30.

Varadarajan, P.R. and Ramanujam, V., 1987, Diversification and performance: a reexamination using a new two-dimensional conceptualization of diversity in firms, *Academy of Management Journal*, 30, 380–393.

von Tunzelmann, G.N., 1995, *Technology and Industrial Progress: The Foundations of Economic Growth*, Edward Elgar, Aldershot.

Part III

Technological diversification in specific industries

6 Technological competencies in networks of innovators

Fabio Pammolli and Massimo Riccaboni

1 Introduction

It is widely recognized that networks of collaborative relationships among firms are one important form of organization of innovative activities (Powell *et al.*, 1996; Kogut, 2000).

Particularly in high growth, technology intensive industries, networks of collaborative relationships are increasingly analyzed as organizational devices for the coordination of heterogeneous learning processes by agents endowed with different skills, competencies, access to information, and assets (Orsenigo *et al.*, 2000).

Despite widespread agreement, available empirical analyses do not address the specific relationships between firms' internal competencies and their external linkages.

In this chapter, we present an empirical investigation, based on a comprehensive data set of more than 11,000 R&D projects, on the role of firms' technological and market competencies in influencing their relational intensity. We highlight the importance of technological factors for explaining the extent to which firms participate to R&D networks.

Since its path-breaking inception in the mid to late 1970s, the biotech industry has appealed not only to scientists and new entrepreneurs, but also to nearly all established pharmaceutical corporations for its promising commercial implications. Most of the large, R&D intensive, Established Pharmaceutical Companies (EPCs) set up in-house capabilities in the new fields of molecular biology and biotechnology, alongside too a wide portfolio of collaborations that have given them access to the scientific and technological competencies of the new Dedicated Biotech Firms (DBFs) (Arora and Gambardella, 1994).

A rich transactional infrastructure for relational contracts and a dense network of collaborative relationships spread out in the last twenty years.[1]

Compared to other industries, R&D activities in biotechnology and pharmaceuticals tend to be characterized by a clear separation between the early upstream stages and the downstream stages of development and commercialization. DBFs tend to be focused mainly on the early stages of target identification/validation and drug discovery, and act as Originators of R&D projects that are licensed to the large, diversified, R&D intensive, multiproduct and multitechnology pharmaceutical corporations, which control the downstream stages of R&D and marketing (Developers) (see Pisano, 1991; Henderson and Cockburn, 1996b). Despite this general distinction, it is important to say that during the 1990s many DBFs have started to act both as Originators and Developers of R&D projects, with a significant turmoil in terms of relational roles and profiles within the industry.

In addition, the R&D network in pharmaceuticals is characterized by a significant amount of technological and market horizontal heterogeneity, both for Originators and Developers. In fact, if it is true that the biotechnology industry started with a small number of companies dedicated to the development and production by recombinant techniques of naturally-occurring proteins, since then the industry has undergone a tremendous degree of diversification. There are now new companies dealing with monoclonal antibodies, antisense molecules, ribozymes, gene therapy, cell therapy, the search for natural compounds, drug delivery systems, genomics (gene mapping, sequencing, expression), pharmacogenomics, combinatorial chemistry, developmental biology, high throughput screening techniques, bioinformatics. All in all, "the industry as a whole is not only very rich in methodology, but also very fragmented from a strategic point of view" (Drews, 2000). In this chapter, also building upon our previous work (Orsenigo *et al.*, 2000; Pammolli *et al.*, 2000), we trace the heterogeneity internal to the industry to two major technological regimes. These regimes coexist within the industry, and have a strong influence on the relationships between the extent of technological diversification and firms' relational behavior. The first regime started from the beginning of the 1980s and, based on the molecularization of physiology, of pathology, and pharmacology, associated with the "Molecular Biology Revolution" has induced a high degree of specialization of R&D programs, in terms of therapeutic and biological targets (see Galambos and Sturchio, 1996). The second regime started from the beginning of the 1990s, being characterized by a wave of dedicated firms that have entered the industry based on *general-purpose technologies* such as combinatorial chemistry, genomics, bio-informatics, and high throughput screening. These firms interact with EPCs and "traditional" DBFs to classify, organize, and select the chemical and biological knowledge generated by means of traditional, highly specialized, biological research techniques and hypotheses. By definition, the new general-purpose research technologies cannot be assigned unambiguously to any given field of application.

Against this background, this chapter is about the coexistence and the complementarities between the vertical and the horizontal dimensions of the evolution of networks, unraveling some major determinants of firms' relational behavior for both Originators – that is, companies that specialize in the production of specific pieces of knowledge – and Developers – multitechnology/multimarket companies that develop, produce, and commercialize products over a relatively vast array of markets (see Pavitt, 1999).

We exploit the potential of our database to show how firms' relational intensities within the network are influenced, shaped, and constrained by their heterogeneous technological profiles and, moreover, by the specific matching among them.

We test different versions of an econometric model, in which the dependent variables are defined, at the firm level, in terms of the number of licensing-in (Developers) and licensing-out (Originators) agreements, while the independent variables aim at capturing some fundamental sources of heterogeneity across firms, especially as far as their specialization and diversification profiles are concerned (Granstrand *et al.*, 1997).

The distinction between Originators and Developers, together with the availability of fine-grained information on technological characteristics and areas of application of R&D projects, as well as on the technological attributes of both EPCs and DBFs, enable us to establish a conceptual and empirical bridge between the literature on networks and the broad field of competence-based views of organizations and firms (Teece *et al.*, 1994).

As for Originators, we show that the number of collaborative agreements that they subscribe tends to be higher in the case of specialized firms, particularly those that are active in the development of general-purpose research technologies.

As for Developers, we were able to include in our sample all the most important multinational firms. Our focus on R&D projects within a broad but relatively homogeneous area, biopharmaceuticals, enable us to assume that activities, technologies, and areas of application which pertain to a given firm have somehow grown out of a complex idiosyncratic bundle of specifics and competencies. The number of licensing agreements comes out to be explained, on the one side, by the extent of firms' market and technological diversification and, on the other side, by the control of evaluative and integrative capabilities associated with economies of scope and technological coherence (Cohen and Levinthal, 1989; Arora and Gambardella, 1994; Teece *et al.*, 1994; Henderson and Cockburn, 1996a, 1996b).

The remainder of the chapter is organized as follows. Section 2 describes the database, the estimation methodology, and the variables and measures to be used in the quantitative analysis. Section 3 turns to a description of the results. Section 4 concludes summarizing the findings of our analysis.

2 Technological competencies and networks of innovators in pharmaceuticals

In this section, we provide a characterization of firms' technological competencies and profiles in pharmaceutical R&D, showing how they affect positions and roles of both Originators and Developers in the network of R&D collaborations.

First, we introduce a set of indicators and measures, which are meant to capture, at the micro level, some major dimensions of firms' competence bases. Second, we discuss the econometric framework of the analysis, which is based on a general theory of stochastic networks.

2.1 Data

The sample for this study is drawn from the Pharmaceutical Industry Database (PHID) built at the University of Siena. PHID combines several sector-specific proprietary datasets about R&D activity, collaboration and final drug markets with data from public sources as well as confidential information and press releases. PHID covers 11,418 R&D projects developed by 2,262 organizations including: 427 pharmaceutical companies,[2] 1,222 biotech firms[3] and 613 universities and other public and private research centers, between 1989 and 1999. Twenty-two percent of all the projects in our database were developed in collaboration by two or more partners.

For each R&D project, the database provides the following information:

1 *Originator* Firm/institution that started the R&D project on a new chemical compound with potential pharmacological activity (or known chemical compounds for new pharmacological targets). Typically, it is the holder of the patent on the new compound (or the new indication).

2 *Developer* Firm/institution that developed the project. This is the same as the Originator for the in-house projects. For the licensed compounds, the Developer is the licensee who is entitled to develop it further. Frequently the relationship between Originators and Developers is not just a pure licensing contract. In 67 percent of the cases it amounts to an R&D collaboration with fairly complex contractual and organizational settings. Moreover, 12 percent of the collaborations are between one Originator and many Developers. In these cases, we considered different projects for different Developers.[4]

3 *Therapeutic categories* Projects have been classified according to their targets in terms of likely therapeutic markets. We adopted the ATC (Anatomic Therapeutic Classification) at the 3-digit level. For example, HIV-antiviral corresponds to the ATC3 class J5C.[5] At the 3-digit level, therapeutic classes reflect quite closely to the basic degree of risk and innovativeness of the compounds. For each new product

the ATC Scientific Committee decides if it can be classified in a class that already exists. If not, new groups/classes are created for new markets for which these products are indicated.

4 *Pharmacological actions and biological targets* The main pharmacological activity of the compounds is described in standard terms. Back to the HIV-antivirals example, we can discern proteinase inhibitors from reverse transcriptase inhibitors and other products with different biological targets.

5 *Development history* The PHID database monitors the whole development history of the projects starting from the patenting date of the compound (priority and issue), through preclinical and clinical development stages (I, II, III), to registration and final launch on the market. For unsuccessful projects it registered the stage in which they have been discontinued.

6 *Collaborations and licensing activity* For the licensed compounds, PHID records the development stage (preclinical, clinical I, II, or III) at which the collaboration agreement was signed, and the type of collaboration that was specified by the parties.

As for the present chapter, our data set includes the collaborative relationships that were drawn before the start of clinical research activities. The set of linkages that we consider is composed by agreements that take different contractual forms. However, they are all characterized by the presence of a specific licensing contract. Moreover, thanks to information on the start of any R&D project, we are able to distinguish, for each agreement, the Originator from the Developer. All the collaborations selected according to this criterion were then carefully inspected to verify their genuine R&D content. The final sample is composed of 859 R&D agreements, which involve a panel of 355 firms, encompassing 83 EPCs and 272 DBFs, from 1980 to 1998. For each firm, in-house projects are monitored, covering a total of more than 9,000 projects. Firms are classified according to (a) year of founding; (b) nationality; (c) number of employees; (d) total revenues (pharma and consolidated); (e) R&D expenditures (pharma and consolidated); (f) sales in seven countries (the USA, Canada, the UK, France, Germany, Spain, and Italy), and (e) a set of indicators of the extent of technological specialization/diversification.

2.1 Relevant technological profiles

Our analysis is based on a pooled, cross sectional approach, which builds upon four sets of indicators, which are aimed at characterizing different technological profiles within the industry.

Number of projects At one extreme, each R&D project can be considered as the unique representative of a given market/technology micro-class, being targeted to the specific mechanisms and biological targets, based on a given research hypothesis and strategy. In this case, technological diversification of the *i*th firm would be measured by the count of its R&D projects (NP_i).

Diversity At another extreme, each R&D program can be classified according to the specific therapeutic micro-classes (relevant markets and fields of application), and biological targets and mechanisms. In this case, the traditional measures of the extent of corporate diversification can be used. In particular, we compute two values for the Herfindhal Index of Diversification (see Berry, 1972), with reference to Therapeutic Classes and Biological Mechanisms of Action:

$$\mathrm{THER\_DIV}_i = 1 - \frac{\sum_k (NP_{ik})^2}{\left(\sum_k NP_{ik}\right)^2}$$

$$\mathrm{BIO\_DIV}_i = 1 - \frac{\sum_z (NP_{iz})^2}{\left(\sum_z NP_{iz}\right)^2}$$

The index equals to 0 if the *i*th firm is entirely committed to a single therapeutic class or biological target, while it tends to 1 when firm *i* diversifies its R&D activity over a large number of therapeutic classes and/or biological targets and pharmacological mechanisms.

Coherence In the absence of a topology defined on cognitive and technological spaces, we refer here to the "survivor principle" that has been used to measure the extent of purposive diversification (Scott, 1991) and corporate coherence (Teece *et al.*, 1994). Based on the survivor principle, "activities which are more related will be more frequently combined within the same corporation" (Teece *et al.*, 1994). In other words, we do assume that firms tend to diversify their R&D efforts in related areas, in order to benefit from scope economies and to exploit the full range of potential applications of their technological core competencies (Nelson, 1959; Henderson and Cockburn, 1996b). As a consequence, the fields in which a firm is active possess some inherent degree of technological *relatedness*, and pairs of fields/activities which are highly frequent in the sample of firms are considered as related.

In this vein, we introduce two measures of technological coherence, for both therapeutic classes ($\mathrm{THER\_COH}_i$), and biological targets and mechanisms ($\mathrm{BIO\_COH}_i$). First, the dichotomous variable P_{ik} is introduced, which is equal to 1 if firm *i* has at least one R&D project in class *k*, and 0 otherwise. Then, we compute the number M_{kl} of firms that are active in both class k and class l:

$$M_{kl} = \sum_i P_{ik} P_{il}.$$

Finally, based on *the survivor principle*, we can measure the degree of coherence of projects of company i in class l with all other projects in different classes:

$$\text{THER\_COH}_{il} = \frac{\sum_{k \neq l} \overline{M}_{kl} NP_{ik}}{\sum_{k \neq l} NP_{ik}}$$

where $\overline{M}_{kl}$ is a standardized measure of market interdependence,[6] and NP_{ik} is the number of projects of firm i in the class k. Finally, the firm-level index of market coherence is obtained as the mean of the coherence measures for all the classes it is active in. Analogously, we compute the index BIO_COH$_i$, which measures the degree of corporate coherence in terms of biological targets.

Centrality The measure of technological diversification in terms of centrality is analogous, in principle, to the relatedness index just discussed. However, the centrality index is defined and measured at the level of the industry (in our case, considering all firms and R&D projects that are monitored in PHID) taking into account the number of potential partners active within any give technological field or market. In other words, the emphasis is now on technological relatedness defined looking at the characteristics of each firm relative to the others, for the overall industry. More precisely, the index C_{ij} computes the number of therapeutic/biological classes in which both firm i and j have at least one in-house R&D project each. Then, the matrix C is dichotomized, coming to the binary matrix $\overline{C}$. Cell $\overline{C}_{ij} = 1$ if firms i and j meet in at least one area, 0 otherwise. As we have already pointed out, the index has been computed taking into account not the sample of firms considered in this chapter, but the overall populations of firms and R&D projects. In synthesis, the Centrality Index for firm i is computed as the proportion of the total number of firms active in pharmaceutical R&D (n) that co-occur with firm i at the level of therapeutic and biological classes:

$$\text{THER\_CEN}_i = \frac{\sum_{i \neq j} \overline{C}_{ij}}{n-1}{}^{7}$$

The meaning of the index is straightforward, since it measures the degree of generality/specialization of firms' therapeutic and biological competencies. If firm i is active in a class which is populated by all the other $n-1$ firms within the industry, then the index is equal to 1. On the contrary, if the ith firm is highly specialized in some biological or therapeutic niche, then the index comes close to 0.

2.3 Control variables and descriptive statistics

In order to check for different explanations of firms' relational intensity within the network, we take into account a set of variables at the firm level (see Table 6.1): *Type* (EPC vs DBF: dummy variable EPC_i); *Size*, as measured by revenues in 1998 ($LOGREV_i$), *Age* (AGE_i); *R&D Expenditures* in 1998 (LOGRD); and *Nationality* (dummy variables JAP_Dum_i, EU_Dum_i). To take into account another important source of heterogeneity, we introduce a dummy variable (GPT_i) that distinguishes the firms that are specialized in GPTs from the others (dummy variable GPT_Dum_i).

Table 6.2 shows that all the variables that are introduced have skewed distributions, revealing that the population of firms in our sample is unbiased and highly heterogeneous. Table 6.2 shows also that EPCs and DBFs

Table 6.1 Definition of variables

Variable	*Definition*
$NLIN_i$	Number of R&D licenses subscribed by firm i as a *licensee*, 1980–1998
$NLOUT_i$	Number of R&D licenses subscribed by firm i as a *licensor*, 1980–1998
AGE_i	*Age* of the ith firm computed from the date of founding
NP_i	Number of internal *R&D projects* started by firm i, 1980–1998
$LOGREV_i$	Log of total *revenues* of the ith firm, 1998
LOGRD	Log of *R&D expenditures* of the ith firm, 1998
$THER\_CEN_i$	Index of inter-firm technological centrality in terms of projects *therapeutic classes*, 1980–1998
BIO_CEN_i	Index of inter-firm technological centrality in terms of projects *biological targets*, 1980–1998
$THER\_DIV_i$	Diversification of the ith firm research project portfolio in terms of *therapeutic classes*, 1980–1998 – Berry, 1972
BIO_DIV_i	Diversification of the ith firm research project portfolio in terms of *biological targets*, 1980–1998 – Berry, 1972
$THER\_COH_i$	Measure of intra-firm technological coherence in terms of *therapeutic classes*, 1980–1998 – Teece, Rumelt, Dosi, Winter, 1994
BIO_COH_i	Measure of intra-firm technological coherence in terms of *biological targets*, 1980–1998 – Teece, Rumelt, Dosi, Winter, 1994
GPT_Dum_i	Dummy variable: 1 if the ith firm is specialized in *high throughput screening, combinatorial chemistry, genomics*, 0 otherwise
JAP_Dum_i	Dummy variable: 1 if firm i is *Japanese*, 0 otherwise
EU_Dum_i	Dummy variable: 1 if firm i is *European*, 0 otherwise
EPC_i	Dummy variable: 1 if firm i is an established pharma, 0 otherwise

Table 6.2 Descriptive statistics

	DBFs				*EPCs*			
	Mean	*Std Dev*	*Min*	*Max*	*Mean*	*Std Dev*	*Min*	*Max*
AGE	9.949	4.721	1	22	–	–	–	–
NLIN	3.257	3.866	0	27	15.723	22.074	0	118
NLOUT	5.761	5.129	0	28	2.181	2.768	0	14
NP	16.768	14.996	1	96	66.940	77.271	1	317
LOGREV	6.743	0.892	4.204	9.434	9.102	1.205	5.010	10.570
LOGRD	7.053	0.550	4.365	8.945	8.460	1.094	5.316	10.080
THER_CEN	0.631	0.241	0	0.938	0.772	0.201	0	0.969
BIO_CEN	0.080	0.087	0	0.434	0.293	0.189	0	0.747
THER_DIV	0.687	0.254	0.058	1	0.850	0.152	0.029	1
BIO_DIV	0.583	0.326	0.017	1	0.614	0.336	0.025	1
THER_COH	0.199	0.090	0	0.524	0.305	0.091	0	0.496
BIO_COH	0.342	0.271	−0.176	1.193	0.625	0.243	−0.092	1.112
	Obs. 272				Obs. 83			

tend to be vertically differentiated in their behavior within the network: DBFs act mainly as Originators/Licensors, while lead pharmaceutical firms act on the market mainly as Developers/Licensees. The two populations of Originators and Developers characteristics differ significantly, and must be analyzed separately. Table 6.3 shows the correlation matrix of explanatory variables for DBFs and EPCs.

2.4 The econometric analysis

In our analysis of the relationships between projects' and firms' attributes and firms' degree distributions within the network of R&D collaborative agreements that we consider, we apply Poisson and Negative Binomial estimation techniques. The Poisson regression has been widely applied to models with count dependent variables.[8]

However, it is difficult to find, in the literature, a careful characterization of the economic or statistical rationales for the dependent variable being Poisson distributed.[9]

In the context of this chapter, we introduce a probabilistic framework, based on a fairly general theory of random graphs (Erdös and Rényi, 1960), which enables us to demonstrate that – under quite general conditions – the number of R&D agreements drawn by any given firm is asymptotically Poisson distributed. On this basis, we are allowed to analyze separately the determinants of relational intensity of Originators and Developers.

The probability that two firms subscribe a licensing agreement on a given research project is modeled as a Bernoulli random variable X, which takes values 0 and 1, with $P(X=1) = p$, $P(X=0) = q$. If we assume that the

Table 6.3 Correlation matrix of explanatory variables

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
AGE									
NP	0.136 (–)								
LOGREV	0.167 (–)	0.239 (0.442)							
LOGRD	0.055 (–)	0.382 (0.489)	0.424 (0.480)						
THER_CEN	0.031 (–)	0.529 (0.516)	0.096 (0.629)	0.197 (0.517)					
BIO_CEN	0.194 (–)	0.607 (0.774)	0.209 (0.431)	0.255 (0.469)	0.387 (0.463)				
THER_DIV	0.109 (–)	0.527 (0.618)	0.034 (0.662)	0.142 (0.474)	0.620 (0.823)	0.328 (0.572)			
BIO_DIV	0.041 (–)	0.042 (0.081)	−0.043 (0.070)	0.063 (0.088)	−0.057 (0.165)	0.023 (0.103)	0.115 (0.048)		
THER_COH	0.009 (–)	0.202 (0.489)	0.036 (0.297)	0.015 (0.204)	−0.036 (0.669)	0.164 (0.377)	0.372 (0.536)	0.128 (−0.016)	
BIO_COH	0.091 (–)	0.181 (0.534)	0.015 (0.266)	0.039 (0.288)	0.005 (0.597)	0.410 (0.499)	0.270 (0.457)	0.169 (−0.055)	0.504 (0.853)

Note
The values for EPCs are reported in parentheses.

$n(n-1)$ random variables Xi defined over the population of n firms active in pharmaceutical R&D are independent, the total number of relationships comes up to be distributed according to a binomial distribution function, with parameters $n(n-1)$ and p:

$$P(S_{n(n-1),p} = k) = b(k;\, n(n-1),\, p) = \binom{n(n-1)}{k} p^k q^{m(n-1)-k}.$$

Moreover, if p depends on n in such a way that $pn \to \lambda$ as $n \to \infty$, where λ is a positive constant, the Binomial Distribution $b(k;\, n(n-1),\, p)$ tends to a Poisson distribution with mean λ

$$p(k;\, \lambda) \sim e^{-\lambda}\lambda^k / k!$$

In other words, if the number of active collaborations is constrained by firms' characteristics (size, age, location, competencies, etc.) and potential partners are, at least in part, substitutes, the probability that any two given firms subscribe an agreement decreases as the number of potential partners increases. Under such circumstances, the binomial distribution follows closely the Poisson distribution.

As we are interested in the total number of agreements subscribed by each firm li, we characterize the asymptotic distribution of the discrete positive sequence $0 \geq l_1 \geq l_2 \geq \ldots \geq l_n$. First, an investigation of the relationship between n and p is needed. In particular, Erdös and Rényi (1960) show that $p(n)$ is neither too rigid nor too elastic,[10] the probability that r firms subscribe exactly k agreements is an asymptotic Poisson distribution with mean $\lambda_k = nb(k;\, n-1,\, p)$:

$$P(X_k = r) \sim e^{-\lambda_k}\lambda_k^r / r!$$

Based on this result, we hypothesize that a Poisson process generates the contacts counts that we observe. The parameter λ_k of the Poisson distribution is estimated as a function of a set of explanatory variables. In particular, we take into account two families of effects on λ_k. A first group of independent variables influence p, that is the propensity to collaborate in drug discovery and development. A second set of independent variables narrows the relevant subgroup of potential partners. In particular, we have introduced some proxies of technological coherence, diversification, and centrality within the network, in order to capture the relevant technological determinants of firms relational behavior.

According to any competence/resource-based view of the firm, organizations are unique combinations of relatively coherent bundles of technological competencies. At this level of the industry, corporate identities coexist with, and benefit from, high levels of organizational and technological heterogeneity. In this vein, the mean = variance property is a (well-known) major shortcoming of the Poisson regression model. Hence – to allow a higher degree of cross sectional heterogeneity – we generalize the Poisson assumption and pass to consider a Negative Binomial model, in which the parameters are distributed gamma instead of being deterministic (see Hausman *et al.*, 1984).

Finally, it is important to notice that in the specific network that we consider the number of licenses-in agreements must be equal to the number of licenses-out. This constraint imposes a restriction on the two equations that we estimate separately. As a consequence, we verify to what extent this restriction influences our results by means of Seemingly Unrelated Poisson Regression (SUPR) estimates, allowing the disturbances across equations to be freely correlated.

3 Firms in networks: on some technological determinants

In this section we present the results of the estimates of the Originators and the Developers models (Tables 6.4, 6.5, and 6.6). We test four different specifications (models I–IV), in which we introduce and compare our different measures of firms technological diversification.

The Developers model provides a measure of the relevance of in-house technological features (number of projects, diversification, coherence, and centrality) to explain the number of licensing-in agreements – measured in terms of number of agreements signed as licensees from 1980 to 1998 – controlling for nationality, size, and R&D intensity. The results of Poisson and Negative Binomial estimates, presented in Table 6.4, can be summarized as follows:

1 EPCs subscribe more licensing-in agreements than DBFs;
2 EPCs act more as Developers if they perform a higher number of in house R&D projects, which are diverse, coherent, and central in terms of therapeutic classes (NP, THER_DIV, THER_COH, and THER_CEN are all positive and significant). Interestingly enough, even the largest firms in the sample do not have research programs in all therapeutic classes (for a similar result, see Henderson and Cockburn, 1996b). Moreover, the number of licensing-in agreements is positively related to centrality of firms' technological competencies, in terms of biological mechanisms (BIOCEN is positive and significant in model IV);
3 Large firms – both in terms of total assets and revenues – are likely to develop more licensing-in agreements. Coefficients of R&D expenditures are not significant, aside from the Poisson regression of models III and IV, where they are negative and significant, suggesting that licensing-in agreements might substitute in-house R&D expenditures;
4 Japanese firms subscribe, ceteris paribus, far less R&D licensing agreements than US firms, while the large European multinationals are almost aligned to the US ones;

Table 6.4 Developers model: Poisson and Negative Binomial regressions; dependent variable = NLIN

	(I) Number of projects		*(II) Diversity*		*(III) Relatedness*		*(IV) Centrality*	
	Poisson	*Neg. Bin.*	*Poisson*	*Neg. Bin.*	*Poisson*	*Neg. Bin.*	*Poisson*	*Neg. Bin.*
EPC	0.916** (0.065)	0.702** (0.173)	1.410** (0.053)	1.497** (0.190)	1.355** (0.057)	1.492** (0.192)	0.877** (0.064)	0.916** (0.212)
NP	0.007** (0.001)	0.011** (0.001)						
THER_DIV			0.898** (0.094)	0.866** (0.217)				
BIO_DIV			0.374** (0.070)	0.219 (0.185)				
THER_COH					1.678** (0.293)	1.601* (0.801)		
BIO_COH					0.032 (0.107)	−0.392 (0.309)		
THER_CEN							0.879** (0.101)	0.981** (0.233)
BIO_CEN							2.889** (0.149)	2.484** (0.541)
LOGREV	0.115** (0.008)	0.085** (0.018)	0.070** (0.009)	0.058* (0.025)	0.114** (0.009)	0.096** (0.021)	0.062** (0.009)	0.046* (0.023)
LOGRD	0.046** (0.007)	0.063** (0.169)	0.001 (0.007)	0.021 (0.021)	0.023** (0.008)	0.057** (0.018)	0.003 (0.007)	0.014 (0.022)
JAP_Dum	−0.547** (0.095)	−0.274 (0.313)	−1.262** (0.094)	−1.188** (0.384)	−1.112** (0.094)	−0.881* (0.350)	−1.250** (0.093)	−1.109** (0.346)
EU_Dum	−0.098† (0.055)	−0.238 (0.173)	−0.179** (0.055)	−0.340† (0.200)	−0.109* (0.055)	−0.138 (0.193)	−0.431** (0.057)	−0.544** (0.211)
Delta (δ)		0.745** (0.078)		0.891** (0.086)		0.933** (0.089)		0.733** (0.074)
Log likelihood	−1350.85	−897.28	−1563.54	−917.14	−1605.92	−923.57	−1287.03	−896.05

Notes
Standard errors in parentheses.
** Significant at the 1 percent level.
* Significant at the 5 percent level.
† Significant at the 10 percent level.

Table 6.5 Originators model: Poisson and Negative Binomial regressions; dependent variable = NLOUT

	(I) Number of projects		*(II) Diversity*		*(III) Relatedness*		*(IV-V) Centrality*	
	Poisson	*Neg. Bin.*	*Poisson*	*Neg. Bin.*	*Poisson*	*Neg. Bin.*	*Poisson*	*Neg. Bin.*
EPC	−1.949** (0.104)	−1.964** (0.160)	−1.693** (0.115)	−1.753** (0.184)	−1.845** (0.095)	−1.896** (0.155)	−1.812** (0.106)	−1.847** (0.180)
NP	0.002** (0.001)	0.002 (0.001)						
THER_DIV			0.103 (0.122)	−0.010 (0.210)				
BIO_DIV			0.024 (0.084)	−0.054 (0.163)				
THER_COH					−0.158 (0.321)	0.113 (0.582)		
BIO_COH					0.246* (0.113)	0.201 (0.208)		
THER_CEN							1.002** (0.116)	0.964** (0.230)
BIO_CEN							−1.815** (0.218)	−1.712** (0.473)
GPT_DUM	0.688** (0.063)	0.760** (0.151)	0.671** (0.073)	0.740** (0.178)	0.737** (0.065)	0.799** (0.156)	0.626** (0.068)	0.699** (0.159)
AGE	0.063** (0.005)	0.072** (0.010)	0.057** (0.006)	0.068** (0.013)	0.062** (0.005)	0.070** (0.011)	0.058** (0.005)	0.065** (0.012)
LOGREV	0.091** (0.012)	0.073** (0.016)	0.079** (0.015)	0.073** (0.022)	0.089** (0.013)	0.070** (0.017)	0.079** (0.013)	0.068** (0.016)
LOGRD	0.049** (0.011)	0.049** (0.018)	0.064** (0.015)	0.068** (0.025)	0.051** (0.011)	0.048** (0.178)	0.041** (0.011)	0.043* (0.019)
Delta (δ)		0.431** (0.052)		0.447** (0.067)		0.434** (0.054)		0.430** (0.053)
Log likelihood	−1033.62	−884.81	−1033.89	−884.95	−1035.31	−885.10	−1032	−884.47

Notes
Standard errors in parentheses.
** Significant at the 1 percent level.
* Significant at the 5 percent level.
† Significant at the 10 percent level.

Table 6.6 Seemingly unrelated Poisson regression models

	SUPR number of projects		*SUPR diversity*		*SUPR relatedness*		*SUPR centrality*	
	LICIN	*LICOUT*	*LICIN*	*LICOUT*	*LICIN*	*LICOUT*	*LICIN*	*LICOUT*
INTERCEPT	−0.204 (0.381)	0.878** (0.205)	−3.641** (0.687)	1.235** (0.340)	−1.667** (0.504)	1.088** (0.199)	−1.092** (0.373)	0.500** (0.268)
NP	0.009** (0.001)	−0.002† (0.0011)						
THER_DIV			3.746** (0.919)	−0.261 (0.406)				
BIO_DIV			1.257** (0.303)	−0.289† (0.204)				
THER_COH					2.964** (0.843)	−1.496** (0.613)		
BIO_COH					0.359 (0.294)	0.200 (0.207)		
THER_CEN							1.496** (0.364))	0.715** (0.245)
BIO_CEN							3.432** (0.434)	−1.461** (0.456)
GPT_DUM		0.681** (0.135)		0.863** (0.188)		0.688** (0.137)		0.516** (0.137)
AGE		−0.004 (0.008)		−0.008 (0.009)		−0.004 (0.007)		0.001 (0.008)
LOGREV	0.158** (0.051)	0.055** (0.022)	0.210** (0.061)	0.053* (0.025)	0.290** (0.084)	0.054** (0.021)	0.139** (0.039)	0.053** (0.023)
LOGRD	0.056† (0.039)	0.051** (0.021)	0.025 (0.045)	0.046* (0.026)	0.059 (0.053)	0.049** (0.021)	0.029 (0.034)	0.051** (0.022)
JAP_Dum	0.087 (0.223)		−0.848** (0.267)		−0.472† (0.331)		−0.770** (0.237)	
EU_Dum	0.157 (0.218)		−0.003 (0.213)		0.265 (0.252)		−0.251† (0.195)	
ξ	0.224† (0.172)		−0.012 (0.204)		0.052 (0.091)		0.134 (0.118)	
Mean Log likelihood	−7.4578		−8.503		−8.3562		−7.1124	

Notes
Standard errors in parentheses.
** Significant at the 1 percent level.
* Significant at the 5 percent level.
† Significant at the 10 percent level.

5 The level of heterogeneity, as measured by the delta (δ) coefficients, is always high and significant, reaching the lowest value in model IV (0.734), confirming that the sample is unbiased and heterogeneous.

Analogously, the Originators model focuses on firms technological features (number of projects, diversification, coherence, and centrality) as determinants of licensing-out behavior, measured in terms of number of agreements subscribed as Licensors from 1980 to 1998. The results of Poisson and Negative Binomial estimates are reported in Table 6.5 and can be synthesized as follows:

1 DBFs tend to act as Originators of projects that are then sold to, and developed by, EPCs (EPC is always negative and significant);
2 Firms collaborate more as Originators if they are specialized on biological mechanisms (BIO_CEN is negative and significant) and, at the same time, are central in terms of therapeutic applications (THER_CEN is positive and significant);
3 Not surprisingly, older, larger, DBFs tend to sign a higher number of agreements, while the R&D intensity coefficient is generally not significant, except for model IV, where it is significant and positive;
4 Model IV minimizes the over-dispersion parameter (ä), which is always positive and significant.

So far, we have tested the license-in and the license-out models separately. In order to take into account the interdependence between the two models that is originated by equality between the number of licensing-in agreements and the number of licensing-out agreements, we test a Seemingly Unrelated Poisson regression model (SUPR).[11]

Table 6.6 presents the parameter estimates and the standard error for the SUPR model comparing the diversification measures defined above. The results are almost perfectly in line with the outcomes of the equation by equation Poisson estimates. The only remarkable difference appears in the relatedness model, where the coherence parameter is now significant also in the license-out case.

In addition, the ξ estimates are not statistically significant, with the exception of the first model. That is to say the seemingly unrelated model is not significantly outperforming the equation by equation Poisson models. This is not surprising, since Originators and Developers play complementary and different roles within the network, with marked difference in terms of their respective technological profiles. As a consequence, the license-in and the license-out models are not significantly interrelated.

All in all, the following results emerge from our analysis:

1 EPCs act typically as Developers of projects originated by DBFs. This result suggests that the network of R&D collaborative agreements in

biopharmaceuticals is structured around, and based on, a division of innovative labor that relies on substantial degrees of *vertical differentiation and specialization* across firms (see Arora and Gambardella, 1994). In fact, the EPC dummy coefficient is always significant: positive in the Developer models, and negative in the Originator ones. In a nutshell, our findings confirm that a *vertical* division of innovative labor is in place within the industry, with DBFs active in the early stages of R&D, and EPCs specialized mainly in the downstream development and commercialization activities.

2 Another relevant distinction emerges from the data. On the one side (Developers) the four measures of technological diversification are all significant in determining the propensity to license-in. On the other side (Originators) only the measures of centrality and generality of firms' technological bases are significant both in Poisson and Negative Binomial regressions. That is to say, a second major organizational distinction results from our analysis of the horizontal dimension of firms' heterogeneity within the network: Originators succeed within the network when they specialize on a cluster of related biological targets or research technologies. On the contrary, the relational intensity of Developers seem to be explained by their *absorptive* and *integrative* capabilities (see Cohen and Levinthal, 1989; Henderson, 1994), as reflected by our measures of the extent and coherence of technological diversification.

3 In addition, our analysis reveals the existence of some interesting relationships between the extent and nature of firms' technological diversification and the number of collaborative agreements they enter into. These relationships are generated by the interplay between the vertical and the horizontal dimensions discussed above. Notably, in the Developers model, THER_CEN and BIO_CEN are significant and positive while, in the Originators model, BIO_CEN is negative. Notably, Developers that are central in terms of biological mechanisms and/or application fields collaborate more. On the contrary, Originators license out mostly when they are specialized on specific biological targets or research technologies that can be applied to a vast array of application fields/therapeutic classes. All in all, the division of labor within the industry is sustained by the coexistence of vertical specialization for Originators and horizontal diversification for Developers. In this context, Originators and Developers rely on technological profiles that are complementary in nature. In fact, the probability of two firms signing a contract is highest when the Developer has many internal programs diversified across a bundle of related therapeutic classes and biological targets, while the Originator controls specific biological mechanisms or research technologies, which apply to a vast spectrum of therapeutic needs.

4 Conclusions

We have analyzed some fundamental mechanisms underlying firms' relational activity in the R&D network that has shaped the evolution of the pharmaceutical industry in the last twenty years.

Although the pharmaceutical industry is particularly apt a context in which to make our points, we do believe that our analysis has more general applicability.

It is well known that specialization in knowledge production and division of innovative labor can be crucial mechanisms for positive feedback from growth through scale economies to more growth (Bresnahan and Gambardella, 1998; Pavitt, 1999). This is especially true when vertical disintegration of economic activities is complemented by the upsurge of "general specialties", which are able to sell the fruits of their invention to a wide variety of distinct types of fields of application and customers/developers.

Despite these results, little empirical work has attempted to investigate the interplay among the vertical and the horizontal dimensions of division of innovative labor in markets and networks, as well as their relationships with firms competencies, market and technological diversification, and coherence (Teece *et al.*, 1994).

Against this background, this chapter shows how major structural features of firms' technological competencies can explain differences in firms' relational intensity in networks.

As for Originators, we have shown the existence of a clear advantage from technological specialization in knowledge production, especially in general purpose technologies. This result is interesting, because, in principle, an Originator diversified across many therapeutic classes could need access to a diverse set of downstream assets (given its size) and therefore, being more likely to license out. However, the evidences produced above suggest that if the firm is specialized technologically, it is more likely to produce licensable molecules and technologies.

As for Developers, the number of licensing agreements seem to be explained, on the one hand, by the extent of market and technological diversification and, on the other hand, by evaluative and integrative capabilities associated with economies of scope, internal spillovers of knowledge between programs, and technological coherence in R&D (Cohen and Levinthal, 1989; Teece *et al.*, 1994; Henderson and Cockburn, 1996b; Arora and Gambardella, 1994).

The positive relationship between indicators of technological coherence and the number of collaborative agreements signed by Developers seems to show that coherent R&D diversification increases not only the Developer's absorptive capacity, but also the likelihood that the Developer has the downstream assets required to exploit the technology (Nelson, 1959).

In general, our findings are coherent with the well-established theoretical statement according to which technology shapes industry-level outcomes. Specifically, this chapter has shown how the specific features of firms' technological competencies shape the formation and evolution of networks in modern industries and influence firms' centrality within them.

Notes

1 One fourth of total active pharmaceutical R&D projects were done in collaboration (1,218 out of 4,974: Scrip, 2000). Some pharmaceutical companies allocate a fourth or more of their research budgets to funding research programs at DBFs (see Stuart and Robinson, 2000), bolstering biotech firms' financing for at least one third ($5.3 of $15.5 billion: Scrip, 2000). Total biotech fundraising includes partnering incomes and all public (IPOs, Secondary offerings, PIPEs and Converts) and private (Venture capitalists funds and Public grants) financing. Partnering figure is based on up-front payments and equity investments for disclosed transactions (Scrip, 2000).

2 Subsidiaries, divisions, and research laboratories of pharmaceutical firms are included. For each project of these subunits our database reports the ultimate parent company.

3 We defined biotech companies to be all the companies in our database that were founded after 1976 (the year in which the first biotech company, Genentech, was founded) and that were originators of projects in the database that applied biotechnological methodologies to the discovery and development of new drugs. We also checked our database to avoid joint-ventures among larger established companies fell into this category. After inspecting our sample, we were confident that this criterion enabled us to single out the NBFs.

4 These are non-exclusive licensing contracts in which the Originator typically licenses the compounds to several Developers who test it for different indications/pathologies. The testing of the same compound for different indications/pathologies also justifies the fact that we treat them as different projects.

5 The Anatomical Classification of Pharmaceutical Products has been developed and maintained by the European Pharmaceutical Marketing Research Association (EphMRA) starting from 1971. A Classification Committee has been constituted to take care for new entries, changes and improvements. The first level of the Anatomic Therapeutic Classification indicates the anatomical main group (C – Cardiovascular System). The second level identifies the main therapeutic groups (C1 – Cardiac Therapy). Finally, the third level separates out the pharmacological/therapeutic subgroups (C1B – Anti-Arrhythmics). The third ATC level is a widely accepted standard (applied for instance by antitrust authorities around the world) to classify products for purposes of identifying the manufacturing market in pharmaceuticals.

6 According to the random assignment hypothesis adopted in Teece *et al.* (1994), the number of firms active in both class l and k, x_{lk}, is assumed to be a hyper geometric random variable depending on the number of diversified firms active in classes l, k, and the total number of diversified firms. In analogy to the t-statistic, the standardized measure of market interdependence is computed as

$$\overline{M}_{lk} = \frac{M_{lk} - \mu_{lk}}{\sigma_{lk}}$$

where μ σ are the mean and the variance of x_{lk}, respectively.

7 The Biological Centrality Index (BIO_CEN$_i$) is obtained in the same way, based on the classification of R&D projects in terms of biological targets and mechanisms.

8 Hausman *et al.*, 1984; recent surveys are in Cameron and Trivedi (1998) and Winkelmann (1997).

9 A remarkable exception can be found in Arora and Gambardella (1994), as they introduce a formal model according to which the number of agreements subscribed by large pharmaceutical firms should obey to a binomial distribution. Regrettably – due to the lack of data on EPCs' attributes and behavior – Arora and Gambardella rely on the assumption that large firms face a perfectly elastic supply of projects, up to a maximum.

10 $\epsilon n^{-3/2} \leq p(n) \leq \epsilon n^{-3/2}, \forall \epsilon > 0$.

11 The SUPR model (King, 1989) is the correspondent of the seemingly unrelated linear regression model (Zeller, 1962) for event count data. However, differently from the former, the SUPR model yields in principle more efficient estimates than separate Poisson models even if, as in our case, the same independent variables are present in both equations.

References

Arora A. and Gambardella A., 1994, "Evaluating Technological Information and Using It: Scientific Knowledge, Technological Capability, and External Linkages in Biotechnology", *Journal of Economic Behavior and Organization*, 24, 91–114.

Berry C.H., 1972, *Corporate Growth and Diversification*, The Brookings Institute, Washington, DC.

Bresnahan T. and Gambardella A., 1998, "The division of inventive labor and the extent of the market", in Helpman E. (ed.), *General Purpose Technologies and Economic Growth*, MIT Press, Cambridge, MA.

Cameron A. and Trivedi P.K., 1998, *The Analysis of Count Data*, Cambridge University Press, New York.

Cohen M. and Levinthal D., 1989, "Innovation and Learning: The Two Faces of R&D", *Economic Journal*, 99, 569–596.

Drews J., 2000, "Drug Discovery: A Historical Perspective", *Science*, 287, 17 March, 1960–1964.

Erdös P. and Rényi A., 1960, "On the evolution of random graphs", *Public Mathematical Institute of the Hungarian Academy of Sciences*, 5, 17.

Galambos L. and Sturchio J., 1996, "The Pharmaceutical Industry in the Twentieth Century: A Reappraisal of the Sources of Innovation", *History and Technology*, 13 (2), 83–100.

Grandstrand O., Patel P. and Pavitt K., 1997, "Multi-Technology Corporations: Why They Have 'Distributed' rather than 'Distinctive Core' Competencies", *California Management Review*, 39 (4), 8–25.

Hausman J., Hall B. and Grilliches Z., 1984, "Econometric Models for Count Data with an Application to the Patents–R&D Relationships", *Econometrica*, 52, 4, 909–938.

Henderson R., 1994, "The Evolution of Integrative Capabilities: Innovation in Cardiovascular Drug Discovery", *Industrial and Corporate Change*, 3, 607–630.

Henderson R.M. and Cockburn I., 1996a, "Measuring Competence? Exploring Firm Effects in Pharmaceutical R&D", *Strategic Management Journal*, 15, 63–84.

Henderson R.M. and Cockburn I., 1996b, "Scale, Scope, and Spillovers: The Determinants of Research Productivity in Drug Discovery", *Rand Journal of Economics*, 27 (1), 32–59.

King G., 1989, "A Seemingly Unrelated Poisson Regression Model", *Sociological Methods and Research*, 17 (3), 235–255.

Kogut B., 2000, "The network as knowledge: generative rules and the emergence of structure", *Strategic Management Journal*, 21 (3), 405–425.

Nelson R.R., 1959, "The Simple Economics of Basic Scientific Research", *Journal of Political Economy*, LXVII, 297–306.

Orsenigo L., Pammolli F. and Riccaboni M., 2000, "Technological Change and Network Dynamics: Lessons from the Pharmaceutical Industry", *Research Policy*, 30 (3), 485–508.

Pammolli F., Riccaboni M. and Orsenigo L., 2000, "Variety and Irreversibility in Scientific and Technological Systems: The evolution of an industry network", Chapter 9 in Pagano U., Nicita A., *The Evolution of Economic Diversity*, Routledge, London.

Pavitt K., 1999, "Technology, Products, and Organization in the Innovating Firm. What Adam Smith Tells Us and Joseph Schumpeter Does Not", in Dow S.C. and Earl P.E. (eds), *Economic Organization and Economic Knowledge. Essays in Honor of Brian Loasby*, Edward Elgar, Cheltenham.

Pisano G., 1991, "The Governance of Innovation: Vertical Integration and Collaborative Arrangements in the Biotechnology Industry", *Research Policy*, 20 (3), 237–249.

Powell W.W., Koput K.W. and Smith-Doerr L., 1996, "Interorganizational Collaboration and the Locus of Innovation: Networks of Learning in Biotechnology", *Administrative Science Quarterly*, 41, 116–145.

Scott J.T., 1991, *Purposive Diversification and Economic Performance*, Cambridge University Press, Cambridge.

Scrip's Pharmaceutical Company League Tables, 2000, PJB Publications, London.

Stuart T. and Robinson D.T., 2000, "Network Effects in the Governance of Strategic Alliances in Biotechnology", paper presented at the *Organization Science Winter Conference*, Keystone Co.

Teece D.J., Rumelt R., Dosi G. and Winter S., 1994, "Understanding Corporate Coherence: Theory and Evidence", *Journal of Economic Behavior and Organization*, 23, 1–30.

Winkelmann R., 1997, *Econometric Analysis of Count Data*, Springer-Verlag, Heidelberg.

Zeller A., 1962, "An Efficient Method for Estimating Seemingly Unrelated Regression and Tests of Aggregation Bias", *Journal of the American Statistical Association*, 57, 34–368.

7 Technological diversification, technology strategies and licensing in the chemical processing industry

Fabrizio Cesaroni

1 Introduction

This chapter discusses the processes of technological diversification of the worldwide largest corporations operating in the chemical processing industry, and the propensity that they show to license out their technologies. The economic and managerial literature in recent years has paid greater attention to the issue of corporate technological diversification. By defining the nature and assessing the motivations of this strategic choice, this study provides an example of how technological diversification can also be used by the largest chemical companies to capture value from their internal R&D activity, through licensing. In so doing, this study tries to assess the effects of technology licensing for those companies without strong technological competences.

R&D activity typically involves a change in the resource, technological and business base of companies, which can lead to an enhancement or reduction of internal competences. The distinction is between competence-enhancing and competence-destroying technological innovation (Tushman and Anderson, 1986). To the extent to which the shift in the competence base adds new competences (and technologies) to the existing base, and existing competences (and technologies) are retained or conserved, than R&D activity implies a process of technological diversification. This pattern is indeed very typical (Granstrand, 1994). The economic literature has widely recognised that when resources that have been acquired to support a specific business have multiple uses, then the existence of economies of scale and scope creates incentives to firms to diversify into new businesses (Penrose, 1959; Teece, 1982; Chandler, 1990). In this sense, technological diversification is somehow related to downstream business diversification. In the acquisition of new technological competences, companies sustain sunk fixed costs that can be spread over several businesses.

If this represents a traditional pattern, in this study we want to show that an alternative strategic option can be pursued as well. Indeed, in the case of the chemical industry, the technological surplus generated by processes of technological diversification according to the needs of business diversification, provided an incentive to chemical corporations to license their technologies to other firms. Largest corporations have extensively operated in the market for chemical process technologies. Thus, we state in this study that the propensity to license out their technologies is positively related to the extent of their technological diversification, and that technology licensing represents an additional possibility for gaining value from technological surplus.

Technological diversification mainly responds to internal reasons. Companies' decision to broaden their technological competences lies on two main causes (Granstrand *et al.*, 1997; Patel and Pavitt, 1997). First, in the case of complex products and production processes, companies need to maintain the (technological) control over all the components of the supply chain, even in the presence of technological outsourcing. The effective integration of outside components and sub-systems requires an adequate absorptive capacity (Cohen and Levinthal, 1989), in order to understand, co-ordinate and manage systematic change. The result of this pattern is an increase in the firms' technological activity spent outside the distinctive technological competences.

As shown by Granstrand and Sjölander (1990) and Patel and Pavitt (1993, 1994), the systemic complexity of process and product technologies often require the development of complementary technologies even in generic technologies like mechanical engineering, chemicals and information technologies. By using information on US patents by large firms, Patel and Pavitt showed that the extent of diversification in the technological base – as measured by patent classes – was much wider than their presence in downstream markets and product mix. Hence, product and technological diversifications often exhibit different degrees.

Second, companies need to explore and to experiment with emerging technologies, in order to assess and appreciate the potential business opportunities. This means that firms need also to invest in technological activities that are marginal to their technological portfolio, at least in the early stages of the research effort. At the same time, competences in fields such as computing or materials are becoming essential for a wider number of sectors, and firms need to accumulate and integrate such technologies with their core competences, by undertaking processes of technological diversification.

Both forces have an "internal" justification, i.e. companies increase their degree of technological diversification in order to strengthen the business competitiveness of existing products and processes, or to explore new business opportunities. However, the main point that will be stressed in this chapter is that technological diversification offers to companies a further ("external") option, i.e. the opportunity to license out their technologies to other firms. It is well recognised that licensing represents one of the possible means that companies can exploit to capture value from their innovative activity (Teece, 1986, 1998). However, the possibility to pursue this strategy depends on the existence of a set of conditions that are not easily satisfied, among which Teece has identified the appropriability regimes, the dominant design paradigm, and the presence of complementary assets.

In recent years, more and more companies in the industrialised countries are licensing out of their unutilised technological portfolio (patents) as a means to gain financial or economic benefits (Granstrand, 1999). A recent survey conducted on 133 firms and 20 universities from Western Europe, North America and Japan operating in different industrial sectors (BTG, 1998), shows that nearly two-thirds of organisations have a share of unutilised patents, and one in eight have in excess of 1,000 patents. At the same time, most of them find licensing out attractive, primarily because of financial, economic or commercial benefits. Indeed, about two-thirds of organisations reported to license technologies to other organisations. In turn, this implies that the management of technological knowledge and other intellectual property rights has to become a "core competence" of any successful enterprise (Rivette and Kline, 2000). The strategic use of patents, technologies and other intellectual property right can enhance the success of a company in three different ways: a) by stacking out and defending a proprietary market advantage; b) by improving firms' financial performance (realising the "hidden value of patents"); and, c) by increasing firms' competitiveness.

It has to be noticed that the presence of cognitive problems, and the nature of transaction costs limit technology licensing to develop and diffuse (Arora *et al.*, 2001). On the one hand, the technological knowledge is often dependant on the context in which it has been produced, and so it becomes difficult to transfer to other, different domains. In other words, the "stickiness" of technological knowledge reduces the probability of an effective division of innovative labour among different agents (von Hippel, 1990 and 1994). On the other hand, the tacit nature of technological knowledge, the presence of information asymmetries, and the uncertainty deriving from technology contracting increase the amount of transaction costs. In turn, property rights for intangible goods can be difficult to define and enforce (Arrow, 1962). These factors cause difficulties in contracting for technologies.

Despite the presence of these problems, the existence of sizeable markets for technologies worldwide has been well documented (Arora *et al.*, 2001). During the 1990s, these markets have grown, especially in some leading hi-tech industries, like software, electronics and the chemical sector. Furthermore, they have a potential for expanding, if conditions on the effective organisation of these markets are created. Among the sectors in which technology markets operate, the case of the chemical processing industry is one of the most relevant. The trade and licensing of process technologies is a common pattern of this industry. For this reason, by studying the behaviour of the largest chemical corporations we aim at analysing whether technological diversification affects companies' licensing strategies. Our results confirm this assumption. We performed a regression analysis to examine the relationship between technological (and business) diversification and technology licensing, and we found that companies which diversify more in terms of technological competences license more to other firms as well.

The chapter is organised as follows. Section 2 provides a brief introduction on the extent of technology licensing in the chemical industry, by showing the evolution of technology strategies by the largest chemical companies. Section 3 describes the methodology and the data used in the quantitative analyses. The analysis has been carried out by using an extensive database of the chemical plants built worldwide during the 1980–1996 period. Information on products, processes and licensors have been used in order to map the patterns of technological and product diversification. Section 4 presents empirical results about the relationship between technological and product diversification, and assesses the existence of sectoral and regional differences. Section 5 presents the results of the regression about the relationship between technological diversification and technology licensing. Section 6 discusses the implications of technology licensing for companies coming from developing countries and provided with weaker technological competences. Section 7 concludes.

2 Diffusion of technology licensing in the chemical industry

The emergence of the petrochemical revolution in the 1940–1950s gave rise to the upsurge of a world's market for process technologies. This was mainly the result of a set of conditions in the cognitive space, the solution of transactional problems, and the growing demand of chemical compounds since the Second World War, which shaped the industry structure and allowed a worldwide division of labour between technology suppliers and chemical companies (Arora *et al.*, 2001). The exchange of process and product technologies was mostly carried out through licensing agreements. The main actors in the chemical market for technologies were firstly the so-called Specialised Engineering Firms (SEFs), although large chemical companies were largely involved in licensing their proprietary technologies. Table 7.1 provides an estimate of the value of the market for process technologies, and compares the five sub-sectors – General Chemicals, Pharmaceuticals, Petroleum Refining, Rubber and Plastics, and Soaps and Cosmetics – both in terms of number of licences and of per-unit value.

While the presence of SEFs in this market for technologies has been the result of an increasing division of labour at the industry level, the presence of large companies is rather a recent event. To be sure, few of them have been active technology licensors for a long time – especially in some

Table 7.1 Value and number of licences by sector (millions of dollars, 1990–1997)

	Estimated value per licence	*No. of licences*	*Total value per sector*
General Chemicals	104.2	248	25,835.4
Pharmaceuticals	117.4	1,394	163,606.7
Soaps and Cosmetics	3.0	29	87.0
Rubber and Plastics	3.0	41	123.0
Petroleum Refining	6.2	33	203.2
Average	46.7	349	16,298.3

Source: Cesaroni and Mariani, 2001.

branches of the chemical industry, like polyolefins, and particularly polyethylene (PE) and polypropylene (PP). Union Carbide and Exxon Chemical, with their Univation Technologies joint venture, Montell, Nova and Borealis are some of these examples. Indeed, 40 to 50 per cent of new PE capacity is built using technology licensed from third parties (*Chemical Week*, 1997a).

The interesting point, however, is that more and more chemical companies, also operating in sub-markets different from polyolefins, are approaching this new strategy, and the licensing process technology is rapidly emerging as one of the most popular growth strategies in the chemical industry. The examples of Dow, Monsanto and DuPont, traditionally reluctant to license their proprietary know-how, are rethinking their strategies and are representative of this new strategic approach.

Dow Chemical began its licensing activity in 1995, evaluating all its 120 manufacturing processes for licensing potential, mainly aiming at contrasting rising R&D costs with a new revenue source. It also recognised the success of such long-time process licensers as Union Carbide and BP Chemicals, and the potential of licensing revenues to be less cyclical than commodity businesses. Further, Dow saw opportunities to acquire new technologies by licensing know-how from other companies. The key of this new strategy was an extensive inventory of Dow's existing portfolio to determine what technologies could be of value to other companies and which technologies Dow needed to acquire. This task was promoted by a newly formed licensing group, which also worked closely with Dow's business groups to ensure that potential licensing revenues for each of the processes would exceed a business group's potential loss of monopoly technology position. In the moment in which the licensing group was formed, Dow's goal was to have a portfolio of a half-dozen technologies to be repeatedly licensed, so as to increase its licensing revenues from $10–20 million/year, to $100 million/year by 2000 (*Chemical Week*, 1997b).

A similar path was covered by **DuPont Specialty Chemicals**, which formed in 1998 a group to license its process technologies, including acrylonitrile, aniline, sulfuric acid, and a range of performance chemicals processes, with the aim of generating $10 million/year in licensing revenues and add 10 licensees/year to its existing listing of about 50. The creation of the new group was the result of a changing behaviour towards technology licensing. In the past, indeed, DuPont carried out licensing only reactively, while the objective of the new group was to open up DuPont's 25 specialty chemicals businesses to licensing, some of which have been available for license for the first time. Indeed, DuPont observed an increasing interest in its acrylo process, especially from Middle East and Asian producers, where only two technology suppliers were operating. The new licensing group coordinated its activities with the Corporate Technology Transfer Group, which was formed in 1994 to oversee all technological transfer activities (*Chemical Week*, 1998a).

Similarly, **Eastman Chemical** established in 1998 a technology licensing unit, called Eastman Global Technology Ventures, in order to sell its under-utilised intellectual property portfolio. Indeed, in the view of the company this choice offers potential for non capital-intensive growth and near-term returns. Hence, the company started assessing its portfolio for possible products (*Chemical Week*, 1998b).

What is behind this increasing interest towards technology licensing shown by the largest chemical producers? The first simple answer is that by both licensing and selling products made by using the same technologies firms can increase the financial return from R&D investments, especially when companies have a share of under-utilised technology assets available for licensing. In this sense, licensing becomes an important growth mechanism for firms. Furthermore, the examples of BP Chemicals and Union Carbide, which have been long-time successful process technology licensors, may have persuaded other companies to license, attracted by the prospects of creating more value from existing technologies.[1]

Licensing, however, implies certain risks, mainly because the licensees can become potential future competitors in the final product market. In order to avoid this risk, companies usually adopt two different solutions. On the one hand, they select for licensing those technologies that are not critical for them. On the other, they keep in-house processes that are a technological step ahead of those licensed. Hence, while they are licensing some process technologies, they are working on the next generation of technology for internal production needs. For example, Monsanto and Nova behaved in such ways, respectively (*Chemical Week*, 1997b).

It is worth noting, however, that these two solutions represent only one possible mean to avoid or reduce the risks involved in licensing, and can be considered traditional answers. On the contrary, under certain conditions, licensing out the latest (or the "best") technology becomes the optimal strategic choice as well. One of these conditions is given by the presence of existing technology suppliers (such as SEFs). By providing technologies to potential entrants, SEFs created new competitors in the product market and increased the "rent dissipation effect", i.e. the erosion of profits due to other firms competing in the downstream product market (Arora and Fosfuri, 1999). This created enough incentives for larger chemical companies to enter the technology market.

3 Methodology and data

Our sample is composed of the 40 largest US, European or Japanese corporations operating in the chemical industry and listed in Fortune 500 (1998 classification). Eighteen companies are European, 18 are from the US and 4 are Japanese. Twenty companies have their core business in petroleum refining, 10 in chemicals, 7 in pharmaceuticals, 2 in plastics and rubber and 1 in soap and cosmetics.

The quantitative analysis has been carried out by using data on chemical plants built worldwide since 1980. Data on chemical plants have been drawn from the Chem-Intell (1998) database, which contains information on about 36,000 plants, concerning:

a *the different firms involved in the construction of the plant* – i.e., the firm owner of the plant, its nationality, the name and nationality of the mother company (in the case the owner firm belongs to a group), the name and typology of the technology licensor (it is possible to identify whether the licensor is a SEF, or a large chemical company, or a small firm);
b *the production/technology* – i.e., the name of the chemical compound produced in the plant, and the kind of process technology used for its production;
c *the plant* – i.e., the country in which the plant is located, its production capacity, the operative costs, and the year of construction.

First, we used information on the chemical compound produced in each plant belonging to the companies of our sample in order to assess their degree of product diversification. Then, information on the process technology involved in each plant has been used to assess the degree of technological diversification. Notice, however, that when we talk about "technological diversification" we are not taking into account technologies different from chemical processing technologies. In other words, the only technological diversification that we were able to assess refers to the capability of producing different chemical compounds. It may clearly be possible that companies belonging to our sample are enlarging their technological competences outside the chemical industry, but this pattern cannot be evaluated by using the Chem-Intell database.

In order to define companies' technological competences, we used information on technology suppliers – i.e. technology licensors – that provided the process technology for each plant. Three cases are possible:

a the technology has been supplied by an external licensor;
b the technology has been supplied by an internal division of the same company, i.e. the company has used a proprietary technology;
c information on the technology supplier is not available.[2]

Hence, we defined companies' technological competences as the sum of process technologies that each company either used internally for production purposes, or licensed to other firms. At the same time, this distinction allowed us to assess the extent to which companies licensed out their technologies, and whether they licensed technologies that are not used for in-house production purposes. As it will emerge clearly in the following sections, it is worth noting that in some cases companies used their technological competences both for internal production purposes and for external licensing. In this situation, they offered to other companies the (technological) possibility to compete in the same downstream product market.

The Chem-Intell database reports information on the chemical compound being produced in each plant, and the process technology used therein. The definition of these technologies is internal to the Chem-Intell database, and the number of process technologies listed is greater than 2,000. We grouped these technologies into 25 different classes (see Table 7.2), and used this classification both to measure product and technological diversification. In some cases, however, we preferred to use the original list of technological classes in order to have a finer understanding of technological competences owned by each company. In this sense, while technological classes reported in Table 7.2 can be considered as macro-technologies, the original list of process technologies can be considered as the corresponding micro-technologies.

Table 7.2 Technological classes

1	Agrochemicals	14	Minerals and Metallurgy
2	Air Separation	15	Miscellaneous
3	Coal Processing	16	Organic Chemical Refining
4	Desalination	17	Organic Chemicals
5	Engineering Materials	18	Petrochemicals
6	Environmental	19	Pharmaceuticals
7	Explosives	20	Plastics and Rubber
8	Fertilisers	21	Polymers
9	Food and Drink Processing	22	Pulp and Paper
10	Gas Handling	23	Storage Tanks
11	Industrial Gases	24	Synthetic Fuels
12	Inorganic Chemicals	25	Textiles and Fibres
13	Inorganic Chemicals – Chlor-alkalis		

4 Multi-technology corporations in the chemical processing industry

The first step of the analysis was to compare the companies of our sample in terms of their degree of technological and product diversification, during the period 1980–1996. As introduced in the previous section, technological diversification has been measured by means of the Herfindhal index of the process technologies in the 25 classes, that our companies either use internally or license out to other companies. On the contrary, product diversification has been measured by means of the Herfindhal index of the chemical compounds produced by each company in the same 25 technological classes.[3]

Figures 7.1 and 7.2 show the distribution of the indexes for technological and business diversification. The two distributions have different shapes. While the companies of our sample are more distributed over the five classes of Herfindhal index in terms of technological competences, the distribution of the index for products is more skewed towards the left. This means that while most companies have production plants distributed over many of the 25 technological classes, only few of them have the same diversification in terms of technological competences, while many show technological competences concentrated over few classes. The average index for technological competences is 0.47 (standard deviation 0.28), while the average index for business operations is 0.28 (standard deviation 0.20). The correlation between the two measures is however positive (and equal to 0.59), thus showing that companies which diversify more in terms of products have a larger competence base as well.

The picture emerging from Figures 7.1 and 7.2 is rather different from

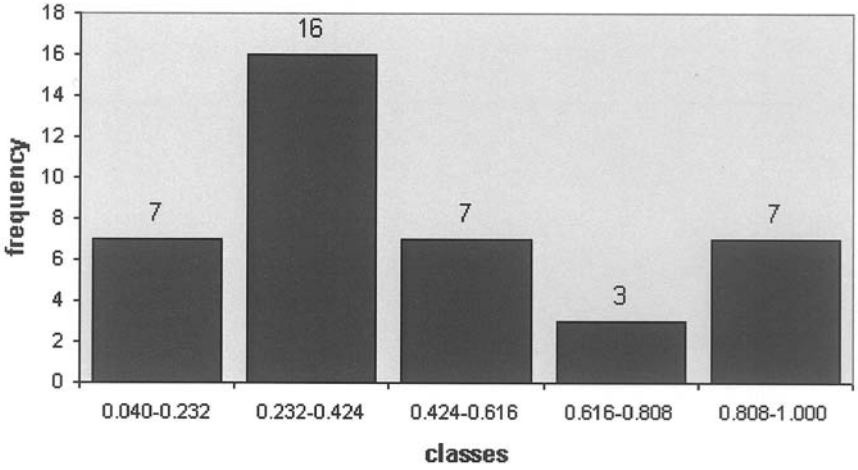


Figure 7.1 Technological diversification (Herfindhal index).

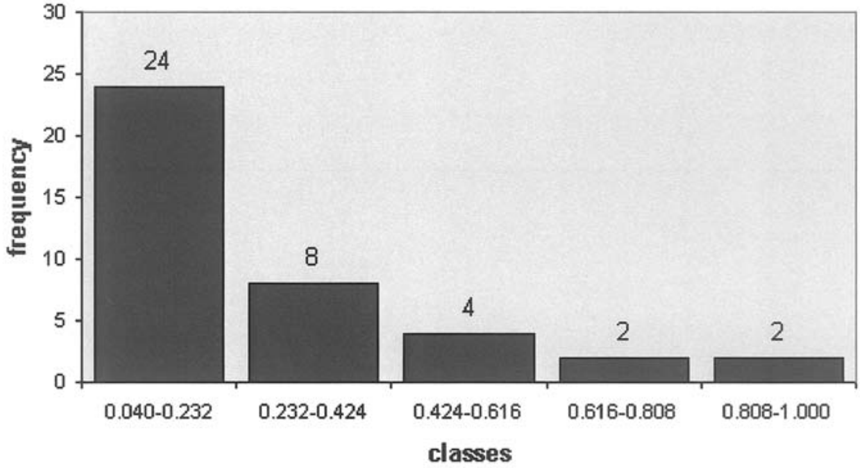


Figure 7.2 Product diversification (Herfindhal index).

those emerging in different industries. For instance, Gambardella and Torrisi (1998) compare technological diversification and diversification in downstream operations of the largest companies in the electronics industry. They show that while companies in their sample have a high degree of technological diversification, the extent of downstream diversification for the same companies is more heterogeneous. However, the difference of results between the electronics and chemical sectors might be due only to methodological concerns. Contrarily to this study, in order to measure the technological competences, Gambardella and Torrisi used patent counts, while they used information on new subsidiaries and acquisitions in order to assess downstream diversification.

An alternative explanation might be lying in the composition of the chemical industry in terms of the five sub-sectors – general chemicals, petroleum refining, pharmaceuticals, rubber and plastics and soaps and cosmetics.[4] The companies belonging to these sectors have indeed a different behaviour both in terms of technological and product diversification. As shown in Figures 7.3 and 7.4, while companies with their core business in petroleum refining, and even more those in general chemicals, have a high degree of diversification both in technologies and in products, companies in pharmaceuticals, rubber and plastics and in soap and cosmetics are more specialised. They manage both a reduced number of process technologies in chemicals, and a reduced number of chemical products (see Appendix for details).

At least companies in the general chemicals and petroleum refining sectors, and at least within the chemical processing industry, can be considered *multi-technology corporations* (Granstrand, 1998), having diversified

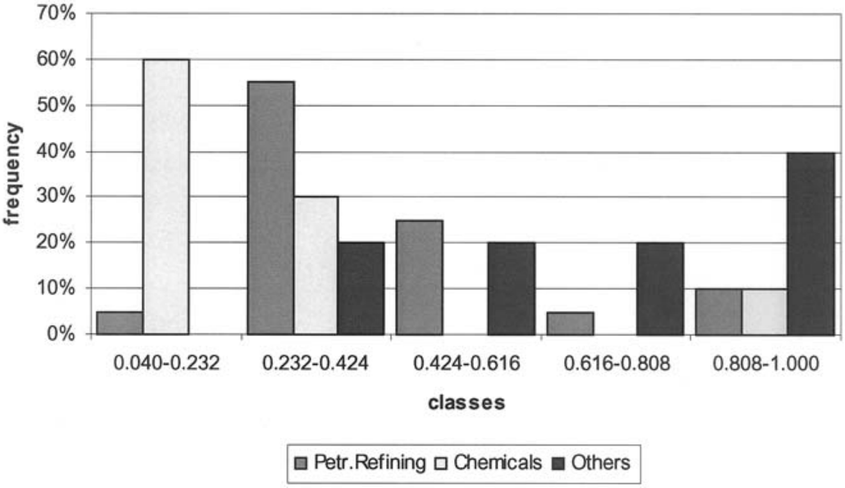


Figure 7.3 Technological diversification by sectors (Herfindhal index).

into several technological areas. Notice also that most of the firms in our sample are indeed the major chemical manufacturers worldwide, both in terms of sales and R&D. As expressed by other studies (see for instance Granstrand, 1998), this might suggest that technological diversification is strictly correlated with corporate growth and growth of R&D expenditures. The importance of economies of scale and scope (Chandler, 1990), and the need to take advantage of an increasing technological interrelatedness may partly justify this pattern.

The pattern described by Figures 7.3 and 7.4 has a historical justification as well. Indeed, the process of technological and knowledge creation and accumulation has a long tradition, provided that many of the companies in our sample are more than 100 years old. For example, BASF has been created in 1861, Hoechst in 1880 and Bayer in 1881. Even after the oil shock in 1973, without fundamental discoveries, chemical companies have systematically developed their stock of knowledge in processes and products (Aftalion, 1991). The enhanced application of electrochemistry in organic synthesis, the advances in chemical engineering (such as the use of rotary compressors in ammonia synthesis), and the development of new synthetic processes for the preparation of established products are examples of product improvements that brought to an enlargement of firms' technological competences. Similar developments were promoted in order to pursue product innovations. Acting as producers of intermediate products for downstream industries, chemical companies have broadened their technological competences in order to satisfy changes in demand. For example, under pressure from major clients like the automotive industry, many companies have brought improvements to plastics.

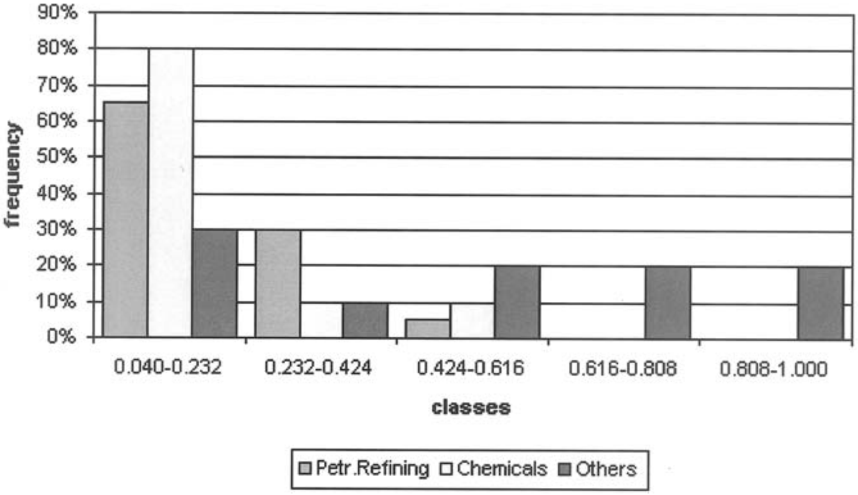


Figure 7.4 Product diversification by sectors (Herfindhal index).

Similar pressures came from agriculture, in order to develop new pesticides or enhanced solutions for plant protection. In sum, the requirements of many downstream industrial sectors have spurred the chemical industry to develop new derivatives, and to pursue a strategy of technological diversification.

Furthermore, with the advent of the petrochemical revolution, petroleum-refining companies realised that economies of scope could be exploited by entering into the market of chemical products. Indeed, technologies for large-scale chemical processing and technologies for large-scale oil refining became very close. This created strong incentives for diversifying both in technological competences and in downstream business. In turn, the increased competition in chemical markets due to the entry of new competitors from the petrochemical sector pushed the chemical companies to move downwards, by engaging in a process of additional diversification in the specialty chemical market (Arora and Gambardella, 1998). And this partly justifies the higher technological diversification both in technologies and in products of chemical companies compared to petrochemical companies – Herfindhal index is equal to 0.29 for technologies and 0.17 for products for chemical companies, and is 0.43 and 0.24 for petrochemical companies.

Obviously, differences emerge in terms of company's behaviour within each sector. Even in general chemicals, some companies show a high degree of technological or product specialisation – e.g. Norsk Hydro's Herfindhal index is 0.81 for technologies, and 0.44 for products (see Appendix for details). These differences seem to suggest diverse strategic behaviour and objectives. So, while some companies tend to concentrate on few technologies by operating a high number of plants (e.g., Atlantic

Richfield and Dow Chemicals), others operate a similar number of plants with a higher number of different process technologies (e.g., Texaco and Hoechst). The two contrasting patterns may be the result of opposite strategies in terms of growth of technological competences, and respond to the classical "breadth vs depth" strategic dilemma. Some companies have concentrated on a limited set of technologies, and others have broadened their technological base. In order to define the proper diversification strategy, companies take into consideration several factors; among others, the capability to spread the costs of innovative activity and technological development over many production plants, or the possibility to license the technology to other firms. Notice, however, that the first solution can be applied only in the presence of a large downstream market, but since the 1980s the chemical industry faces a decline in the demand growth. Hence, licensing represents a promising opportunity to recover the costs of R&D activity, especially for broadly diversified firms.

5 Different uses of the technological portfolio: in-house exploitation vs licensing

The traditional managerial theory has always considered in-house exploitation of technologies as the most efficient way to capture value from internal R&D activity (Teece, 1986, 1988). Over the past decades, however, there has been a growing attention to alternative solutions, among which a particular interest has been placed over the strategy of technology licensing. The recent development of specialised markets for technology is a clear signal of this pattern. As suggested in section 2, the chemical industry is one of the key examples of this process, and the companies of our sample seem to pay a similar attention to the strategy of licensing out their proprietary technologies.

In order to analyse their propensity to licensing, or their willingness to use technologies for internal production purposes, we considered all the plants in Chem-Intell in which companies appeared as technology licensor. In this count we included also the technologies used internally in proprietary production plants, and the technologies that companies both exploited in-house and licensed out to other firms. Figure 7.5 reports the results of this analysis. It emerges clearly that most of the largest corporations license out a large amount of processing technologies developed internally. On average, 59.5 per cent of the technologies are sold to other firms. However, if we compare each company with one another, it is possible to observe some interesting differences. While there are firms that license out more than 80 per cent of their proprietary technologies (e.g., ICI, Elf and Texaco), there are other firms that sell only a small amount of their technologies (e.g. Dow Chemicals and Roche), or that do not license at all (e.g. Novartis and Idemitsu Kosan). These differences reflect contrasting strategic approaches of companies.

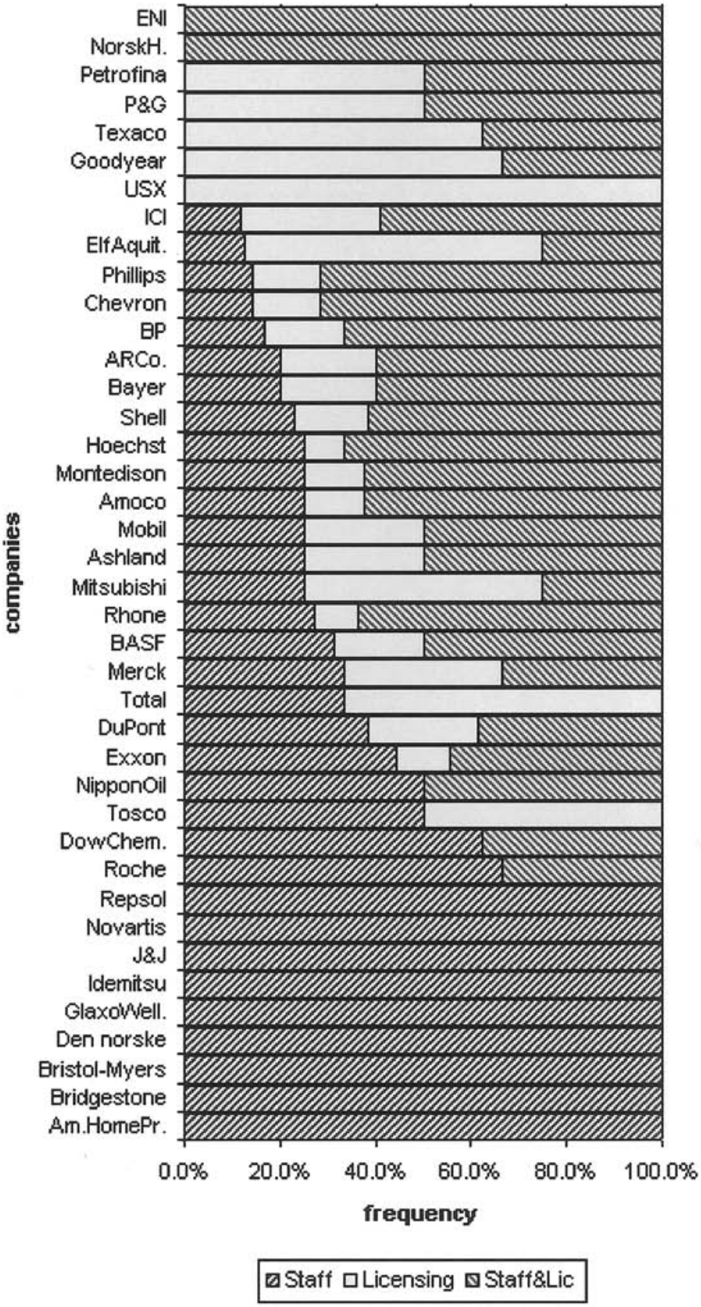


Figure 7.5 Share of technologies used in staff, licensed out, and both.

An interesting result emerging from Figure 7.5 is that most firms have a share of technologies that at the same time exploit in-house and license out to other firms. Without controlling for other conditions, this result seems to suggest that companies license their processing technologies to potential competitors in the product market, thus reducing expected profits in the product market. However, they are increasing rents in the technology market, so that firms' strategies may be the result of the comparison of the losses in product market with the earnings in the technology market. Also in this case, differences emerge in firms' strategies. While some of them tend to limit or to avoid this possibility, even though by licensing out, others have a very high share of technologies that both exploit in-house and license to other firms. ENI and Norsk Hydro, for instance, license out 100 per cent of technologies that they use for production purposes as well.

In order to explore the effect of technological diversification on companies' propensity to license out their technologies, we performed a regression analysis. Our sample is composed of our 40 firms. We first regressed the log of the number of technologies that companies licensed to other firms – L_TECLIC – against the value of the Herfindhal index for the technological diversification – HER_TECH. As control variables, we used:

- a measure of company's size, i.e. the log of revenues in 1997 – L_REV97;[5]
- a country dummy, in order to take into account regional effects – D_USA;
- a set of sectoral dummies, in order to take into account the effects of belonging to one of the five chemical sectors specified above – D_SECT1 . . . D_SECT4.

Thus, by using a linear specification, our regression is:

$$\begin{aligned} \text{L\_TECLIC}_i = \alpha + \beta_1\, \text{HER\_TECH}_i + \beta_2\, \text{L\_REV97}_i + \beta_3\, \text{D\_USA}_i \\ + \beta_4\, \text{D\_SECT1}_i + \ldots + \beta_7\, \text{D\_SECT4}_i + e_i \end{aligned}$$

where e_i is the error term.

Results of this exercise are reported in Table 7.3. It emerges that the degree of technological specialisation is indeed negatively correlated with the number of technologies that companies of our sample license out to other firms. Firms with a larger technological base show a higher propensity to license their technologies. This result, however, may be affected by problems of endogeneity between the dependent variable (L_TECLIC) and the Herfindhal index of technological diversification. Hence, we preferred to make use of a "two-stage least squares" technique (2SLS), and use an instrument for HER_TECH. Among others, the instrument that

Table 7.3 Diversification and licensing: OLS (dependent variable: L_TECLIC)

	Coef.	*Std err.*
HER_TECH	−0.727	0.374*
L_REV97	0.201	0.149
D_USA	0.164	0.162
D_SECT1	0.191	0.552
D_SECT2	−0.077	0.510
D_SECT3	−0.376	0.528
D_SECT4	0.271	0.605
_CONS	−1.085	1.738
Number of obs:	40	
F(7, 32):	3.26	
Prob. > F:	0.0099	
R-squared:	0.4166	
Adj. R-squared:	0.289	

Notes
* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

best resulted correlated with HER_TECH, but not with the disturbance term, resulted the Herfindhal index of product specialisation (HER_PROD). Indeed, as indicated in the previous section, firms with a higher product diversification show a high technological diversification as well. Intuitively, companies enlarge their technological base primarily to satisfy the technological needs of the businesses in which they operate (or intend to operate). In this sense, technological diversification may be the result of processes of product diversification. We tested this assumption by regressing HER_TECH against HER_PROD. Results are reported in Table 7.4. Table 7.5 presents the results of 2SLS regressions.

In Table 7.5 we presented two specification of the regression. In the first specification, the number of technologies that companies licensed out to other firms (L_TECLIC) has been measured in terms of the 25 technological classes reported in Table 7.2. Results in this case are as expected, and confirm that the propensity to license increases as the degree of technological diversification increases as well. Linking this result with those presented in Table 7.4, it emerges that the higher the degree of product diversification, the higher is the degree of technological diversification and, in turn, the higher is the number of technologies that companies license out. This result is confirmed by the second specification of Table 7.5. There, instead of considering the 25 technological classes, L_TECLIC has been measured in terms of the over 2,000 micro-technologies that we aggregated in order to obtain the 25 technological classes. Because L_TECLIC shows in this case a higher variability compared to the previous specification, results of the 2SLS regression are statistically more significant.

Table 7.4 Technological vs product diversification: OLS (dependent variable: HER_TECH)

	Coef.	*Std err.*
HER_PROD	0.476	0.222***
L_REV97	−0.131	0.062***
D_USA	−0.008	0.072
D_SECT1	−0.429	0.232*
D_SECT2	−0.267	0.220
D_SECT3	−0.225	0.240
D_SECT4	−0.031	0.274
_CONS	1.941	0.687***
Number of obs:	40	
F(7, 32):	4.930	
Prob. > F:	0.001	
R-squared:	0.519	
Adj. R-squared:	0.414	

Notes
* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Table 7.5 Diversification and licensing: 2SLS (dependent variable: L_TECLIC)

Dependent variable:	*L_TECLIC$_{macro}$*		*L_TECLIC$_{micro}$*	
	Coef.	*Std err.*	*Coef.*	*Std err.*
HER_TECH (HER_PROD)	−0.727	0.374*	−1.581	0.524***
L_REV97	0.201	0.149	0.705	0.209***
D_USA	0.164	0.162	0.165	0.227
D_SECT1	0.191	0.552	1.859	0.774***
D_SECT2	−0.077	0.510	0.947	0.714
D_SECT3	−0.376	0.528	0.150	0.740
D_SECT4	0.271	0.605	0.887	0.848
_CONS	−1.085	1.738	−5.788	2.435***
Number of obs	40		40	
F(7, 32)	3.260		13.560	
Prob. > F	0.010		0.000	
R-squared	0.417		0.748	
Adj. R-squared	0.289		0.693	

Notes
* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

In sum, results of these analyses confirm that the propensity to exploit technological competences through licensing increases in the presence of multi-technology corporations. This represents a rather new result. Traditional theory on technological diversification states, indeed, that the process of technological diversification increases firms' R&D expenditures, which call for a need to recover them through expanding the business base. Firms may satisfy this need either by choosing to engage in processes of market diversification (i.e., internationalisation), or in technology-related product diversification, or in technology-related partnering (Granstrand, 1998). Results of our analyses, however, illustrate that there is also another general response to the rising of R&D costs: exploiting the technological surplus induced by processes of technological diversification by selling the proprietary technologies in the market for technology.

It is worth noting that all the companies in our sample are large companies directly involved in downstream operations of production, distribution and marketing. Contrarily to (small) firms which do not possess the required complementary assets, and which can gain profits from their innovative activity only through licensing, in this case technology licensing is not a second-best solution. Licensing represents then an additional business opportunity that companies can pursue *together with* internal production. As a matter of fact, many companies of our sample use their technological competences both for in-house production and for licensing. But this option is available only under certain conditions that allow markets for technology to operate. Among these is the possibility to codify the technological knowledge that, in turn, improves the possibility of its accumulation and transfer. Hence, firms may have advantages in promoting the codification of technological knowledge (Arora and Gambardella, 1994). Indeed, this pattern actually happened in the chemical industry, thanks to the developments of chemical engineering, and the efforts promoted by SEFs in order to codify chemical processing technologies (Cesaroni and Mariani, 2001).

6 Effects of technology licensing on developing countries

The last section of this chapter aims at evaluating the effects of the strategies of technology licensing promoted by large companies in the chemical industry, and especially on chemical firms operating in the less developed countries (LDCs). In general terms, one of the main consequences of the existence of markets for technology and international technology trade is that barriers to entry in the downstream product markets decrease (Arora *et al.*, 2001). In the presence of lower entry barriers, companies with weaker technological competences, but provided with distinctive downstream complementary assets (i.e., production, marketing and distribution) can enter the product markets and become possible competitors of incumbent firms, simply by acquiring the needed processing technologies. The main idea is that the fixed costs of developing the technologies have been already sustained by the technology suppliers, and hence are largely sunk. As a result, the cost of acquiring the technology is lower than it would be if companies had to develop it in-house. Of course, this process offers a great advantage especially for those firms without significant technology expertise (i.e., those supporting higher development costs). On the contrary, the development of a market for process technologies means that the ownership of process technologies is no longer a distinctive competence of the large established firms.

This pattern happened in the chemical industry (Arora and Gambardella, 1998). SEFs arose in the second post-war period in the US, following the rapid growth of demand for chemical products. SEFs were a fundamental source of process technologies primarily for many American chemical producers. During the 1950s and 1960s, however, the American SEFs were also a powerful engine for growth of the European and Japanese chemical industry. In so doing, they provided the chemical processing technologies that allowed European and Japanese firms to catch up with US companies. Later, the same pattern was replicated from all the advanced countries towards firms in the LDCs. US, European and Japanese SEFs supplied chemical processing technologies to local companies, and stimulated a process of economic growth of the local chemical industry (Arora *et al.*, 1996). As a consequence, the rise of technology suppliers in the advanced countries increased the competitiveness of foreign rivals to the Western chemical manufacturers, thanks to the technologies provided by Western suppliers.

Our data offers a partial confirmation to this pattern. If we consider all the worldwide chemical plants belonging to firms coming from developing countries, and look at the suppliers of process technologies, then we can observe that more than 90 per cent of the local companies exclusively refer to external suppliers (Figure 7.6). Only a limited number of local producers have the technological competences and expertise to develop some proprietary process technology.

At the same time, this result shows that most of those firms, now competing with Western manufacturers, were able to take advantage of the existing international market for process technologies. They could enter

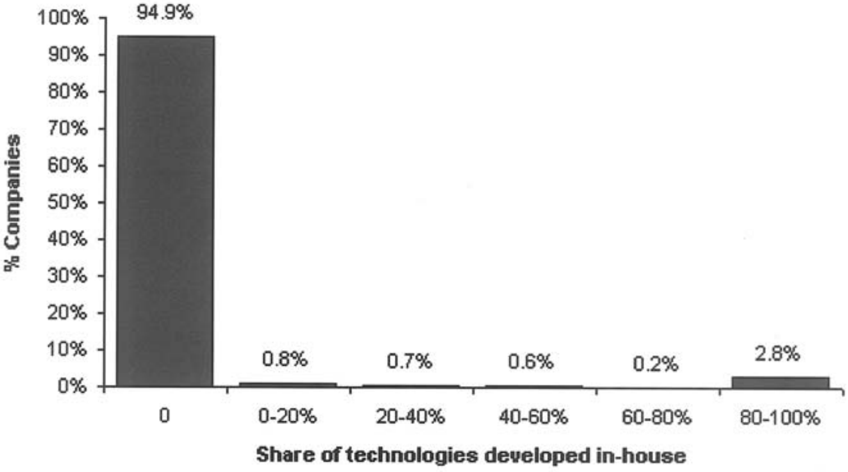


Figure 7.6 Supply of process technologies (companies from LDCs).

Table 7.6 Nationality of licensors operating in LDCs

	Share of licensors	
Western Europe	2,976	43.6%
North America	2,160	31.7%
Asia	1,142	16.7%
Rest of the World	544	8.0%
Total	6,822	100.0%

the markets of chemical products, without significant technological competences. Hence, they could save resources and time of internal processes of technology development. Notice also, that more than 90 per cent of the technology suppliers operating in the LDCs come from countries other than LDCs (see Table 7.6), and more than 40 per cent come from countries of Western Europe. Hence, the process of growth of the chemical industry in the LDCs was mainly promoted by external sources. But companies from LDCs are now the main competitors of the largest chemical corporations of the advanced countries.

For the period covered by the Chem-Intell database (1980–1996), about 7.7 per cent of the process technologies (1,174 out of 15,239) supplied to companies from the LDCs came from the corporations of our sample. This result clearly shows that the largest corporations are an important factor in the market for technology. On the side of companies from the LDCs, however, this pattern has relevant strategic implications. If markets for process technologies reduce the role of technological knowledge as a source of distinctive capability, the latter has to be sought in other directions. The heterogeneity of demand is a potential source of distinctive advantages (Arora *et al.*, 2001). In other words, knowledge about the local product markets in which companies operate, a clear understanding of customers' needs, and investments in linkages with the peculiar resources existing at the local level are potential sources of distinctive advantages (Porter, 1998).

According to this theoretical framework, one possible response is to increase the degree of product diversification, in order to satisfy a diversified demand. Indeed, many companies from LDCs show a rather high degree of product diversification (see Figure 7.7). The important point in this respect is that the processes of product diversification have been promoted without substantial technological competences, i.e. most of the process technologies come from external suppliers. In sum, the existence of international markets for process technologies, also promoted by the licensing activity of the largest corporations, not only allowed companies from LDCs to enter the product market, by reducing the costs of technology acquisition, but allowed companies to provide distinctive solutions to a heterogeneous demand.

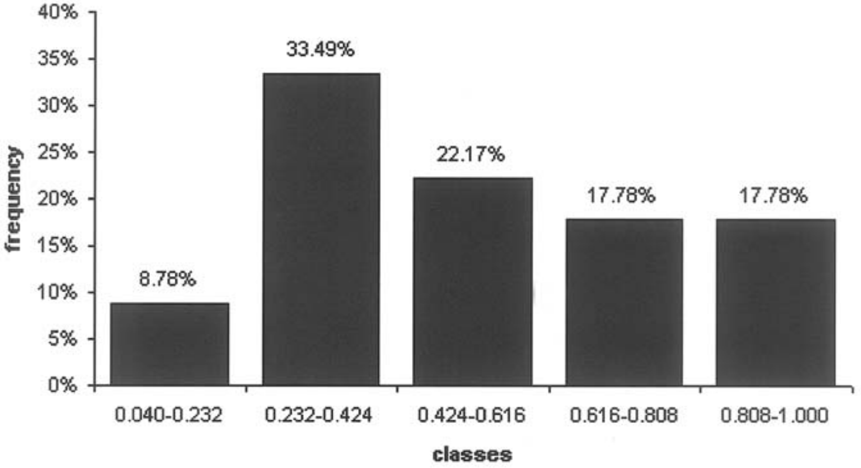


Figure 7.7 Product diversification for companies from LDCs (Herfindhal index).

7 Conclusions

The aim of this study was to discuss the nature of patterns of technological diversification promoted by the largest multi-technology corporations in the chemical processing industry. The long tradition of this industry and the nature of the chemical processing technology make this analysis particularly interesting. The key question that this study tried to answer was: Provided that the chemical companies of our sample show a wide technological portfolio, how do they manage their technologies? The economic and business literature has already discussed the reasons of processes of technological diversification, among which the need to maintain a control over all the components of the technological supply chain, and the opportunity to explore new technological trajectories and research fields are the most relevant. However, once developed (i.e., once that choices of technological diversification have been implemented), how do companies use their technologies? Do they use technologies only for internal production purposes, or do they sell those technologies to other firms? And, what about under-utilised technologies?

The answer to those questions has relevant implications. What emerges clearly in the case of the chemical processing industry is that most large multi-technology corporations uses internally developed technologies both in-house and for external licensing. Truth to tell, the characteristics and nature of chemical processing technologies, the existence of SEFs, and the developments of chemical engineering make the case of this industry quite peculiar. However, the story of the licensing activity in the chemical industry might become a common pattern also in different industries (see, for instance, the semiconductors). Hence, this industry may represent an example of a more general pattern.

The economic justification of technology licensing (as a firm strategy) lies on the possibility of increasing the returns from innovation. It is worth noting that, in order to pursue a strategy of technological diversification, companies have to increase their investments in R&D. If the company does not face a sufficiently large demand, the possibility to recover the costs of R&D activities through in-house exploitation drastically reduces. And this is particularly true when technological diversification is directed towards fields that are marginal to the "core" technological competences, or to the firm's main business. So that licensing out may become an appealing strategy. And, indeed, this is what has happened to most large chemical companies.

One important implication of this approach is that technology licensing, and the consequent rise of specialised markets for technology, lowers the entry barriers to downstream product markets. This creates advantages particularly to companies without strong technological expertise, because they can acquire the processing technologies required to enter a product market at costs that are lower than investments of in-house technology development. In other words, markets for technology promote a division of innovative labour at the industry level between technology suppliers and technology users. And multi-technology corporations may play relevant role on the supply-side. Again, the analysis of the chemical processing industry provides evidence of this pattern. Licensing of process technologies allowed companies from less developed countries to enter many product markets in chemicals, without having strong technological competences. And the largest corporations of advanced countries were an important actor in this respect.

There is a consequent corollary to this framework. If technological entry barriers have lowered, because technologies are available at lower costs in technology markets, companies can (and have to) concentrate on their distinctive capabilities other than technology. In the case of firms from developing countries, this means to concentrate on satisfaction of customers' needs. The knowledge of local markets is a clear competitive advantage for them, compared to companies coming from other countries. Indeed, the capability to satisfy a heterogeneous demand comes directly from the existence of markets for technology, because they can acquire the required process technologies directly from the market. As the results of our analyses have demonstrated, chemical companies from LDCs show a high degree of product diversification, completely induced by technologies provided by other companies.

In sum, the strategy of licensing out the marginal or surplus technologies resulting from processes of technological diversification promoted by larger multi-technology corporations represents an advantage not only for large firms themselves, but also for the economy of specific regions or industrial sectors. The former can increase the financial or economic returns from their innovative activity. The latter can undertake a process of economic growth and enhance the overall level of profitability.

8 Appendix Product vs technological diversification by companies, sectors and countries

Table 7.A1 Summary table

Company	*Sector*	*Region*	*Total no. plants*	*HER PROD*	*Total no. prod.s*	*HER TECH*	*Total no. techn.s*
American Home Products	Pharmaceutical	North America	78	0.163	78	1.000	1
Amoco	Petroleum Refining	North America	181	0.201	166	0.277	112
Ashland Oil	Petroleum Refining	North America	39	0.142	37	0.300	10
Atlantic Richfield	Petroleum Refining	North America	140	0.199	134	0.459	83
BASF	Chemicals	Western Europe	395	0.141	350	0.224	257
Bayer	Chemicals	Western Europe	254	0.143	223	0.196	128
Bridgestone	Rubber and Plastics	Asia and Oceania	10	0.580	10	1.000	6
Bristol-Myers Squibb	Pharmaceuticals	North America	16	0.680	16	0.556	3
British Petroleum	Petroleum Refining	Western Europe	219	0.208	201	0.307	162
Chevron	Petroleum Refining	North America	156	0.187	145	0.307	53
Den norske stats oljeselskap	Petroleum Refining	Western Europe	41	0.252	39	1.000	1
Dow Chemical	Chemicals	North America	363	0.243	320	0.384	177
E.I. Du Pont de Nemours	Chemicals	North America	361	0.117	316	0.252	162
Elf Aquitane	Petroleum Refining	Western Europe	59	0.200	59	0.457	41
Eni	Petroleum Refining	Western Europe	365	0.146	353	0.268	202
Exxon	Petroleum Refining	North America	326	0.203	302	0.340	116
Glaxo Wellcome	Pharmaceutical	Western Europe	65	0.939	64	1.000	9
Goodyear Tire & Rubber	Rubber and Plastics	North America	26	0.510	25	0.806	19
Hoechst	Chemicals	Western Europe	412	0.128	375	0.165	189
Idemitsu Kosan	Petroleum Refining	Asia and Oceania	66	0.260	66	0.318	22
Imperial Chemical Industries	Chemicals	Western Europe	463	0.115	426	0.147	410
Johnson & Johnson	Pharmaceutical	North America	14	0.867	14	1.000	4
Merck & Co.	Pharmaceutical	North America	32	0.631	32	0.375	4
Mitsubishi	Chemicals	Asia and Oceania	112	0.097	69	0.164	23
Mobil	Petroleum Refining	North America	148	0.220	135	0.365	31

Montedison	Chemicals	Western Europe	125	0.172	124	0.288	125
Nippon Oil	Petroleum Refining	Asia and Oceania	35	0.209	34	0.520	5
Norsk Hydro	Chemicals	Western Europe	187	0.437	177	0.810	68
Novartis	Pharmaceutical	Western Europe	89	0.169	81	0.346	18
Petrofina	Petroleum Refining	Western Europe	86	0.261	82	0.663	28
Phillips Petroleum	Petroleum Refining	North America	98	0.149	94	0.278	120
Procter & Gamble	Soaps, Cosmetics	North America	31	0.253	29	0.680	5
Repsol	Petroleum Refining	Western Europe	54	0.388	44	0.500	2
Rhone-Poulenc	Chemicals	Western Europe	329	0.122	295	0.231	166
Roche Holding	Pharmaceutical	Western Europe	44	0.220	42	0.500	6
Shell	Petroleum Refining	Western Europe	599	0.193	493	0.233	336
Texaco	Petroleum Refining	North America	183	0.339	180	0.207	63
Tosco	Petroleum Refining	North America	14	0.488	11	0.556	3
TOTAL	Petroleum Refining	Western Europe	90	0.365	84	0.375	4
USX	Petroleum Refining	North America	56	0.172	55	1.000	1

Notes

1 In 1997, Union Carbide and Exxon Chemical set up a joint venture to sell technology for producing polyethylene (PE). The new joint venture company, Univation Technologies, started licensing Carbide's Unipol gas-phase process and Exxon's metallocene technology. In the PE licensing business, it held a leading position with roughly 50 per cent of the market (*Chemical Week*, 1997b). One of the objective of the joint-venture was to offer cutting edge processes and supply catalysts used in the manufacturing of PE for the Asia Pacific region. The joint venture targeted at the Asia-Pacific region because consumption of all types of PE was projected to grow 7–9 per cent annually till 2000. Indeed, at that time, Asian demand for PE was comparable to North America's and surpassed Western Europe's (*Business Times Singapore*, 1997).

2 This latter case can be interpreted either as a "missing value" case due to some imperfections of the database, or as the case in which that technology is "common knowledge" in the industry. In other words, it may be the case in which the technology is rather mature and diffused among the different companies. In order to avoid any error of judgement, the cases of missing value have not been taken into consideration in the following analyses.

3 For both indexes, the Herfindhal index varies between 0.04 and 1. The first value represents a situation of max diversification (equal shares), while the second represents a situation of max specialisation (only one sector with share equal to 1).

4 The inclusion of each company of our sample in one of the five sub-sectors reflects the classification reported in the Fortune 500 list (1998 classification).

5 Information on revenues have been drawn from Fortune 500 (1998 classification).

References

Aftalion F., 1991, *A History of the International Chemical Industry*, University of Pennsylvania Press, Philadelphia.

Arora A. and Fosfuri A., 1999, "Licensing the Market for Technology", *CEPR Discussion Paper*, 2284, November.

Arora A. and Fosfuri A., 2000, "The Markets for Technology in the Chemical Industry: Causes and Consequences", *Revue d'Economie Industrielle*, Vol. 92 (Special Issue), pp. 317–334.

Arora A. and Gambardella A., 1994, "The Changing Technology of Technological Change: General and Abstract Knowledge and the Division of Innovative Labor", *Research Policy*, Vol. 23, pp. 523–532.

Arora A. and Gambardella A., 1998, "Evolution of Industry Structure in the Chemical Industry", in Arora A., Landau R. and Rosenberg N. (eds), *Chemicals and the Long Term Economic Growth*, John Wiley & Sons, New York.

Arora A., Fosfuri A. and Gambardella A., 1996, "Division of Labour and Transmission of Growth", *CEPR Discussion Paper Series*, 474, July, University of Stanford.

Arora A., Fosfuri A. and Gambardella A., 2001, *Markets for Technology: Why They Exist, Why More Do Not Exist, and Why Should We Care*, MIT Press, Boston.

Arrow K., 1962, "Economic Welfare and the Allocation of Resources for Invention", in National Bureau of Economic Research, *The Rate and Direction of Inventive Activity*, Princeton University Press, Princeton.

British Technology Group (BTG), 1998, www.btgplc.com.

Business Times Singapore, 1997, "Polyethylene Venture Eyes Asia", April 22, 1997, p. 2.

Cesaroni F. and Mariani M., 2001, "Markets for Knowledge in the Chemical Sector", in Guilhon B. (eds), *Technology and Markets for Knowledge. Knowledge Creation, Diffusion and Exchange within a Growing Economy,* Kluwer, Boston.

Chandler A.D., 1990, *Scale and Scope. The Dynamics of Industrial Capitalism,* Harvard University Press, Cambridge.

Chem-Intell, 1998, Reed Elsevier Ltd., London.

Chemical Week, 1997a, "Betting on the Right Route to Growth", March 26, 1997, p. 39.

Chemical Week, 1997b, "Turning Process Know-how into Profits", July 23, p. 45.

Chemical Week, 1998a, "DuPont's New Licensing Group", June 10, 1998, p. 46.

Chemical Week, 1998b, "Eastman Forms Licensing Venture", March 11, 1998, p. 12.

Cohen W. and Levinthal D., 1989, "Innovation and Learning: The Two Faces of R&D", *Economic Journal,* Vol. 99, pp. 569–596.

Gambardella A. and Torrisi S., 1998, "Does Technological Convergence Imply Convergence in Markets? Evidence from the Electronics Industry", *Research Policy,* Vol. 27, pp. 445–463.

Granstrand O. (ed.), 1994, *Economics of Technology: Seeking Strategies for Research and Teaching in a Developing Field,* North-Holland, Amsterdam.

Granstrand O., 1998, "Towards a Theory of the Technology-Based Firm", *Research Policy,* Vol. 27, pp. 465–489.

Granstrand O., 1999, *The Economics and Management of Intellectual Property,* Edward Elgar, Cheltenham.

Granstrand O. and Sjölander S., 1990, "Managing Innovation in Multi-technology Corporations", *Research Policy,* Vol. 19, pp. 35–60.

Granstrand O., Patel P. and Pavitt K., 1997, "Multi-Technology Corporations: Why They Have 'Distributed' Rather Than 'Distinctive Core' Competences", *California Management Review,* Vol. 39 (4), pp. 8–25.

Patel P. and Pavitt K., 1993, "Technological Competencies in the World's Largest Firms", *STEP Discussion Paper* no. 13, SPRU, University of Sussex, Brighton.

Patel P. and Pavitt K., 1994, "The Continuing, Widespread (and Neglected) Importance of Improvements in Mechanical Technologies", *Research Policy,* Vol. 23, pp. 533–545.

Patel P. and Pavitt K., 1997, "The Technological Competencies of World's Largest Firms: Complex and Path-Dependent, But Not Much Variety", *Research Policy,* Vol. 26, pp. 141–156.

Penrose E., 1959, *The Theory of the Growth of the Firm,* Wiley, New York.

Porter M., 1998, "Clusters and the New Economics of Competition", *Harvard Business Review,* November–December, pp. 77–90.

Rivette K.G. and Kline D., 2000, "Discovering New Value in Intellectual Property", *Harvard Business Review,* Vol. 78 (1), January–February, pp. 54–66.

Teece D.J., 1982, "Towards an Economic Theory of the Multiproduct Firm", *Journal of Economic Behavior and Organization,* Vol. 3 (1), pp. 39–63.

Teece D.J., 1986, "Profiting from Technological Innovation: Implication for Integration, Collaboration, Licensing and Public Policy", *Research Policy,* Vol. 15, pp. 285–305.

Teece D.J., 1988, "Technological Change and the Nature of the Firm", in Dosi G. *et al.* (eds), *Technical Change and Economic Theory,* Francis Pinter, London.

Teece D.J., 1998, "Capturing Value from Knowledge Assets: The New Economy, Markets for Know-how, and Intangible Assets", *California Management Review*, Vol. 40 (3), Spring, pp. 55–79.

Tushman M. and Andreson P., 1986, "Technological Discontinuities and Organizational Environments", *Administrative Science Quarterly*, Vol. 31, pp. 439–465.

Von Hippel E., 1990, "Task Partitioning: An Innovation Process Variable", *Research Policy*, Vol. 19, pp. 407–418.

Von Hippel E., 1994, "'Sticky Information' and the Locus of Problem Solving. Implications for Innovations", *Management Science*, Vol. 40 (4), pp. 429–439.

8 Large companies from all sectors patenting in ICT

Is there a link between corporate technological diversification and the information revolution?

*Sandro Mendonça**

1 Introduction

This paper focuses on the increasing tendency among the world's largest companies to patent in information and communication technology (ICT) when they patent outside their core technical domains. This empirical work draws on the established Multi-technology Corporation (MTC) literature but seeks to add another piece to the puzzle by contributing with new information about recent, under-emphasised trends. By analysing the composition of technological diversification we aim at inserting specific qualifications on what has already been pointed out in the literature, thereby complementing what is already understood about this complex and evolving phenomenon.

Two main questions are addressed. First, we seek to find out if the diversification phenomenon, as measured by patents, has been evenly distributed across technological fields. We introduce this as a general point and then proceed to investigate which technologies stand out as most prominent. Second, besides arguing that some technologies are more relevant than others for MTCs we also wish to provide evidence on one precise point: we examine the hypothesis that ICT is distinctively important in corporate technological diversification when compared with other technology families.

This work uses patent counts and classifications based on the SPRU-OTAF (Science and Technology Policy Research Unit – Office of Technology Assessment and Forecast) database for nearly 500 of the world's largest innovating companies as ranked by sales revenues. We also use complementary data on the 200 largest US manufacturing firms of the twentieth century compiled from Chandler (1990) and Fortune magazine by Louçã and Mendonça (2002). We rely on descriptive statistics throughout. The results for the period under analysis, which is 1980 to 1996, can be summarised as follows:

a Large firms are increasingly diversifying into ICT, Drugs and Biotech and Materials technology,
b ICT is clearly the field attracting more patents when companies patent outside their core technical fields,
c There is considerable variety across industries in the level and pace of increase in ICT patenting.

We suggest that the apparent pervasiveness of the development of ICTs can be associated with the neo-Schumpeterian Long Wave (LW) hypothesis of long-term techno-economic change. In this way we attempt to show that the MTC and the LW literatures are connected for they deal with linked phenomena.

Section 2 presents the theoretical and historical frameworks that provide the conceptual orientation to our empirical exploration. This section also provides introductory evidence that turbulence among the 200 largest US industrial corporations in the last decades of the twentieth century is related to the rise of ICTs as the core technology of a new techno-economic paradigm. Section 3 discusses both the potential and the perils of using the patent data as an indicator of technological capabilities. Section 4 presents the key empirical findings. Section 5 appreciates the patterns found in the light of the theoretical framework and suggests some areas for further research. Section 6 concludes.

2 Theoretical framework and reasoned historical background

The body of theorising about the organisation of business that we adopt is the Penrosian/evolutionary capabilities approach. The reasoned historical viewpoint that serves as a backdrop for the statistical analysis is the neo-Schumpeterian Long Wave theory as put forward by Freeman and Pérez (1988) and Freeman and Louçã (2001).

2.1 Business organisations and the nurture of technological knowledge

Much of the empirical contributions to the field of innovation studies has helped to rationalise, and has been stimulated by, evolutionary economics and related modes of theorising about the institutions of capitalism. The explanations of technical and corporate change usually call upon concepts of learning, path-dependence, organisational adaptation, selection mechanisms, etc. (Winter, 1987). A concrete spillover of the technological diversification literature has been a contribution to the debate around 'core competencies' in the management literature (Prahalad and Hamel, 1990). Evidence suggests that a small number of distinctive competencies are insufficient to coordinate continuous technical change within the organisation as well as throughout the company's supply chain and broader business environment. Large innovative companies need to master a range of competencies with varying degrees of commitment and relative advantage. Contemporary technological profiles among large industrial firms tend to nurture a mix of technologies including fields of excellence plus ‘background’, ‘niche’ and ‘marginal’ competencies (Granstrand *et al.*, 1997).

As Pavitt, Patel, Granstrand and colleagues have put forward in several contributions to the study of MTCs (for instance Granstrand and Sjölander, 1992; Patel and Pavitt, 1994b) the most striking feature of large innovating companies is the wide range of fields in which they command technical expertise. In a pioneering article, Granstrand and Sjölander (1990, p. 36) defined the MTC as a “corporation that operates in at least three different technologies”. This diversified knowledge base develops in interaction with external sources of knowledge, indeed, as Hagedoorn *et al.* (2000) showed, technological diversification is also associated with strategic alliance building. By combining patent and alliance indicators these authors found fresh evidence that companies develop internally a wider range of technologies when compared with external agreements.

This research on the MTC has helped to give empirical content to the competencies/capabilities perspectives of the firm, which put corporate learning, internal and external relationships and dynamic processes of change in centre stage. The capabilities view, in its various guises (Penrose, 1959, 1995; Prahalad and Hamel, 1990; Teece and Pisano, 1994), focuses on the firm-specific knowledge that allows an organisation to produce goods and services and improve on them. For the limited purposes of this research we will take Teece and Pisano’s (1994) definition of dynamic capabilities as the patterns of organisational and production methods (routines) and tacit knowledge “which allow the firm to create new products and processes, and respond to changing market circumstances” (1994, p. 541). This approach will provide a context to interpret the corporate patenting trends depicted in our study as shifts in knowledge bases over time.

2.2 Business history and technological evolution

As Landes (1991) emphasises, historians analyse changes in the mode of production that economists usually take for granted. With Landes, but also with Marx and Schumpeter, we believe that any attempt to understand technological innovation and its organisation must pay attention to change and the sequence of change.

Big business institutions were rare until the late nineteenth century. Since then the world has witnessed the rise (and fall) and continued change of many large corporations, especially in advanced economies like the US. But institutions do not enter metamorphoses alone, they co-evolve with technology (Nelson, 1999) and it could be argued that the MTC, which has emerged as a major stylised fact in the late twentieth century, can be seen as a new organisational subspecies of capitalism.

Following the early Schumpeterian insights about long-term industrial and technological change authors like Freeman and Pérez (1988) and Freeman and Louçã (2001) have used the concept of techno-economic paradigm to refer to the structural changes that new clusters of important technologies induce across the whole economy. The appearance and diffusion of innovations turns out to be a very uneven process and certain combinations of radical innovations may even give rise to phenomena described as technological revolutions. Even so, these authors argue that since the British Industrial Revolution there are major empirical regularities as well as techno-economic transformations. The long periods of consistent socio-economic development ignited by these factors are known as long waves. According to this view, at the moment of this writing, we are living through the tough times of transition that characterise the passage from a techno-economic paradigm to another.

In an important restatement and empirical assessment of the theory, Freeman and Louçã (2001) apply and develop the framework in relation to the third of the industrial revolutions, the Information Revolution. The key radical innovation behind its rise was the development of the electronic microprocessor. This key factor is called the 'Core Input', and its characteristics are a) falling relative prices, b) universal availability and c) a broad range of applications. The producers of core inputs are called 'Motive Branches' (e.g. the semiconductors industry). Those new industries producing or delivering the most emblematic applications of the new paradigm are 'Carrier Branches' (computers, software and telecommunications industries). The main 'Organisational Innovation' highlighted for this wave is the network. We shall adopt these categories in our analysis.

2.3 Big business and ICT in historical context

Large companies in all industries are hardly able to exploit all the new market opportunities emerging in and around their traditional business. A clear illustration of this has been the case of information processing machinery. It was IBM, NCR, Remington and Honeywell, producers of punch cards and adding machines, typewriters and heat regulators, and not the producers of electrical equipment (GE and RCA) that were able to diversify into computing technology. ICT producers, as we would call them today, are essentially newcomers in the Fortune's top list. An argument put forward by Louçã and Mendonça (2002) is that this is not merely an exception, but a pattern of evolution that challenges the established firms, leading to their adaptation or replacement by new firms.

Using cross-sections of the 200 largest US manufacturing firms for six dates covering about 100 years, this study points out that persistence among the giants of the twentieth century is very limited. Only 28 (5 per cent) of the total number of companies considered appear in the list for all the six years, whereas 267 (49 per cent) appear only once, with the 'persistent' giants being typically born in the 1880s. The average level of entrants throughout the century is substantial, around 70, or 35 per cent in 200, per data point. Transition, however, is not smooth rather it occurs by impulses and has increased in the last years of the past century, with the peaks of entry happening at the beginning and the end of our time period.

The specific industries driving the increase in turnover and shift in company rankings for the last years of the twentieth century have been the carrier branches of the new techno-economic paradigm. The performance of the Office Equipment industry (non-existent in 1917) in 1983 and 1997 is remarkable, both in terms of significant new entries, as can be seen in Table 8.1, and improved average ranking in terms of sales. This movement is accompanied by the relative decline of the large producers based on the mechanical and chemical processes that dominated the fourth Kondratiev wave characterised as an age of mass production, automobiles and oil (Freeman and Louçã, 2001).

These trends represent a pattern of structural change in our population since they indicate changes in the weight of the sectors of an economy. The increase in the relative importance of the ICT sector has been the responsibility of essentially 'newcomers', confirming the disturbing effect of the new ICT technological paradigm on established industrial patterns. However, more than being interested in transformations in the pattern of business activity in the population of large companies, we are also interested in qualitative change. If ICT is both a creative and destructive force in highly concentrated corporate structures, one might suspect that it has also influenced the range of capabilities companies must master to go about their business. What these patterns of internal change have been, and how ICTs and other new technologies have become profoundly embedded in the corporate knowledge base, is precisely the focus of the contribution.

Table 8.1 Industrial sectors with the largest number of entrants along the twentieth century

	1930	*1948*	*1963*	*1983*	*1997*
Food, Beverages and Tobacco	16	10	15	5	7
Chemicals, Pharmaceuticals and Cosmetics	10	11	9	11	7
Oil, Plastic and Rubber	14	7	4	12	5
Electrical and Electronic Equipment	1	3	11	6	7
Aerospace	2	4	10	1	–
Office Equipment	3	–	–	3	19
Total entrants in each data point	87	65	73	44	80

Source: Louçã and Mendonça, 2002.

3 Data, methodology and hypotheses

To capture the internal process of change within the corporation we will take patents as the prime source of information about in-house technological capabilities.[1]

3.1 Technical knowledge

Following Granstrand (1998) and many other authors, we will equate technology to a body of engineering knowledge. Even though capabilities are tacit, necessarily unobservable, and measuring them is therefore infeasible, Granstrand and Sjölander (1990, p. 36) suggested a number of proxies that could be used to measure the degree of technological diversification, such as disciplines and professions represented in the R&D personnel, patent statistics, expert panels etc. With these authors we are aware of the epistemological difficulties of measuring the hidden knowledge structure that underlies the performance and change in the (very) large firm. However, since the patent indicator constitutes a precious window (however narrow) into those deeper corporate characteristics, i.e., the potential to generate improved technical knowledge, it will be used here to screen the breadth and depth of technological competencies of companies across given patent classes.

3.2 The database

The analysis is based on the SPRU-OTAF database. This database reports accumulated patents assigned to their main classes for the years 1980–85, 1986–90 and 1991–96, patents for 463 of the world's largest companies[2] distributed according to 14 principal product groups. This data set represents a huge effort of consolidation of 4500 subsidiaries and divisions: different assignee names, kept or bought by the 463 firms up to 1992, were identified using the ownership profile of 1992 and attributed to their parent. The method of consolidation is described in detail in Patel (1999). Working with the SPRU database implies therefore working with its original characteristics as building blocs. In the analysis below, besides using the original classifications we also proceed to a further reorganisation given our specific research objectives.

Three reasons lie behind this reorganisation. The first is *synthesis*, simplification is important because patterns emerging from SPRU's original 34 individual classes times 14 sectors during three time periods are difficult to always bear in mind or even to visualise. Second, *new information* on unexpected patterns can be gained with a new aggregation of patent categories. Finally, the *reliability* of conclusions is substantially upgraded by allowing for sensitivity testing. The rearrangement of the technology classifications is shown in Table 8.2.[3]

Table 8.2 Technology families

Chemicals	*Fine Chem*	*Drugs and Biotech*	*Materials*	*Mechanical*	*Transport*	*ICT B*	*Other*
InOrChem	OrgCh	Drugs and bioengineering	Materials	NonElMach	VehiEngi	ICT N	Medical
AgrCh	ChePro			SpecMach	OtherTran	Telecoms	MiscMetProd
Hydroc				MetalWEq	Aircraft	Semicond	Metallu Pro
Bleach				AssHandApp		Computers	Nuclear
Plastic				Mining		ImageandSound	PowerP
ChemApp							FoodandT
						ICT+	TextWood etc
						Instruments	Other
						PhotogandC	
						ElectrDevi	
						ElEqup	

Source: Elaborations from the SPRU-OTAF database.

An important clarification here is the operational definition of ICT. The definition of ICT we employ sees ICT as a set of information processing, storage and transmission technologies that have been enabled by the advent of microprocessors in the early 1970s (Mansell and Steinmueller, 2000). With this definition in mind we incorporate four patent classes in our core ICT family: Telecommunications, Semiconductors, Computers and Image and Sound Equipment. This Narrow group of technologies we call ICT N. The sectors that specialise in this technology set are called ICT industries (or Motive/Carrier branches in the Freeman, Louçã and Pérez terminology): Computer and Electrical/Electronics sectors. Moreover, the ICT+ category was constructed to represent the family of technologies that has been strongly influenced by the advent of the microchip and incorporated a strong digital element. The ICT+ group includes Instruments and Controls, Photography and Photocopy, Electrical Devices and Systems and Generically Electrical Industrial Apparatus. Our two ICT categories can be joined in a new one, ICT B, which increases the potential for testing the sensitiveness of our conclusions using different operational definitions (more or less strict) of ICT.

3.3 The patent indicator

The limitations of patents as indicators of technological activity are well known and will not be discussed in detail here although we incorporate in our approach a great deal of care derived from lessons taken from many contributions (Pavitt, 1985; Narin and Olivastro, 1988; Griliches, 1990; Patel and Pavitt, 1995). Patents are an indicator not a measure. Patents are a codified institutional record of invention and, unfortunately, cannot be assumed to be in direct and constant correspondence to innovative efforts. There are, for instance, different inter-firm propensities to patent and differences in the patenting patterns across technologies and across industries. For the present, however, it will suffice to make reference in section 5 to a set of four recent studies that strengthen the legitimacy of using US patents to assess the technological evolution of big business institutions.

3.4 Research objectives

It is worth emphasising that this empirical engagement is mainly concerned with the ‘What’ (what is happening?) question and not with the ‘Why’ question. We have, therefore, an exploratory goal. Answering the ‘Why’ question would require a more in-depth, qualitative case-study type of analysis. Our data does not allow us to infer the main motivations behind specific patterns of technological diversification. Notwithstanding, we make an attempt to discuss main interpretations of the empirical findings in section 5. We believe the comparative advantage of this research lies above all in its original empirical results.

An aspiration of this chapter is to discuss a relatively implicit assumption in the most known and influential literative on technological diversification: the assumption being that technological diversification of industries is relatively uniformly spread across technological fields. We hypothesise, and explore the data accordingly, that if technologies are not equal in their opportunities for future development and potential for interrelation with existing technologies, certainly there could be technological fields or technological families attracting more diversification efforts than others. This we wish to confirm. Furthermore, ICT is certainly one of the most likely candidates to figure among the most "demanded patent fields", at least in recent times. This will be the fundamental hypothesis under review.

Our analysis is complementary in a broad sense to the research of Granstrand, Patel and Pavitt (1997) and others as it accepts the main MTC insights and because it will try to give an account of the relative attracting power of ICTs in the context of corporate technological diversification. Moreover, our focus can also be regarded as complementary to the analysis of Gambardella and Torrisi (1998) and von Tunzelmann (1999) who have concentrated on the degree of technological diversification within the ICT sectors themselves: our emphasis is the reverse, how have ICT technologies been developed outside ICT sectors?

It is also worth emphasising what we are not researching. First, organisational competencies such as strategic or marketing competencies cannot be assessed through this data set. Second, we will not try to establish country differences. Third, we also cannot assess intra-industry heterogeneity due to the way the data set is built. Fourth, we will not try to assess the role (facilitating or inhibiting) of ICT in the process of diversification itself.

4 The link between technological diversification and ICT: empirical findings

The goal of this section is to specify in more detail what sorts of technological knowledge companies are developing (diversifying into) as expressed by patent data. More specifically, we will carefully scrutinise the dynamics of the ICT capabilities of our corporation sample.

4.1 The explosive growth of ICTs, Drugs and Biotech and Materials technology

It is widely acknowledged in the innovation literature that the accelerated development and diffusion of ICT was a distinctive feature of the last quarter of the twentieth century. Table 8.3 shows that the growth of (narrowly defined) ICT was striking when compared to other technological fields. It is also interesting to detect that the other most dynamic

Table 8.3 Technology families' growth

	(1991–96/1980–85) (%)
ICT N	287.3
ICT B	230.5
Materials	201.4
Drugs and Biotech	191.6
All technologies	180.7
ICT+	174.7
Other	168.8
Transport	143.8
Fine Chemicals	142.6
Mechanical	140.2
Chemicals	121.2

Source: Elaborations on the SPRU-OTAF database.

technological groups are Materials and Drugs and Biotechnology. This comes as no surprise as numerous analysts and futurists have systematically anticipated these as key generic technologies in the last 30 years. It can be seen that the number of patents in ICT N in 1991–96 is about three times what it was in the period 1980–85. It also comes out that ICT N corresponds to almost one third of total patents in the early 1990s while its weight in the early 1980s was one fifth. It also can be noted that the broadly defined ICT group or ICT B has been rising to explain almost 50 per cent of all patents during the 1991–96 period.[4] This behaviour contrasts, for instance, with the unchanged flow of mechanical innovations as measured by absolute patent counts, a trend which has been emphasised by Patel and Pavitt (1994a), which has not been enough to sustain the relative fall in share of mechanical classes in total patents.

4.2 The extent of technological diversification across industries

The analysis shown bellow in Table 8.4 is based in Patel's (1999) correspondence between industries and their main bundles of technical fields (see *Appendix 2*). For instance, this classification puts ICT N technologies in the centre of Computer and Electrical/Electronics industries' competencies, it then becomes possible to assess the extent of technological diversity in each industry by the proportion of patents granted outside the industries' 'core technical fields' (CTF). The numbers in Table 8.4 were calculated by simply subtracting the patents obtained in the respective core technical fields and dividing the remainder by the industries' total. We can see that all sectors have at least 25 per cent of their patent portfolio in technological areas not directly related to their core business. For instance, Electrical/Electronics, Computer and the Pharmaceutical sectors are among the least diversi-

Table 8.4 Industries patenting outside 'core technical fields'

	1991–96 (%)
Aerospace	74.0
Materials	69.5
Metals	66.5
Photography and Photocopy	65.3
Motor Vehicles and parts	63.6
Machinery	62.0
Mining and Petroleum	58.3
Paper	57.7
Chemicals	47.0
Rubber and Plastics	45.1
Food, Drink and Tobacco	42.6
Electrical/Electronics	39.3
Pharmaceuticals	30.2
Computers	25.1
All industries	48.3

Source: Elaborations on the SPRU-OTAF database.

fied, which can be interpreted as indicating that the explosive patenting performance in the related technological areas has been primarily driven by the specialist sectors.

An alternative measure of technological diversification is to calculate the sum of the squares of the shares of all the classes for each industry, the Herfindhal index (H). A lower H indicates that companies or industries are spreading their patents across a broader set of fields or, in other words, it reveals that the agents command knowledge in more technologies. By calculating the H of the industries on the basis of the 34 patent classes we find that the Computer sector, as well as the Electrical/Electronics sector, appears again to be focusing on their core technological competencies over time.[5] Putting it another way, the ICT sectors, or the Motive/Branch branches in the Freeman–Louçã–Pérez terminology, have been diminishing substantially the weight of non-ICT technologies in their portfolios. This again suggests that the growth in the patents of the Computer industry has been driven by ICT N, i.e., the core technology of the sector, something one could expect from the theory. This pattern is also in line with the findings derived from the same database by Gambardella and Torrisi (1998) and Patel (1999) and also Hagedoorn *et al.* (2000) who used Techline data for a similar sample of large European, Japanese and American companies.

4.3 The 'attraction' of ICT and other generic technologies

We have just seen that ICT, Drugs and Biotech and Materials technology are a legitimate object of particular interest due to the evidence on a) their explosive growth and b) of a broadening industry base from which these technologies are being originated. Figure 8.1 shows the result of sorting the highest growth technological groups between 1980–85 and 1991–96 when companies from all sectors patent outside the traditional technical fields that traditionally characterised of their sectors. It emerges that generic technologies are the most diversified into (above average). The case of ICT N is particularly striking. This is the most 'demanded' technological group, being more than three times more diversified into during 1991–96 than 1980–85. This performance is resilient if compounded by ICT+. This can be interpreted as indicating that technical knowledge about ICT is getting widely dispersed across industrial sectors and that the ICT family behaves in a distinct fashion when compared to the rest of the technological families, including the other generic technologies.

When considering the problem of assessing trends in technological diversification or specialisation the *H* is usually applied to companies, industries and countries. In this sub-section we instead apply the index to technologies on the basis of the industries' contribution to them, that is, we calculate it the other way around. In this case, one is changing the angle of analysis and investigating the sectoral source structure of a technology (the extent to which different industries are contributing to total patenting in one technical field). A high index reflects concentration of technological activity: the fewer industries 'supplying' the patent class means that fewer industries are integrating that technical field in their knowledge portfolios in a substantive way.

In Table 8.5, several technological families seem to be diversifying the sources where new inventions and improvements are recruited from,

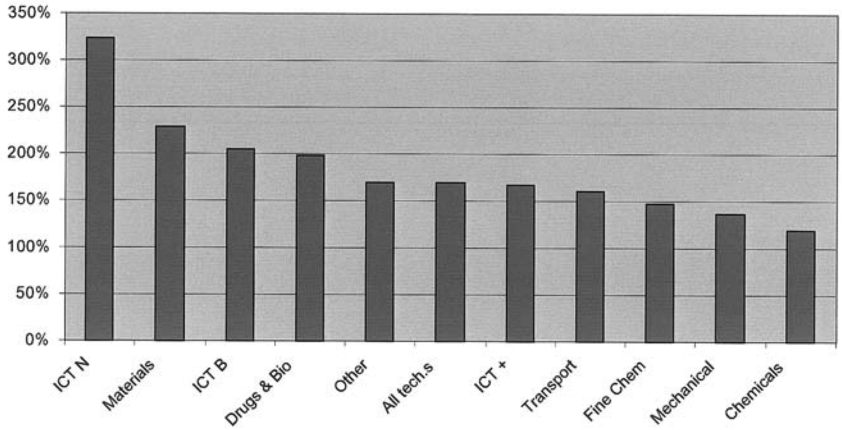


Figure 8.1 Patenting increase in technologies that have been diversified into (1991–96/1980–85).

Source: Elaborations on the SPRU-OTAF database.

Table 8.5 Herfindhal index: technology families in terms of industries

H	*1980–85*	*1991–96*	*Change*	
Chemicals	0.1861	0.1573	−0.0288	Div
Fine Chem	0.2494	0.2759	0.0264	
Pharm and Bio	0.4028	0.3885	−0.0144	Div
Materials	0.1366	0.1401	0.0035	
Mechanical	0.1300	0.1356	0.0055	
Transport	0.5156	0.4764	−0.0392	Div
ICT N	0.3672	0.3189	−0.0483	Div
ICT+	0.2053	0.1990	−0.0063	Div
ICT B	0.2691	0.2587	−0.0103	Div
Other	0.1041	0.1102	0.0061	
All technologies	0.1308	0.1383	0.0075	

Source: Elaborations on the SPRU-OTAF database.

especially the ICT N group. The ICT families appear to be recruiting patents from a broader set of industry contributions. Both ICT N and ICT+ appear to be recruiting patents from a broader set of industry contributions. It seems as though more industries are entering into ICTs in a serious way and enlisting important additions to the total amount of ICT patents generated.[6] This observation represents a very interesting difference between ICT (technologies) and the ICT sectors. These findings set the tone for a deeper inquiry, namely into the way in which this diversification is primarily orientated towards ICT. An interesting question now is what are the most ‘pro-ICT’ industries and what specific ICTs are attracting non-ICT specialists.

4.4 The ICT component of corporate technological portfolios

Table 8.6 shows that all (but one) industries (Paper) increased the weight of ICT N in their technological portfolios when comparing the periods 1980–85 and 1991–96. This result is very important and it is again substantially stronger for ICT N than it is for ICT+. Companies of all industries are consistently patenting into ICT and when they go the movement tends to be into ICT N, the most science-based of the ICT technologies. On average, if we take the row for all industries, it is as if each industry increased its patenting by 11 percentage points (18.8 per cent plus 11.1 per cent). Concerning the non-ICT sectors, it can be noted that the level of ICT N is important (above 10 per cent) for the Aerospace and Motor Vehicles and Parts sectors, Machinery, and very much so for the Photography and Photocopy industry. Furthermore, the Metals and Materials sectors both register a step-jump rise (above 5 percentage points) in the ICT N component of their technology portfolios, which is a substantial

Table 8.6 The ICT component of the corporate technology portfolio

	ICT N		*ICT+*		*ICT B*	
	1980–85 (%)	*1991–96 (%)*	*1980–85 (%)*	*1991–96 (%)*	*1980–85 (%)*	*1991–96 (%)*
Aerospace	12.7	13.3	20.0	19.5	32.6	32.8
Motor Vehicles and Parts	9.7	15.8	20.0	22.9	29.7	38.7
Machinery	7.0	12.9	18.0	18.2	25.0	31.1
Photograph and Photocopy	23.9	36.5	47.9	37.5	71.8	74.0
Electrical/ Electronics	41.7	53.3	29.2	23.6	70.9	77.0
Computers	59.1	70.2	22.1	17.9	81.2	88.1
Metals	2.2	7.4	13.3	13.8	15.5	21.2
Mining and Petroleum	2.5	2.6	7.6	7.0	10.1	9.7
Materials	1.7	7.1	11.1	9.4	12.9	16.5
Chemicals	1.2	2.2	7.7	6.6	8.9	8.9
Rubber and Plastics	2.3	2.8	5.2	5.9	7.5	8.7
Paper	4.2	2.9	9.0	7.7	13.2	10.7
Pharmaceuticals	0.5	0.6	2.6	2.0	3.1	2.6
Food. Drink and Tobacco	0.9	1.0	4.2	4.4	5.1	5.4
All industries	18.8	29.9	19.2	18.5	38.0	48.4

Source: Elaborations on the SPRU-OTAF database.

change especially taking into account their low initial shares. The above six sectors, which reveal a strong performance in ICTs, account for half of the non-ICT sectors.

ICT N was the group registering more net increases into its individual patent classes followed by Drugs and Biotech and Materials. Overall, the ICT family is the most pervasive in technology development, although this trend slowed down for 1991–96 in relation to Fine Chemicals and Drugs and Biotech, which have been strongly increasing their share of the corporate technological portfolio. In our database, the step-jump in the importance of ICT N patents for non-ICT sectors happened basically during the 1980s. Nonetheless, the stylised fact appears to be robust. ICT N was the technology family that increased more on the average portfolio during our time span.

We should also add two further comments in interpreting our results. Both these caveats point out that the ICT N trend across sectors is underestimated in our analysis. First, if we brake down ICT N for the Aerospace industry it emerges that Telecommunications and Semiconductors have been registering sharp rises (therefore the small rise of 0.08 per cent from

1980–85 to 1991–96 in Table 8.6 can be misleading). Second, if we could account for software activity the performance of the Pharmaceuticals sector in ICT N would probably be much stronger due to the innovative use of computer simulation technology in this sector (Nightingale, 2000), the same is true again for the Aerospace industry in the precise case of the digitalisation of the engine control systems (Prencipe, 2000).

4.5 Variety across industries when patenting outside the 'core technical fields' into ICT

Measuring the extent of technological diversity in each industry by the proportion of patents outside the industries' 'technological competencies' yields a list of the most 'preferred' technologies when companies patent outside their traditional technological competencies. The propensity to patent in ICT[7] when companies patent outside their CTF can be described as:

$$\text{Propensity to patent in ICT} = \frac{\text{Patents granted in ICT}}{\text{Total patents granted outside CTF}}$$

This approach shows that the ranking of technology families when they patent outside their core technological fields competencies is rather stable for the generality of the industries. However, if there was a change in this path dependent knowledge structure this has been driven by ICT. As we can see in Table 8.7, ICT N climbed up the ranking of corporate diversification in five of our industries, it remained in the same relative position for 6 and only fell down in 2 industries. This table provides ordinal information derived from computing the sectors' propensity to patent in ICT (data not shown). For the average company, ICT N climbed up from the sixth position it was occupying during 1980–85 to second in 1991–96. Changes in the propensity to patent in ICT N are striking. In the first period only 8.3 per cent of the patents were obtained in ICT N when companies patented outside their core technological competencies, as for the later period that figure was 15.8 per cent. The propensity to patent in ICT N doubled (on average), making it the second 'most demanded' technology only behind ICT+.

This indicator also makes the Motor Vehicles and Parts, Photography and Photocopy, Machinery and Aerospace sectors stand out as those with the highest propensity to engage in ICTs when patenting outside their CTF. Also with this indicator, the secondary importance of ICT N for Chemical and associated sectors (Pharmaceuticals, Mining and Petroleum, Paper, Rubber and Plastics, Food, Drink and Tobacco) becomes apparent.

Table 8.7 Ranking of ICT N share in the technological portfolios of the industries

Industry	*Ranking of ICT patent share in technological portfolios in 1991–96 (change from 1980–85 to 1991–96)*
Photography and Photocopy	First (no change in relative position)
Motor Vehicles and parts	Second (fourth in 1980–85)
Aerospace	Second (no change)
Average of all industries	Second (sixth in 1980–85)
Machinery	Third (no change)
Materials	Fourth (fifth in 1980–85)
Metals	Fifth (sixth in 1980–85)
Paper	Sixth (no change)
Food, Drink and Tobacco	Sixth (seventh in 1980–85)
Rubber and Plastics	Seventh (no change)
Chemicals	Seventh (sixth in 1980–85)
Mining and Petroleum	Seventh (sixth in 1980–85)
Pharmaceuticals	Seventh (no change)

Source: Elaborations on the SPRU-OTAF database.

4.6 Industries' contributions to ICT N patenting

This sub-section is devoted to assess the contribution of the different industries to total patenting in ICT N. Table 8.8 shows the percentage of ICT patents in 1980–85 and 1991–96 that are explained by ICT sectors, i.e., the Computers and Electrical and Electronics sectors. The figures indicate that the ICT sectors have by no means a monopoly on ICT patenting and that their share has indeed decreased from 1980 to 1996. In contrast, Pharmaceuticals and Bioengineering-related sectors explain 90.9 per cent of all the patents in the Drugs and Bioengineering field while the Materials-related sectors explain 20 per cent of patents in material technology. Our previous sections showed the existence of an increase in the share of the ICT N component in almost all the non-ICT industries. It can now be seen that this trend is behind a small increase in the share of their contribution to overall ICT N patenting, even in the face of the very fast and accelerating rate of growth of patenting by the Computers and Electrical/Electronics sectors.

This result is in line with the Hicks *et al.* (2001) study on the composition of patenting activity in the US. In this study 'information technology' companies are found to be responsible for the production of three-quarters of the 'IT' patents (broadly correspondent to our ICT N category) between 1993 and 1998. However, if our methodology is correct, the increase in ICT N patents, or 'IT' in the Hicks *et al.* (2001) terminology, is coming from a broader range of sectors than their findings suggest. Hicks *et al.* (2001, p. 686) found the 'IT' sector to be responsible for 98 per cent

Table 8.8 Percentage of ICT patents accounted by the ICT sectors

	ICT N	*ICT+*	*ICT B*
ICT sectors in 1980–85	77.3	46.1	61.6
ICT sectors in 1986–90	73.9	46.4	61.7
ICT sectors in 1991–96	74.5	44.9	63.2

Source: Elaborations on the SPRU-OTAF database.

of the growth in 'IT' patents while our figures point to a considerably lower degree of concentration even though that share increased in the later period of 1991–96. The Computer and Electrical/Electronics sectors (our 'IT sector') were on the whole responsible for just 73 per cent of the increase in ICT N patents. It is important therefore to check the sensitivity of these results by evaluating the effect of including the Photography and Photocopy sector in the class of ICT industries. In this case the percentage of ICT N patents generated by ICT sectors averages at 89 per cent for 1991–96 with an increasing trend as well. Either way, the divergence with Hicks *et al.* (2001) remains. Table 8.9 displays the contribution of ICT sectors versus non-ICT sectors to the increase in patenting defined as the difference between the numbers of patents in the three periods.

The non-ICT sectors contribution to ICT N (patent counts and percentage) is depicted in Table 8.10 for our 12 non-ICT industries. As can be seen in column (a), this is a highly skewed distribution, those that contribute substantially to ICT N contribute a lot: the four largest contributing sectors are equivalent to 80 per cent of the patents. Photograph and Photocopy explains more than 50 per cent of the total of ICT N that are generated by non-ICT sectors in 1991–96 while the next two contributing sectors – Motor Vehicles, and Parts and Machinery – put in a further 31 percent. A number of other interesting patterns can also be detected with the help of Table 8.9. First, column (b) shows that several industries have recently registered a huge increment in the absolute number of patents in

Table 8.9 Sectoral contributions to the increase in ICT N patents

	Growth between 1980–85 and 1986–90 (%)	*Growth between 1986–90 and 1991–96 (%)*	*Total Growth in the period 1980–96 (%)*
ICT sectors	68.9	75.4	73.0
Non-ICT sectors	31.1	24.6	27.0
ICT sectors including the Photography and Photocopy sector	85.8	90.9	89.0

Source: Elaborated from SPRU-OTAF database.

Table 8.10 Non-ICT contributors to ICT N

	1980–85	*1991–96*	*a (%)*	*b (%)*	*c (%)*
Aerospace	761	1,144	5.5	50	14.5
Chemicals	325	899	4.3	177	4.0
Food, Drink and Tobacco	18	37	0.2	106	1.1
Machinery	684	2,344	11.2	243	19.7
Materials	57	212	1.0	272	75.6
Metals	106	526	2.5	396	19.6
Mining and Petroleum	309	352	1.7	14	2.8
Motor Vehicles and Parts	1,545	4,129	19.7	167	25.1
Paper	65	65	0.3	0	0.0
Pharmaceuticals	49	85	0.4	73	0.61
Photography and Photocopy	2,537	11,117	53.0	338	43.2
Rubber and Plastics	35	58	0.3	66	4.2
Total	6,491	20,968	100.0	223	43.7

Source: Elaborations on the SPRU-OTAF database.

Notes

a Contribution of each industry to the total increase of ICT N patents in 1991–96.

b Net growth in patent counts from 1980–85 to 1991–96.

c ICT N as percentage of total increase in patenting of each industry between the periods.

ICT N: Metals (396 per cent), Photography and Photocopy (338 per cent), Materials (272 per cent), Machinery (243 per cent). Second, statistics in column (c) tell us that almost half (43.7 per cent – the total row) of the increase in total patenting in our database between 1980–85 and 1991–96 was the responsibility of a growth in patenting in ICT N (the whole of classes in ICT B explain 61.4 per cent of total patent growth). It is also worth noting that ICT N represented almost 76 per cent of the increase in the number of patents obtained by the Materials sector, 43 per cent for Photography and Photocopy, 25 per cent for Motor Vehicles and Parts, and 20 per cent for Machinery and Metals sectors.

Third, although strong trends are detectable some caveats should be kept in mind: a) the increase of ICT contribution of non-ICT sectors is less strong in the later period; b) patenting has been consistently higher in Computers and Image and Sound Equipment classes; c) finally, the Computer industry continues to increase its patenting share in total of ICT N patents generated by the ICT sectors at the expense of the Electrical and Electronics sector.

5 The ICT–MTC link: a tentative discussion of the findings

The first words of comment must acknowledge the possibility that our results can simply be explained by artificial shifts in the indicator that could bias it towards ICT. Next we discuss the usefulness of the conceptual frameworks employed and present challenges for further research.

5.1 Appraisal of the empirical analysis: the propensity to patent in ICT

Recent studies on the patenting practices of business firms by Cohen *et al.* (2000), Hicks *et al.* (2001) and Jaffe (2000) argue that there is no solid evidence implying that the observed shift in patenting shares towards ICT is due to confounding variation in the indicators. First, 80 per cent of all patents were granted to business firms in the last quarter of the twentieth century, out of these about half were granted to the world's largest innovative firms (Patel and Pavitt, 1995; Pavitt, 1998). Second, a survey questionnaire administered to 1,478 R&D labs in the US manufacturing sector suggests that patents have become a more central protection mechanism and that statistics can be relied upon somewhat more for the large firms than in the early 1980s (Cohen *et al.*, 2000). Third, Jaffe (2000) in a recent paper was not able to establish that the intellectual property reinforcement by US courts since the early 1980s has given rise to any significant distortions in the propensity to patent across different technologies. Fourth, Hicks *et al.* (2001), find that the propensity to patent (patents per million dollar expenditure) in ICT has doubled in the last twenty years but with no correspondent decrease in the quality of patents as measured by patent citations, indeed a slight increase is reported. In summary, the combination of these results reveals that the rise of a pro-patent institutional environment in the US might have increased the patenting rates in most technologies but in a step-wise fashion. In the specific case of ICTs, which have grown exponentially with no quality deterioration, the possibility that the patent indicator lost reliability due to patent policy changes or patent-portfolio races is not supported.

Our empirical results were made robust in three ways:

a they were tested against reclassifications of the data and qualifications were offered when variance was detected;
b we also attempted various approaches and techniques in order to filter robust empirical regularities, those that do not change with different ways of measuring different aspects of the same phenomena;
c whenever possible the findings were compared with similar studies using SPRU-OTAF and other databases.

We thus believe that the movement towards technological diversification is not evenly distributed across neighbouring technological fields as some studies would imply, and the shift of patenting shares towards ICT is not due to spurious turbulence in the indicators.

5.2 Appraisal of the theory: the development of dynamic capabilities in ICT

In our sample the cluster of ICT-related technologies is, simultaneously, a) the technology group growing the most in terms of number of patents granted and b) the area where companies are developing capabilities faster on average. If our appreciation of these trends is correct, the following qualification should therefore be kept in mind when thinking about MTCs: diversification is directed more to some technologies than to others. The increasing dispersion of ICT capabilities (their pervasiveness in development) should not be underestimated. ICTs are key for an increasing number multi-technology companies.

The patterns derived for the particular case of the ICT-related industries are in accordance with results of Gambardella and Torrisi (1998) and von Tunzelmann (1999), who using SPRU-OTAF data found evidence of increasing technological convergence within the ICT sectors coupled with a low level of extra-ICT diversification. These patterns of 'internal cross-fertilisation' and 'deepening' can be understood as indicative of the long-term technological (and competitive) potential of ICT capabilities.

From another perspective Hagedoorn *et al.* (2000), using patent and alliance indicators from Techline and SDI databases, help to confirm the results we wish to emphasise in our study, that cutting-edge ICT capabilities are not restricted to of ICT sectors. The comparison between patent and alliance data done by these authors provides interesting complementary information:

a the Mechanical sector concentrates its technological alliances in Semiconductors and Computers;
b the Automotive sector concentrates its technological alliances in Computers and Telecommunications;
c for the Aerospace industry the second most important kind of alliance involves Computer technology,
d for the Chemical sector Computer technology is the third most important type of alliance;
e the second most important technology alliance developed by the Pharmaceutical sector concerns Medical Equipment and Medical Electronics.

Their key finding, in what concerns this chapter, is that the external acquisition of ICT capabilities was a top priority for many non-ICT industries during the 1990s:

> It is interesting that in non-IT sectors – such as automotive, aerospace, machinery and chemical sectors – computer technologies, including software, appear in the top three positions of receiving technological alliances ... Companies that do not have internal competencies to master such technologies seem to use external strategies to acquire or jointly develop them.
>
> (Hagedoorn *et al.*, 2000, p. 20)

Recent results brought forward by Cantwell and Noonan (2001) on technological relatedness measured by the degree to which different technologies are co-patented by the same industrial sectors, also suggests that ICTs may be regarded as increasingly pervasive. This paper contributes evidence that ICT appears increasingly associated with other technological groups, namely chemicals and transports. The upsurge in the technological relatedness of electronic technologies is felt in the period 1969–95 and is driven by telecommunications, special radio systems, semiconductors, image and sound equipment and office/data processing systems.

Our work exhibits, however, a discrepancy in relation to Hicks *et al.* (2001) who used the Techline patent database of the CHI consultancy company. We find that large non-ICT companies have been responsible for 15 per cent to 25 per cent of the ICT patents generated in the early 1990s and not just 2 per cent as claimed in that paper. In trying to account for such a disparity we should first point out the differences between the samples, in fact their analysis is based on patent counts for about 560 US Companies for the years 1989–98. Second, we alert to differences stemming from possible disharmonies between the data classifications, which are not infrequent in patent analysis.[8] Although these factors probably explain for a part of the divergence between the two studies there certainly remains an uncounted residual.

5.3 Appraisal of the historical framework: changing capabilities and the new techno-economic paradigm

The neo-Schumpeterian LW framework served well in guiding the analysis through the complex web of changes taking place in contemporary historical time. A by-product of our empirical study is that it can be considered a partial test of the theory, the results are positive in this regard. Our interpretation is that the evidence on the (widening) pervasiveness of ICT capabilities can be used to support the neo-Schumpeterian LW hypothesis that a period of *structural change* is triggered by a new key productive factor (the 'Core Input') and the new set of technological combinations associated with it.

Large companies of all sectors are dynamically expanding their ICT capabilities, the engine of growth in the last quarter of the twentieth century. The impact of ICT on large companies in many sectors suggests a link between multi-technology trends and the rise a new technological paradigm. The work of Helpman and his colleagues (1998) illuminates this link by suggesting that ICT is a typical general-purpose technology by evidencing strong complementarities with other technologies. Furthermore, our findings are in line with a study by Fai and von Tunzelmann (2000) on the historical evolution of technological scale and scope. The long-term patent analysis in that paper, using Reading University's database, points to a preponderance of a diversification strategy in technological capabilities, or scope over scale, in the last quarter of the twentieth century. Their hypothesis is that:

> in the guise of emerging technological paradigms, firms may extend their patenting into these fields and relatively diminish that in their old areas of strength. In such cases, the technological scope of a firm may increase without any necessary change of in technological scale. On the other hand, if the technological opportunities of a rising paradigm were exploited in extreme, it might appear that technological concentration occurs, again with uncertain impacts on technological scale.
>
> (Fai and von Tunzelmann, 2000, p. 8)

Our research confirms that the 'Core Input' behaves as expected by the LW theory: Semiconductors is the single fastest moving patent class (an explosive growth technology by all accounts) and is basically produced by the specialist sectors (the Electrical/Electronics and Computer industries explain above 80 per cent of the Semiconductors patents throughout the three time periods). The 'Motive/Carrier Branches' of the emerging paradigm also exhibit a growth pattern that is consistent with the theory: the ICT sectors, i.e., the computer industry (in particular) and the Electrical/Electronics industry, are among the fastest growing sectors in terms of patents produced. The last element of the LW we can pronounce about is 'Organisational Change'. With the help of other pertinent work, notably Hagedoorn *et al.* (2000), we are able to draw attention to the association between the rise of the ICT in technological diversification and the phenomena of networks for ICT development, which again confirms the reasoned historical account of Freeman and Louçã (2001).

Therefore, the pervasive, although uneven, development of ICT knowledge among large companies has implications for economic growth debates. For instance, a paper by Harberger (1998) presents a distinction between two types of growth: 'mushrooms' versus 'yeast'. In the latter case growth starts from one point and spreads uniformly. Mushrooms instead grow randomly, and not in a uniform way. Harberger argues that modern US productivity growth is driven largely by the internal growth of some sectors in a given period whereas in other periods other industries assume that role implying the 'mushrooms' hypothesis. Our findings suggest a need for extra caution in growth accounting exercises when technologies such as ICT are involved. ICT capabilities are not only developed by the specialist sectors and their diffusion is highly structured. What we pick up from studying our specific period in the evolution of corporate capabilities is that the impact of ICT on aggregate trends is likely to be qualitatively complex. In this sense our findings point to forces pervasive enough to have far-reaching effects in the population of the world's largest manufacturing firms, a 'general-purpose' feature that David and Wright (1999) would interpret as further evidence that the 1990s were a decade of 'yeast-like' productivity growth. Moreover, the economy-wide adjustments required for exploiting ICT are bound to take their time, which only an historical perspective can fully appreciate (Pavitt and Steinmueller, 2001).

5.4 Unsolved questions and new hypotheses: incomplete corporate coherence and the relational role of R&D

This research is insufficient to allow us to make a strong statement about the microeconomic and technological reasons behind the depicted trends. The database would have to be much larger and more detailed to allow us to know what exactly those ICT patents are and what they mean for those non-ICT specialist firms that obtain them. For instance, the database could be expanded to encompass the multiple technological fields in which each patent is classified, other information could show citations of ICT patents granted to ICT and non-ICT firms, patents in which software technology was incorporated, etc. However, case studies cannot be easily replaced as a source of empirical knowledge. Indeed, it would also be valuable to investigate if and how business organisations from non-specialist sectors have contributed to other general-purpose technologies identified by economic historians. For the remainder of this chapter we wish only to present two hypotheses that could be researched using these and other approaches.

First, an interesting question is the extent to which R&D is increasingly being used as an instrument of external coordination. R&D can be seen as a strategic asset that companies use with the intention to strategically manage technological and productive relations with other players of the national (and international) system of innovation and web of relations in which the firm is embedded. This source of advantage can be used to manage relations with innovative suppliers (but also with), rivals, buyers, potential entrants, producers of substitute products, universities, government laboratories, regulators, etc. Knowledge is power, and big business institutions might be found to use it to obtain more knowledge and sustain themselves as central knots in a network of technological and economic relations. We might suggest that there is room for future interesting research on the 'third face of R&D' in connection with the view of ICT as the most strategic technology for corporate development in the late twentieth century.

Following this speculation, alliances and other loose-coupling governance mechanisms should be at centre-stage of multi-technology analysis in the future. Another interesting question is the extent to which ICT as functioned as a catalyst of diversification by facilitating the processes of social interaction and sustained networking or market exchanges among different specialists. These ideas are compatible with the findings from a variety of sources:

a Cohen, Nelson and Walsh (2000) on the new rationales for patenting;
b the discussion of modularity in product innovation (Brusoni *et al.*, 2001);
c the signalling incentives behind the publishing of scientific papers by companies as pointed out by Hicks (1995);
d the increasing role of Intellectual Property Management (Granstrand, 1999);
e the rise of the importance of markets for technology (Arora *et al.*, 2001).

Potential managerial and public policy implications could be explored. For instance, the necessities of networking imply an increased need for social skills among engineers and other employees. This might be achieved through the integration of social sciences in higher courses of natural sciences and engineering.

A second proposal for future research considers enlarging the notion of the multi-technology corporation. A large company active in *natural science-based technologies* might sooner or later need to develop *social science-based technologies* carried out by 'social R&D units' in order to improve managerial competence in uncertain socio-economic environments. Dosi, Teece and Winter (1992) addressing the issue of corporate coherence from the product side, argue that companies, as a rule, "diversify into 'related product lines', and that this 'coherence' is relatively stable over time" (1992, pp. 185). They present as a first page example the case of Royal Dutch/Shell that, having spent the twentieth century in the oil business, "diversified into petrochemicals and little else". (1992, p. 185) The authors fail to note that Shell tried to diversify into other energy businesses, like nuclear power, with dismal success. But why were conglomerates (product line incoherence) unsuccessful and multi-technology companies apparently very successful? A famous, yet still secret, report of Shell Group Planning staff dating from the early 1980s, when the company was facing serious trouble, gives interesting clues. The Shell report, entitled *Corporate change: A look at how long-established companies change*, argued that the most long-lived companies in the world (Sumitomo, Du Pont, Procter & Gamble, etc.) have been historically "tolerant of activities at the margin: outliers, experiments, and eccentricities within the boundaries of the cohesive firm, which kept stretching their understanding of possibilities" (de Geus, 1997, p. 14).

Long-term corporate survival implies regeneration and this means keeping technological options open because they are costly to develop and the evolution business environment is uncertain. In this sense, a certain degree of tolerance for impurity in technological activity may be a formula to prevent competencies becoming rigidities. As Hodgson (1999, p. 126) states in his description of the so-called impurity principle, every socio-economic system relies on at least one 'structurally dissimilar subsystem' in order to function. Incomplete coherence or impurity in technological activity could be, in this sense, a necessary condition to facilitate corporate learning and change. This is, indeed, the role that Shell, DaimlerChrysler and other large companies have assigned to their strategy departments, which act as internal consultancies in technology foresight and business environment monitoring.[9]

6 Conclusions

A key idea suggested by the empirical work leading to this chapter is that the movement towards technological diversification is clearly not evenly distributed across technological fields. ICT, Drugs and Biotech and Materials technology are the highest growth technology families and simultaneously those in which companies are increasingly patenting when they patent outside their core technical fields. However, technological diversification is distinctively strong in relation to ICT, for other technologies patterns are less clear.

Looking at the relation between the multi-technology trend and the new information and communication technologies by using patent data we found that dynamic capabilities in ICT are more widespread than previously emphasised in the literature. While the ICT industries (Computers and Electrical/Electronics companies) have focused in their technology scope there is evidence that core ICT technologies have been progressively diversified the sectoral base from which new patents have been harvested. It emerges that ICT capabilities, the engine of growth in the last quarter of the twentieth century, are pervasive for an increasing number of large corporations. Moreover, the speed of diversification into ICT has been considerably fast given the relatively short time span of our data. This implies that there is compelling evidence to believe that there has been a significant 'bias' or leaning towards ICT in corporate technological diversification during the last two decades of the twentieth century. As could be expected, there is considerable inter-industry variance in the level and pace of increase in ICT patenting as well as differentiated trends among specific ICTs (Semiconductors, Computers, Telecommunications, Image and Sound). Considering the evolving link between ICT patenting and technological diversification our empirical information shows that:

a ICT is important, and increasingly so, for the Photography and Photocopy, Motor Vehicles and Parts, Aerospace, Machinery industries;
b ICT is not so important, but rising fast in importance, for Metals and Materials;
c ICT is apparently not so important for Chemicals and related sectors (Pharmaceuticals, Food, Drink and Tobacco, Paper, Mining and Petroleum, Rubber and Plastics).

It is a contention of this chapter that the increasing component of ICTs in corporate technological diversification can be related to the neo-Schumpeterian Long Wave hypothesis as conceptualised by Freeman, Louçã and Pérez. Our findings are consistent with its main propositions and show the usefulness of the operational categories of that theory. In this way we also attempt to show that the MTC and the LW literatures are linked for they deal with related phenomena. An aim of this contribution has been to argue that the expansion of the ICT component in the corporate knowledge base may be a specific feature of an ongoing process of structural change. We hope that this investigation manages at least to unveil some new mysteries, and areas for future research.

Appendices

Appendix 1 The SPRU-OTAF patent classes

1 Inorganic chemicals
2 Organic chemicals
3 Agricultural chemicals
4 Chemical processes
5 Hydrocarbons, mineral oils, fuels and igniting devices
6 Bleaching, dyeing and disinfecting
7 Drugs and bioengineering
8 Plastic and rubber products
9 Materials (including glass and ceramics)
10 Food and tobacco (processes and products)
11 Metallurgical and metal treatment processes
12 Apparatus for chemicals, food, glass, etc.
13 General non-electrical industrial equipment
14 General electrical industrial apparatus
15 Non-electrical specialised industrial equipment
16 Metallurgical and metal working equipment
17 Assembling and material handling apparatus
18 Induced nuclear reactions: systems and elements
19 Power plants
20 Road vehicles and engines
21 Other transport equipment (excluding aircraft)
22 Aircraft
23 Mining and wells machinery and processes
24 Telecommunications
25 Semiconductors
26 Electrical devices and systems
27 Calculators, computers and other office equipment
28 Image and sound equipment
29 Photography and photocopy

30 Instruments and controls
31 Miscellaneous metal products
32 Textile, clothing, leather, wood products
33 Dentistry and surgery
34 Other – (ammunitions and weapons, etc.)

Appendix 2 Correspondence between industry and 'core technical fields'

Industry (i.e., principal product group)	*'Core Technical Field'*
Aerospace	Aircraft; General Non-electrical Industrial Equipment; Power Plants
Chemicals	Organic Chemicals; Agricultural Chemicals; Drugs and Bioengineering
Electrical/Electronics	Telecommunications; Semiconductors; Electrical Devices; Computers; Image and Sound Equipment
Food, Drink and Tobacco	Food and Tobacco; Chemical Processes; Drugs and Bioengineering
Machinery	General Non-electrical Industrial Equipment; Metallurgical and Metal Working Equipment; Chemical Apparatus; Vehicles Engineering; Mining Machinery; Specialised Machinery
Materials	Materials
Metals	Metallurgical and Metal Treatment Processes; Materials; Metallurgical and Metal Working Equipment
Mining and Petroleum	Organic Chemicals; Inorganic Chemicals; Mining Machinery
Motor Vehicles and Parts	Vehicles Engineering; General Non-electrical Industrial Equipment; Other transport equipment
Paper	Materials; Specialised Machinery
Pharmaceuticals	Organic Chemicals; Drugs and Bioengineering
Photography and Photocopy	Photography and Photocopy; Instruments and Controls
Rubber and Plastics	Plastics and Rubber Products; Materials

Source: Adapted from Patel, 1999.

Notes

* Helpful comments and suggestions by Alfonso Gambardella, Pari Patel, Ed Steinmueller and Nick von Tunzelmann on earlier versions of this chapter are gratefully acknowledged. Keith Pavitt's influence is much greater than can be depicted from the reference list. He was a sounding board against which many of the ideas were initially tested. Without his support and his willingness to be challenged this chapter would not have been written. I am also grateful to Paul Wright whose rigorous scrutiny constituted a key contribution in the revision of the final version of this chapter. The use of SPRU's, University of Sussex, database is gratefully acknowledged. This research benefited from a scholarship for advanced studies by CISEP-ISEG, Technical University of Lisbon. The usual disclaimer applies.

1 We do not assume, for instance, patents to be a proxy of inventions stemming from R&D resources, thus implying the notion of 'knowledge production function' akin to the much abused 'linear model of innovation'. This view would face theoretical and empirical problems that can be avoided here (see Pavitt, 1985)

2 More specifically, the population is made up of the largest companies according to sales as reported in the Disclosure Global WorldScope database, excluding those based outside the Triad, e.g., Australia, Latin America, South Africa and South Korea.

3 We will refer to technological classes or individual patent classes to distinguish from technological families or groups in the forthcoming analysis. Appendix 1 shows the complete names of the 34 individual classes.

4 The patent study by Hicks *et al.* (2001) establishes that information and health technologies had grown by more than 400 per cent between 1980 and 1999, with information technologies (computers, telecommunications, semiconductors,. . .) accounting for 25 per cent of total US patents by the later date.

5 The calculations of H for the industries on the basis of individual patent classes and technology groups are not shown for reasons of economy of space.

6 It should be noted here that the only non-diversifying ICT N class is Computer technology, something that should be interpreted as stability of the sectorial source structure of this class (the Electrical/Electronics and Computer industries explain 77 per cent of all Computer patents throughout the three periods).

7 Two notes: 1) this concept is an extension of the propensity to patent concept; and 2) naturally it makes no sense when applied to ICT sectors.

8 That is why we also controlled for the inclusion of the Photography and Photocopy sector in our ICT sectors as part of our sensitivity analysis.

9 For an account of the cases of Shell and DaimlerChrysler and for an exploration of the connection between social sciences and organisational competencies see Mendonça (2001a, 2001b).

References

Arora, A., A. Fosfuri and A. Gambardella (2001), 'Markets for technology and their implications for corporate strategy', *Industrial and Corporate Change*, vol. 10, no. 2, pp. 419–451.

Brusoni, S., A. Prencipe, and K.L.R. Pavitt (2001), 'Knowledge specialization, organization coupling, and the boundaries of the firm: Why do firms know more than they make out?', *Administrative Science Quarterly*, vol. 46, no. 4, pp. 597–621.

Cantwell, J. and C. Noonan (2001), 'Technological relatedness and corporate diversification: 1890–1995", paper presented at Druid's Nelson and Winter Conference, 12–15 July 2001, Aalborg, Denmark.

Chandler Jr, A.D. (1990), *Scale and Scope – The Dynamics of Industrial Capitalism*, Belknap, Harvard University Press.

Cohen, W., R. Nelson and J. Walsh (2000), 'Protecting their intellectual assets: appropiability conditions and why U.S. manufacturing firms patent (or not)', NBER Working Paper Series 7552.

David, P. and G. Wright (1999), 'General purpose technologies and surges in productivity: historical reflections on the future of the ICT revolution', mimeo, paper presented to the international symposium on *Economic Challenges of the 21st Century in Historical Perspective*, Oxford, England, 2–4 July.

de Geus, A. (1997), *The Living Company: Habits for Survival in a Turbulent Business Environment*, Boston, MA: Harvard Business School Press.

Dosi, G., D. Teece and S. Winter (1992), 'Toward a theory of corporate coherence: preliminary remarks', in Dosi, G., R. Gianneti and P.A. Toninelli (eds), *Technology and Enterprise in Historical Perspective*, Oxford: Clarendon Press.

Fai, F. and N. von Tunzelmann (2000), 'Scale and scope in technology: Large firms 1930/1990', mimeo.

Freeman, C. and F. Louçã (2001), *As Time Goes By: The Information Revolution and the Industrial Revolution in Historical Perspective*, Oxford: Oxford University Press.

Freeman, C. and C. Pérez (1988), 'Structural crises of adjustment: business cycles and investment behaviour', in Dosi, G., C. Freeman, R. Nelson, G. Silverberg and L. Soete (eds), *Technical Change and Economic Theory*, London, Pinter, pp. 38–66.

Gambardella, A. and S. Torrisi (1998), 'Does technological convergence imply convergence in markets?: evidence from the electronics industry', *Research Policy*, vol. 27, pp. 445–464.

Granstrand, O. (1998), 'Towards a theory of the technology-based firm', *Research Policy*, vol. 27, pp. 465–489.

Granstrand, O. (1999), *The Economics and Management of Intellectual Property – Towards Intellectual Property*, Edward Elgar: Cheltenham, Northampton,.

Granstrand, O. and S. Sjölander (1990), 'Managing innovation in multi-technology corporations', *Research Policy*, vol. 19, pp. 35–60.

Granstrand, O. and S. Sjölander (1992), 'Internationalisation and diversification of multi-technology corporations', in Grandstrand, O., L. Håkanson and S. Sjölander (eds), *Technology Management and International Business: Internationalisation of R&D and Technology*, Chichester: John Willey and Sons.

Granstrand, O., P. Patel and K. Pavitt (1997), 'Multi-technology corporations: why they have "distributed" rather "distinctive core" competencies', *California Management Review*, vol. 39, pp. 8–25.

Griliches, Z. (1990), 'Patent statistics as economic indicators: a survey', *Journal of Economic Literature*, vol. 27, pp. 1661–1707.

Hagedoorn, J., P. Giuri, and M. Mariani (2000), 'On technological diversification and strategic alliances', mimeo.

Harbeger, A.B. (1998), 'A vision of the growth process', *American Economic Review*, vol. 88, no. 1, pp. 1–32.

Helpman, E. (ed.) (1998), *General Purpose Technologies and Economic Growth*, Cambridge, MA: MIT Press.

Hicks, D. (1995), 'Published papers, tacit competencies and corporate management of the public/private character of knowledge', *Industrial and Corporate Change*, vol. 4, no. 2, pp. 401–424.

Hicks, D., T. Breitzman, D. Olivastro and K. Hamilton (2001), 'The changing composition of innovative activity in the US – A portrait based on patent analysis', *Research Policy*, vol. 30, pp. 681–703.

Hodgson, G. (1999), *Economics and Utopia: Why the Learning Economy is Not the End of History*, London and New York: Routledge.

Jaffe, A.B. (2000), 'The U.S. patent system in transition: policy innovation and the innovation process', *Research Policy*, vol. 29, nos 4–5, pp. 531–557.

Landes, D.S. (1991), 'Introduction: On technology and growth', in P. Higonnet, D.S. Landes and H. Rosovsky (eds), *Favorites of Fortune: Technology, Growth, and Economic Development Since the Industrial Revolution*, Harvard University Press: Cambridge, MA, pp. 1–32.

Louçã, F. and S. Mendonça (2002), 'Steady change: the 200 largest US manufacturing firms throughout the twentieth century', *Industrial and Corporate Change*, vol. 11 no. 4, pp. 817–845.

Mansell, R. and W.E. Steinmueller (2000), *Mobilizing the Information Society: Strategies for Growth and Opportunity*, Oxford and New York: Oxford University Press.

Mendonça, S. (2001a), 'Scenarios as a social science-based technology: Evidence from Royal Dutch/Shell', in Stevenson, T., E. Massini, A. Rubin and M. Lehmann-Chadha (eds), *The Quest for the Futures: A Methodology Seminar in Futures Studies*, Selections from the methodology seminar in futures studies, Turku, Finland, pp. 94–112.

Mendonça, S. (2001b), 'Futures research at the driver's seat: scenario planning at DaimlerChrysler', in van Asselt, M., J. Rothmans and S.C.H. Greeuw (eds), *Puzzle Solving for Policy: A Provisional Textbook for Integrated Assessment*, proceedings of the advanced summer course, International Centre for Integrative Studies, pp. 133–144.

Narin, F. and D. Olivastro (1988), 'Technology indicators based on patents and patent citations', in van Raam, A. (ed.), *Handbook of Quantitative Studies of Science and Technology*, Amsterdam: North-Holland, pp. 465–495.

Nelson, R.R. (1999), 'The coevolution of technology and institutions as the driver of economic growth', *CISEP Working Paper*, Technical University of Lisbon.

Nightingale, P. (2000), 'Economies of scale in experimentation: knowledge and technology in pharmaceutical R&D', *Industrial and Corporate Change*, vol. 9, pp. 315–359.

Patel, P. (1999), 'Measurement and analysis of technological competencies of large firms', draft report for the *Dynamic Capabilities, Growth and Large Firms* (DYANCOM) Project.

Patel, P. and K. Pavitt (1994a), 'The continuing, widespread (and neglected) importance of improvements in mechanical technologies', *Research Policy*, no. 23, pp. 533–545.

Patel, P. and K. Pavitt (1994b), 'Technological competencies in the world's largest firms: characteristics, constraints and scope for managerial choice', STEEP Discussion Paper no. 13.

Patel, P. and K. Pavitt (1995), 'Patterns of economic activity: their measurement and interpretation', in Stoneman, P. (ed.), *Handbook of Economics of Innovation and Technical Change*, Oxford: Blackwell.

Pavitt, K. (1985), 'Patent statistics as indicators of innovative activities: possibilities and problems', *Scientometrics*, vol. 7, nos 1–2, pp. 77–99.

Pavitt, K. (1988), 'The uses and abuses of patent statistics', in van Raam, A. (ed.), *Handbook of Quantitative Studies of Science and Technology*, Amsterdam: North-Holland.

Pavitt, K. (1998), 'Technologies, products and organisation in the innovating firm: what Adam Smith tells us and Joseph Schumpeter doesn't', *Industrial and Corporate Change*, vol. 7, no. 3, pp. 433–452.

Pavitt, K.L.R. and W.E. Steinmueller (2001), 'Technology in corporate strategy: change, continuity, and the information revolution', in Pettigrew, A., H. Thomas and R, Whittington (eds), *Handbook of Strategy and Management*, London and Thousand Oaks, CA: Sage.

Penrose, E. (1959), *The Theory of the Growth of the Firm*, Oxford: Basil Blackwell.

Penrose, E. (1995), *The Theory of the Growth of the Firm*, Third Edition, Oxford and New York: Oxford University Press.

Prahalad, C.K. and G. Hamel (1990), 'The core competence of the corporation', *Harvard Business Review*, May–June, pp. 79–91.

Prencipe, A. (2000), *Divide and Rule: Firm Boundaries in the Aeroengine Industry*, PhD Dissertation, SPRU, University of Sussex.

Teece, D. and G. Pisano (1994), 'The dynamic capabilities of firms: an introduction', *Industrial and Corporate Change*, vol. 3, no. 3, pp. 537–556.

von Tunzelmann, G.N. (1999), '"Convergence" and corporate change in the electronics industry', in Gambardella, A. and F. Malerba (eds), *The Organization of Economic Innovation in Europe*, Cambridge: Cambridge University Press, pp. 125–157.

Winter, S.G. (1987), 'Knowledge and competences as strategic assets', in Teece, D.J. (ed.), *The Competitive Challenge*, Cambridge, MA: Ballinger.

Winter, S.G. (1993), 'On Coase, competence and the corporation', in Williamson, O.E. and S.G. Winter (eds), *The Nature of the Firm – Origins, Evolution, and Development*, Oxford and New York: Oxford University Press paperback, pp. 179–195.

9 The changing boundaries of the firm

Empirical evidence from the aircraft engine industry

Andrea Prencipe[1]

1 Introduction

Two research traditions have analysed the boundaries of the firm. The first tradition is the theoretical and empirical literature on the theory of the firm. The competing theoretical paradigms provide different and diverging interpretations of firms' boundaries. In the last decade there has been a surge of interest in the *internal resources* of the firm. Drawing on the seminal work of Penrose (1959), the resource-based view of the firm has emerged as an alternative paradigm for theoretical interpretations of the business organisation. In contrast to the contractual view that maintains that a firm can be conceived as a nexus of contracts, the resource-based view conceives a firm as an organised bundle of resources.

The second tradition of research that deals with the boundaries of the firm is the composite stream of literature on the division of innovative labour. Recently, much of the debate has revolved around the concept of modularity. Industrial economists, management scholars and organisation theorists have discussed the implications of this concept for inter-firm division of labour (Arora *et al.*, 1998; Sanchez and Mahoney, 1996). It is argued that modularity is a characteristic of the product, its underlying technological knowledge and firm's organisation design. The conclusion drawn is that there is a perfect overlap between the product boundaries and the boundaries of a firm's technological knowledge.

Building upon these two streams of literature, the aim of this chapter is to investigate the dynamics of the boundaries of firms operating in the aircraft engine industry. Firm's boundaries can be measured and assessed along multiple dimensions. This chapter aims to analyse the extent to which aircraft engine manufacturers rely on internal or external suppliers for the design, development and manufacture of components, subsystems, materials and production equipment of the aircraft engine.

The civil aircraft engine industry shows some peculiar features that render it interesting in relation to the issue of boundaries of the firm. The aircraft engine is a multicomponent, multitechnology product. This poses significant managerial challenges for aircraft engine manufacturers in terms of the technological capabilities to be developed and make-buy decisions. These challenges are exacerbated by the existence of various driving forces at work in the industry that 'enable' and 'push' engine manufacturers to externalise greater parts of their activities in relation to the research, design, development and manufacture of new engines.

This chapter argues that the nature of the boundaries of the firm is complex and determined by the interplay of the product *and* technology dynamics. It shows that the boundaries of the firm are multifaceted and should not be confined to (or confused with) the boundaries of the firm as defined by product interfaces. In other words, the technological boundaries of the firms differ fundamentally from the boundaries of the firm as defined by make-buy decisions. A corollary of this is that decisions to outsource technological knowledge do not follow automatically make-buy decisions related to product components. These results show that the scope for technology outsourcing for aircraft engine manufacturers is limited due to the technological requirements of engine integration and the co-ordination task they perform in the industry. Although engine manufacturers make extensive use of collaborative agreements, they maintain a *broad* range of in-house technological capabilities in order to understand and co-ordinate the technological work of the network of suppliers involved in the industry. External sources of technologies are considered complementary to internal sources.

This chapter is organised as follows. Section 2 discusses the literature on the boundaries of the firm. Using the interpretative framework proposed by Miller *et al.* (1995) to study complex product systems industries. Section 3 illustrates the structure of the innovation process and the role of the industry's major actors. Section 4 discusses the multitechnology, multicomponent nature of the aircraft engine and details the driving forces impinging on engine makers' in-house technological capabilities. Section 5 presents the results of the analysis of engine makers' technological profiles as reflected in US patent statistics. Section 6 concludes.

2 Literature review and the analytical framework

2.1 The modularity paradigm

The concept of modularity has become centre stage in the debate on the appropriate forms of technological and organisational co-ordination. Drawing on the concept of *decomposability* put forward by Herbert Simon (1962, 1976), industrial economists, management scholars and organisational theorists have elected modularity as the principle that should inform product and organisation design and firms' cognitive activity.

Modularity was first proposed as a product design strategy aimed at decomposing products through the definition of stable interfaces among its components (modules). Accordingly, the design of each module can be improved within a predefined range of variation and a predefined period without impacting on the design of other modules (Ulrich, 1995). Management scholars and industrial economists have used the concept of modularity to analyse the dynamics of products' underlying technological knowledge, organisational design, and inter-firm relationships (Arora *et al.*, 1998; Sanchez and Mahoney, 1996). The position that emerges from research on modularity is as follows. By adopting a modular design strategy, firms fully specify and de-couple both components and the different stages involved in the product development process. They focus either on the development of the product architecture or on the different modules. In this way, firms reflect the modular development process and embed the modular knowledge underlying each component. A corollary of this line of reasoning is that modularity in products, organisations and technologies is positively correlated. As a consequence, a greater division of labour at each level (product, organisation and technology) characterises the different industrial settings.

According to modularity advocates, therefore, the evolution of an industry technological knowledge base into more general and abstract categories allows for a better understanding of the *inner workings* of products and processes. Such an understanding enables the adoption of more complex design strategies (e.g. modularity). Firms de-couple the development of the product architecture from the development of the modules, and then specialise in either the architecture or a few modules. Furthermore, since the product architecture acts as a sort of 'glue', the organisational processes underlying architecture and module development are also separated and carried out independently. The combined effect of the different dimensions of modularity paves the way to a greater division of labour both within and across firms at the level of product, organisation and technology. A corollary of this is that a firm's boundaries are defined by the boundaries of the products (i.e. the product's interfaces).

2.2 Technological and organisational co-ordination: what the management literature suggests

Modularity advocates argue that due to the positive correlation between product, organisation and technology modularity, industrial sectors are characterised by a greater inter-firm division of labour at each level. Accordingly, co-ordination across firms is achieved through the market mechanism, since modularity characterises and informs products, the organisations designing and producing them, and the technological knowledge underlying the products. Though management scholars acknowledge the far-reaching effects of the modularity paradigm, they argue that in order to understand the relationships between product, organisation and technology analysis of further dimensions is required. In particular, the number of external sources, technological change and the different dynamics underlying technologies and products are factors that should be taken into account.

2.2.1 Systemic vs autonomous innovation and the number of external sources

Chesbrough and Teece (1996) deal with the issue of technological and organisational co-ordination within the discussion of the appropriate organisational form for technological innovation. They maintain that the appropriateness of a firm's organisational form is defined by the interplay of two sets of factors, namely the number of external sources of knowledge and the types of technological innovation.

With regard to the former, Chesbrough and Teece argue that when the number of external sources (i.e. suppliers) is low, firms should adopt integrated forms to counteract the likely suppliers' opportunistic behaviour and *vice versa.* With regard to the latter, they identify two main types of innovation, autonomous and systemic. Autonomous innovations can be pursued independently of other innovations because they are characterised by standardised interfaces with existing component technologies that are often codified in industry standards. Systemic innovations can be realised only in combination with complementary innovations. The management of this system of innovations requires the continuous exchange and sharing of information and knowledge across units of production since systemic innovations redefine the interfaces "throughout an entire product system" (p. 68).

These different features of innovation call for distinct organisational designs. Autonomous innovations can be easily co-ordinated via market mechanisms, since their integration with existing technologies rests on well-defined interfaces. In this case firms can adopt virtual structures that are more responsive than integrated ones, since they can use market-based incentives to access quickly and economically the technical resources they need. Likewise, they can easily form alliances with other companies deemed relevant for the commercialisation of the autonomous innovation. Large integrated companies are unable to duplicate such a responsive mode. Systemic innovations instead are best managed within the same company. When innovations are interdependent, virtual corporations become vulnerable due to their inability to co-ordinate the required exchanges of knowledge and information through the market mechanism, and to settle conflicts between companies over integration. According to Chesbrough and Teece, integrated companies can therefore take advantage of their scale and their complementary assets when systemic innovations are introduced. Similarly, market leadership is required when new standards have to be set.

2.2.2 Technology vs product: technological and organisational co-ordination

Building on Chesbrough and Teece (1996), Granstrand *et al.* (1997) draw some conclusions on firms' technology outsourcing decisions. They distinguish two sets of factors that affect corporate outsourcing decisions: a) the degree to which the innovation is autonomous or systemic and b) the number of independent suppliers outside the firm. On these grounds, they propose a two-by-two matrix that identifies four cells. Each cell is associated with a different case calling for a particular degree of internal technological capabilities. In particular, Granstrand *et al.* identify four intermediate corporate positions between full integration and full disintegration, namely exploratory research capability, applied research capability, systems integration capability, and full design capability. For instance, when the number of external sources is low and the innovation is systemic, then companies should maintain a wide range of in-house capabilities, from exploratory and applied research down to production engineering.

Granstrand *et al.* (1997) have enriched the framework proposed by Chesbrough and Teece (1996). In identifying the above-mentioned intermediate stages between full integration and full disintegration, they contend that decisions related to products are distinct from those concerning their underlying technological capabilities. They argue that "whatever the type of innovation and the number of external sources, companies should maintain capabilities in exploratory and applied research in order to have the competence to monitor and integrate external knowledge and production inputs" (p. 20). This identifies a critical deficiency in the research that does not distinguish between technologies and products.

This chapter builds upon the works of Chesbrough and Teece (1996) and Granstrand *et al.* (1997) to explore the dynamics of the changing boundaries of firms operating in the aircraft engine industry. It understands a firm's *technology base* as a stock of technological capabilities (Dierickx and Cool, 1989). The aircraft engine industry was specifically chosen because of the significant managerial implications posed by the multitechnology, multicomponent nature of the aircraft engine. The multicomponent nature of the aircraft engine requires engine manufacturers to maintain a differentiated set of technological capabilities in terms of component knowledge, knowledge about the ways in which the components are linked together and interact as a system, and knowledge about the system as a whole. The multitechnology nature of the aircraft engine demands that engine manufacturers develop capabilities in multiple technological fields. Due to some driving force at work in the industry, however, engine manufacturers usually focus on those capabilities regarded as crucial and contract out peripheral ones. This leads to critical outsourcing decisions and puts severe demands on the types of R&D activities that are carried out in-house.

3 The structural context of the innovation process in the aircraft engine industry

This section illustrates the main characteristics of the structural context of the innovation process in the aircraft engine industry. The discussion opens with a summary examination of the main characteristics of complex product systems industries as identified by Miller *et al.* (1995) and Hobday (1998). Based on this work, an interpretative scheme is proposed to identify the roles of the main actors involved in the innovation process and to highlight the factors influencing sources, pace and direction of technical change in the aircraft engine industry.

3.1 Mass-manufactured products vs complex product systems industries

Complex product systems have been defined as "high cost, engineering-intensive products, sub-systems, or constructs [i.e. capital goods] supplied by a unit of production" (Hobday, 1998: 690). Hobday has identified a number of dimensions to compare and contrast mass-produced products and complex product systems.[2] Accordingly, complex product systems differ from simpler, mass-produced products in terms of product and production characteristics, dynamics of the innovation process, competitive strategies, managerial constraints, industrial co-ordination and market characteristics.

3.2 The aircraft engine industry as a complex product systems industry

The aircraft engine industry shares some of the characteristics of complex product systems industries as identified by Miller *et al.* (1995) and Hobday (1998). An aircraft engine is a high cost capital good composed of many interacting and often customised elements that belong to different technological fields. The number of components varies according to the size and, therefore, thrust of the engine. The powerful engine powering such aeroplanes as the Boeing 747 and the Airbus A340 may encompass up to 40,000 components. In addition, although the same basic engine powers these two aeroplanes, certain engine parts need to be customised to each application. The software governing the engine control unit is a case in point since it has to be fine-tuned with the avionics system of the aeroplane.

Aircraft engines are batch produced. The design, development and production of a new aircraft engine involves several firms and the degree of user involvement is very high. Airframers, airlines, regulatory bodies, specialised suppliers and engine makers closely collaborate during new engine development programmes. The development costs of a new engine are extremely high, notably between US$500 million and US$2 billion.[3] These figures highlight that any failure of a programme may badly affect the financial situation of an engine maker and/or push it towards receivership as in the case of Rolls Royce during the development of the RB211 engine in the 1970s. Such huge financial outlay has led to financial collaborative agreements between engine makers and suppliers for the development of new engines.

With regard to the dynamics of the innovation process in the aircraft engine industry, the Abernathy and Utterback (1975) life cycle model does not seem to capture its salient characteristics. Although the turbofan engine configuration can be regarded as the industry dominant design, its emergence does not seem to have slowed down the rate of product innovation. In the aircraft engine industry, product and process innovations are closely intertwined and product innovations are always performance maximising.

3.3 The structure of the innovation process in the aircraft engine industry

Miller *et al.* (1995) argue that the appropriate unit of analysis for studying the process of innovation in complex product systems industries is the network of actors involved in the process as well as the single supplier companies. They propose that the innovation parameters of complex product systems industries can be described in terms of a meso-system composed of three main groups, notably the innovation superstructure, the systems integrators (in this case the engine makers), and the innovation infrastructure. Drawing on such framework, this section illustrates the structure of the innovation process in the aircraft engine industry.

The scheme depicted in Figure 9.1 is organised as follows. The engine manufacturers make up the core of the meso-system; they co-ordinate the functioning of the innovation process by organising the roles of the different actors involved. Suppliers are part of the innovation infrastructure. They provide materials, components, subsystems, machine tools and software to the engine makers. Suppliers are increasingly involved in new engine programmes both financially as risk and revenue sharing partners, and technologically as they take on larger chunks of engine design and manufacturing tasks. Government-funded laboratories and universities are also part of the innovation infrastructure. They provide the research infrastructure as well as the technologies and training. Engine makers and the innovation infrastructure are the supply side of the industry. They can be regarded as the sources of technical change.

The innovation superstructure represents the ‘market’ for aircraft engines. Airlines, airframers, certification agencies and professional bodies that comprise it, heavily influence the pace and direction of tech-

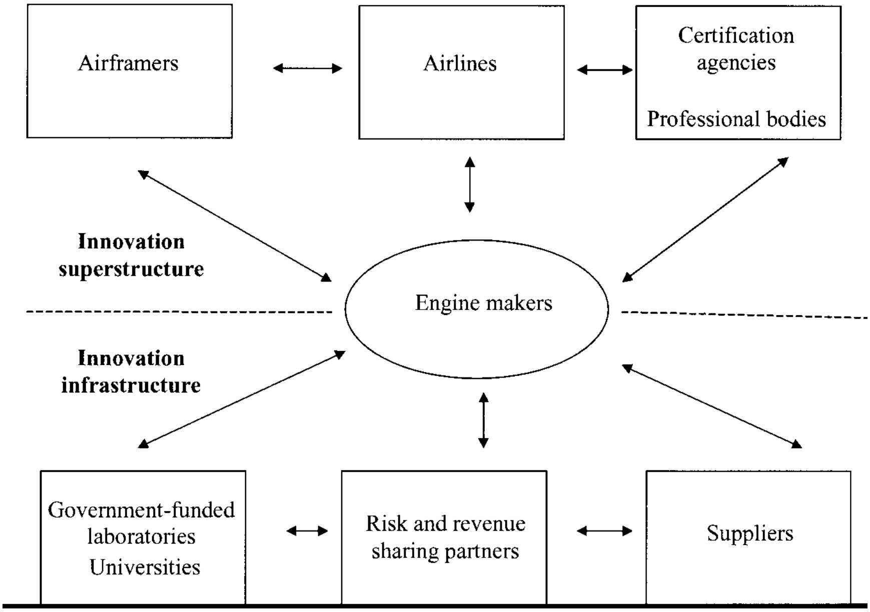


Figure 9.1 The aircraft engine industry meso-system.

nical change. The airlines are the buyers of the engines. Airframers define engine requirements in relation to aircraft characteristics and pass them on to the engine manufacturers. Certification agencies and professional bodies form the remaining part of the innovation superstructure. The former set engine certification requirements, whereas the latter act in the context of information exchange between the different parties involved in the process. A substantial role in directing technical change is also played by the high level of regulations imposed by national governments and international organisations.

It is worth analysing the role of each group and how they interact in the innovation process in order to have a better understanding of the functioning of the process itself. Each group therefore will be examined in turn.

3.4 Engine makers

As reported in Figure 9.1 the engine makers represent the core of the innovation meso-system of the industry. Engine makers design, develop and manufacture engines according to the airlines', airframers' and regulator's requirements. They co-ordinate the activities of a large number of specialised suppliers, integrate components and add value through their systems integration capabilities.

At the systems integration level, the industry is highly concentrated. The large turbofan market (over 35,000lb) is dominated by the so-called Big Three or Primes, notably General Electric Aircraft Engines, Pratt & Whitney, and Rolls-Royce. In the medium- and small-sized engines market (below 35,000lb), the main actors are AlliedSignal Engines, Rolls-Royce Allison, General Electric Aircraft Engines, Pratt & Whitney Canada, Williams International and two international joint-ventures, CFM International and International Aero Engines. CFM International was set up by General Electric and Snecma, whereas International Aero Engine (IAE) is composed of Pratt & Whitney, Rolls-Royce, Motoren und Turbinen Union (MTU), Fiat Avio and Japanese Aero Engine (in turn a consortium of Japanese aerospace companies). In the turboshaft/turboprop market, in addition to the previously mentioned engine makers, it is worth mentioning the French company Turbomeca. In the aircraft engine industry, East Asian firms play a relatively minor role. They are in fact suppliers or at the most joint venture partners, such as Mitsubishi Heavy Industries and Kawasaki Heavy Industries from Japan and Samsung Aerospace from Korea (Nakamoto, 1997).

In the last ten years a number of mergers and acquisitions has further concentrated the industry. AlliedSignal Engines acquired Textron Lycoming and Garret Engines, and Allison Engines was acquired by Rolls Royce. Mergers and acquisitions have also taken place at the supplier level.

3.5 The innovation infrastructure

3.5.1 Risk and revenue sharing partners and specialised suppliers

The industry is characterised by an ever-increasing number of international collaborative agreements for the design, development and manufacture of new engines. This practice has been borrowed from the military side of the industry where collaborations among companies from different countries have been taking place since the early 1970s. The reasons why the development of new engines is shared among different companies lie in the increasing development cost and related risk of failure of the programme. Competition in the large turbofan market is in fact severe and price-based. Industry trade journals report that engine list prices are heavily conceded by engine makers in order that they can secure a foothold in the spares market business considered to be the 'gold mine' of the industry.

Thus, new engines are developed using a new form of contractual relationship, labelled a risk and revenue sharing partnership (RRSP). Accordingly, suppliers, typically first-tier ones, are invited to join the engine programme early on and to buy a stake in it (usually one or more components or an entire subsystem) in order to share the risks and future revenues (if any) of the programme. The shares held by suppliers have been increasing over time. On the one hand, engine makers want to 'split' risks and revenues across several suppliers to reduce their own stakes and to gain customers (i.e. airlines) via the involvement of suppliers of the same nationality as the customers. According to some industry experts, airlines (usually state-funded) are more likely to place engine orders when national component suppliers have been involved in the engine programme. On the other hand, component suppliers, especially from developing countries, push to get bigger engine programme shares in order to get experience with more engine parts. The industry therefore is characterised by a three-tier structure made up of engine makers, RRSPs and suppliers. The world's largest RRSPs are MTU, Snecma and Fiat Avio.

3.5.2 Government-funded laboratories: the role of national governments

Mowery and Rosenberg (1982) argue that government policy has influenced both the demand and supply of the US commercial aircraft industry. On the supply side, the industry has received government support via research on commercial application technologies undertaken at national laboratories such as NASA, direct funding of firm internal research programmes, and spill-over from the military side. The demand side has been influenced via the imposition of heavy regulations for safety and subsequently environmental concerns.

The support of national governments for the development of new engine technologies via direct and indirect funding is still strong. Government in both developed and developing countries fund research as well as development programmes; the former to strengthen the technological leadership of their national champions, the latter to improve their technological capabilities in such a value-added industry.[4] As regards Western countries, there are several differences between the organisation of supports for technical progress between Europe and the US.

3.5.3 The role of universities

Universities are also part of the innovation infrastructure. Their role is not confined to being mere providers of general knowledge, however. Universities are heavily involved in research projects with a much larger scope. In fact, the scope of academic research projects ranges from design of components, verification of company's design and development and verification of design codes, through the population of experimental databases and exploration of component physical behaviour, to the training of researchers and technical process improvements. Companies interviewed fund studentships on specific topics and contemplate using *in-house professors* for trouble-shooting and problem-solving activities as well as for longer-term research guidelines. The importance of the role played by academic units is demonstrated by the fact that the companies interviewed consider the technological areas investigated in collaboration with them to be highly confidential. It is worth noting that academic collaboration is a phenomenon that interests engine makers as well as first and second tier suppliers.

3.6 The innovation superstructure

3.6.1 The regulatory network imposed by national governments

The effects of regulation on aircraft engine demand are both *direct* and *indirect.* Direct effects concern the issuing of rules that regulate engine noise and emissions and the certification of new engines. These effects are analysed in the following sections through a discussion of the role of certification bodies. The indirect effects are discussed below.

The indirect effects result from the heavy regulatory network imposed by national governments and international bilateral and multilateral agreements to regulate the exploitation of the air space over each national state by air carriers. These rules influence air carriers' competitiveness in terms of price and route structuring. According to such rules, air carriers are granted licences to exploit the air space. The International Air Transport Association (IATA) is the regulatory body with regard to fares. Bilateral air carriers' agreements (for instance code sharing) overlap this heavy regulatory network.

This dense regulatory structure has shrunk dramatically in the last 20 years. In the US, the tight control of the Civil Aeronautics Boards (CAB) that since 1938 had controlled pricing policies and entry and exit from air transportation, came to an end in 1978 (Mowery and Rosenberg, 1982). The deregulation had a profound impact on the US air carriers' route structures. Air carriers have in fact adopted a *hub-and-spoke* strategy. Airlines choose an airport as *hub* where they concentrate passengers coming from other airports (*spokes*) to redirect them to yet others (*spokes*). In Europe, the European Union's Third Package of aviation liberalisation became effective in April 1997 giving airlines the right to cabotage in another country (Rolls-Royce, 1997). However, according to industry sources this last stage in European liberalisation was only a symbolic move for the European Governments since national carriers still enjoy big cost advantages in their respective domestic market (Boeing, 1999; Rolls-Royce, 1997).

3.6.2 The certification agencies and the professional bodies

Certification agencies are part of the innovation superstructure. Engines have to comply with rules defined by regulatory agencies, such as the Federal Aviation Administration (FAA) in the US and the Joint Aviation

Authorities (JAA) in Europe. There is a close, dialectic, and ongoing dialogue between engine makers and regulatory agencies during the design and the development of new engines. Safety requirements have an important and constraining effect on the application of new technologies. The introduction of new technologies is in fact always extensively discussed between engine makers and regulators. New technologies often attract specific new regulations and stringent testing procedures. In this way, the severe testing procedures imposed via new rules act as *targeting devices* for innovation (Miller *et al.*, 1995). The first phase in the dialogue between engine maker and regulator ends with the formal certification of the engine after long and arduous testing carried out by the engine maker and overseen by the regulator. According to Miller *et al.* (1995) this *focusing role* played by the regulator for the introduction of the innovation is a salient characteristic of many complex product systems industries as compared to mass-productions where innovation is predominantly mediated by the market.

The fact that the introduction of new engine parts based on innovative technologies is discussed between engine manufacturers and the certification authority does not lessen the importance of feedback as mediated by the market. Information related to engine behaviour gathered by engine operators (i.e. airlines) and maintenance engineers is deemed extremely valuable by the engine makers during the innovation process. One of our interviewees emphasised that the acquisition of maintenance companies by engine makers in the last five years has realised as a by-product an important source of information about customer requirements.[5] The acquisition of information related to engine behaviour is now facilitated by digital engine control technologies that have replaced the hydromechanical control system. Digital engine control units, also labelled FADEC (i.e. full authority digital engine control unit) are able in fact to monitor and store engine performance data throughout the life of the engine (Prencipe, 2000).

3.6.3 The airlines

Airlines are another group part of the innovation superstructure of the aircraft engine industry. As they are the final customers for the engines, they are in a position of considerable power to influence the performance characteristics of an engine. Airlines demand reliable engines with low operating costs for a variety of reasons but ultimately to boost their profit margins.[6] In addition, they demand quieter and less polluting engines to comply with the rules set by airports and regulatory agencies.

Airlines' strategies heavily influence the rate and direction of technological change in the aircraft engine industry. An airline's demand for aircraft in terms of size and range depends on its route structures. Route structure in turn depends on firms' individual strategies but it is also influenced by the rules imposed by national governments. As mentioned earlier, since deregulation in the US, airlines have adopted a *hub-and-spoke* strategy, which requires a change in the composition of airline fleets in terms of long- and medium-range aircraft. Long-range or medium- and short-range aircraft and twin or quad require the optimisation of different engine design parameters such as specific fuel consumption and noise.

3.6.4 The airframers

The airframers are also part of the innovation superstructure. Though they are no longer the final customers of the engine manufacturers, airframers play a central and active role in future (and futuristic) engine configurations as well as during new engine programmes within an established engine configuration. Airframe/engine integration is of paramount importance for efficient and safe air transport. Radical changes concerning the engine design configuration involving new airframe/engine installation solutions require the joint and close co-ordination effort of both airframers and engine makers. Even within established engine design configurations, such as the turbofan, airframers heavily influence aircraft engine characteristics. The choice of engine cycle, size and thrust is in fact weighted by its intended application.

4 The driving force impinging on the in-house technological capabilities of aircraft engine manufacturers

Using the framework proposed by Miller *et al.* (1995) to study complex product systems industries, the foregoing sections analysed the role of each actor in the industry highlighting their influence on source, rate and direction of technical change. Particular attention was paid to the dense regulatory network imposed by national governments and certification bodies and how it stimulates and affects the introduction of new technologies. Engine makers are required to have a clear understanding of such rules as well as of customer requirements. The analysis has highlighted the organisational and technological co-ordination endeavours that engine manufacturers undertake throughout new engine development programmes.

Aircraft engines are multitechnology multicomponent products. The large turbofan engines can encompass up to 40,000 components. These components may differ in kind and variety. They belong to different and often distant technological fields. To name but a few, thermodynamics, aerodynamics, fluid dynamics, tribology, heat transfer, combustion, structures, materials, manufacturing processes, instrumentation and controls (Mattingly *et al.*, 1987). The number of components can increase further over time, as firms have to cope with customers' evolving needs as well as ever-tighter regulations. The multicomponent and multitechnology nature of the aircraft engine requires that engine makers be active in multiple technological fields in order to design, develop, integrate and manufacture engines.

Therefore, engine makers' activities span many different knowledge domains:

a the scientific and technological fields underpinning the high variety of components and subsystems,
b organisational (e.g. project management) and relational (e.g. marketing) capabilities required to manage and integrate the roles of the actors involved in the industry;
c knowledge about client requirements, and
d knowledge about rules and regulations for engine certification.

The challenging task for engine manufacturers is to integrate these different knowledge domains in order to be able to identify business opportunities, and translate regulatory and customer requirements into technical specifications that can be met relying on its own and suppliers' technological capabilities. There are, however, some driving forces that play a counteracting role that affects engine makers' technological capabilities (Table 9.1). As argued below, the combined overall effect of these factors 'enables and pushes' engine makers towards greater externalisation of activities.

4.1 The enablers

Internal accumulated technological knowledge related to the engine system enables engine makers to understand better the behaviours of components within the engine's operating environment. The accumulation of this ability rests upon advances in scientific and technological disciplines, complex mathematical models and design knowledge embodied in

Table 9.1 The driving forces affecting engine makers' technological capabilities

Enablers	*Pushers*
• Internal accumulated technological knowledge of the engine system behaviour • Accumulated technological knowledge of the engine components suppliers • Increasing use of ever more powerful computational capacity • Knowledge codification process • Modularisation of the engine system	• Spiralling costs of development • Pressure from developing countries • Cut in defence budget (entailing personnel reduction) • Advantages of specialisation

people. The use of powerful computers and sophisticated computer models also underpins the progress of knowledge in this industry. In particular, computational fluid dynamics (CFD) enables engine designers to optimise the shape of compressor and turbine blades to improve their efficiency. The use of increasingly powerful computers does not, however, downplay the importance of empirical data gathered via experimental activity and during engine in-flight service, and the engineers' embodied tacit knowledge. CFD codes are, in fact, always validated using empirical data related to engine behaviour and performance stored in the databases held by engine makers. These databases represent an important and extremely valuable part of the memory of these companies. In addition, engineers' accumulated experience and rules of thumb are still prominent in the choice of new design routes.

A better understanding of the technological principle governing the engine system enables engine manufacturers to conceive engines in terms of basic modules. In particular, engine makers can specify component interfaces in terms of their functional and spatial specifications as well as their physical properties. In this way most complex interactions take place within rather than across the same modules. Modular aero engines have been launched since the early 1970s. The section on aircraft engines contained in *Jane's All the World Aircraft* has included 'modular engines' and 'engines composed of modules' since 1970. From an operational viewpoint, the concept of modular engines has its origin in the efforts of engine makers to standardise component parts to ease the maintenance of engines in use. Gardiner and Rothwell (1990) illustrated the case of the RB211 engine for which Rolls Royce was able to scale-down or scale-up (or more precisely de-rate and up-rate) the original design to cater for a variety of market requirements and power outputs. Such modular design enabled Rolls Royce to exploit economies of scale and scope across a substantial number of engines and over time.

This design philosophy is common in the industry. By adopting it, manufacturers can launch engine families rather than single engines and take advantage of the associated cost benefits. Using a common engine core manufacturers spread the recovery of non-recurring design costs over several market segments and benefit in terms of cost from larger scale production. Thrust ranges can be targeted by the addition to the engine of a tailored low-pressure system. Modularity in this industry also paved the way for the practice of 'retrofitting' and 'design commonality' whereby engine makers improve existing engine versions by introducing technological modifications, which, in turn, permit performance improvements within the same thrust range. The Chief Design Engineers interviewed confirmed that modularity is a powerful tool to reap economies of scale, scope and knowledge in design, production and use. Similarly, they confirmed that there is a strong trend towards greater modularity.

4.2 The pushers

New engines are increasingly developed via international collaborative agreements among engine makers and suppliers. The development of new engines is split among different companies because of the increasing development cost and related risk of failure of the programme. Competition in the large turbofan market is fierce and price-based. Table 9.2 reports on companies' collaborative agreements between 1985 and 1996.[7] The relatively low number does not permit a statistical analysis of the portfolio of agreements of each company. A close scrutiny of the content of each of them proved to be extremely useful, however. The content of each agreement was reviewed and arranged according to the kind of activity involved in the contractual agreement. A two-tier classification was devised in order to investigate at which level in the industry the division of labour occurs. Six types of activities are identified, namely research, development, manufacturing, testing, maintenance and 'other'. Also, those agreements involving engine development and manufacturing were further classified in relation to the scope of the deal.

The table shows that the number of agreements shows a sharp rise in 1992–96 (from 30 to 65). Analysis of the content of each agreement reveals that they are set up for several reasons. The activities concerned include suppliers' involvement in new engine programmes, research on new engine technologies, manufacturing of engine components and engine maintenance and repairing.[8]

It is worth noting that whereas agreement portfolios of RRSPs are focused almost exclusively on new engine programmes, engine makers are involved in agreements of all sorts. In particular, alongside new engine programmes, manufacturers' agreements involve research, development and manufacturing of specific components and testing equipment. The broader scope of the agreement portfolios of engine makers indicates that they resort to a larger number of external sources than RRSP companies.

Table 9.2 Total number of collaborative agreements (number in brackets indicates agreements that have been terminated)

Activity	*Scope*	*1987–91*	*1992–96*	*Subtotal*
Design/manufacturing	Engine	12	27 (1)	39 (1)
Design/manufacturing	Component		4	4
Manufacturing	Engine/component	3	7	10
Research		7	11	18
Testing		–	1	1
Maintenance		2	11	13
Design/manufacturing	Airframer	3	2	5
Other		3 (1)	2	5 (1)
Subtotal		30 (1)	65 (1)	95 (2)

Not only do engine manufacturers enter collaborative agreements to develop new engines, but they also team up with research centres and suppliers to acquire and develop new technologies for future engine concepts. Using US patents section 5 assesses the impact of the increasing use of external sources of technologies on engine manufactures' *technology bases.*

The largest number of agreements (39 out of 95) falls in the category related to new engine development programmes. This result reflects the increasing use of partnership agreements for the development of new engines. CFM International, for instance, is a long-standing joint venture between General Electric Aircraft Engines and SNECMA. The CFM56 has become the world's best selling engine. International Aero Engine is the response to this joint venture by Rolls Royce and Pratt & Whitney teaming up with MTU, Fiat Avio and Japan Aero Engine. Furthermore, new turbofan engines, such as the GE90, the Rolls-Royce Trent, and the Pratt & Whitney PW4000, were developed using RRSP agreements. As mentioned at the beginning of the section, the flourishing use of RRSP is due to the rising development costs of new engines and high risks of programme failures.

The shares held by suppliers have been increasing over time. On the one hand, engine makers want to share risks and revenues across several suppliers to reduce their own stakes and to gain customers (i.e. airlines) via the involvement of suppliers of the same nationality as the customers. According to some industry experts, airlines (usually state-funded) are more likely to place engine orders when national component suppliers have been involved in the engine programme. On the other hand, component suppliers, especially from developing countries, push to get bigger shares of engine programmes in order to be able to learn about more engine parts.

5 Stability and variation of aircraft engine makers' in-house technological capabilities

The purpose of this section is to assess the degree of stability and variation of engine manufacturers' technological profiles over time. The analysis of the stability and variation of engine manufacturers' technological profiles allows an assessment of the changing boundaries of engine makers' technological capabilities. In particular, Herfindhal indices and Cantwell's (1989, 1991, 1993) methodology[9] are used to understand whether engine manufacturers are 'broadening out' their technological capabilities or specialising in a few of them. Increased specialisation would indicate a positive correlation between the technological boundaries of the firm and the products' boundaries, and *vice versa.*

5.1 The breadth of technological capabilities

The boundaries (or more precisely the breadth) of the technological capabilities of the companies analysed can be assessed using concentration indices, notably the Herfindhal index and the concentration ratio. The Herfindhal index is one of the most commonly used measures of concentration. As is well known, it is defined as the sum over all classes of the squares of the shares of the variable. As regards this study, the Herfindhal index for company j in one time period is:

$$H_j = \Sigma_{i=1.58} (x_{ij}/X_j)^2$$

where i = technological field; j = company; x = number of patents granted to company j in the technological field i during the period in question; X = total number of patents granted to company j during the period in question.

In this case there are 58 classes corresponding to the 58 identified technological fields. The Herfindhal index then varies between 0.017 (i.e. 1/58, each technological field has the same share) corresponding to max diversification and 1 corresponding to max specialisation (share of the highest technological field is 1). Therefore, the lower the index, the greater the *breadth* of the technological capabilities of the company at issue.

Table 9.3 shows the Herfindhal index for the companies under consideration. The degree of technological specialisation of the companies analysed as reflected in the Herfindhal is very low. In other words, all companies are rather diversified in terms of the technologies listed in the 58-technological field map. Engine manufacturers display the lowest Herfindhal indices as compared to the RRSP companies. Although the dynamics of their Herfindhal indices display a rather erratic pattern over time, the differences in each index across the time period are rather small and overall the index is very low throughout the period examined. These low values and hardly little change in the magnitude of the indices suggest that the companies are not pursuing a strategy of specialisation at the technological level.

Table 9.3 Herfindhal index distribution (minimum: 0.017)

Company	*1977–81*	*1982–86*	*1987–91*	*1992–96*
Company A	0.036	0.038	0.045	0.03
Company B	0.036	0.028	0.034	0.032
Company C	0.037	0.039	0.034	0.036
RRSP A	0.055	0.05	0.038	0.035
RRSP B	0.045	0.053	0.049	0.056

5.2 Stability and dynamics of change in the long term: some statistical evidence

This section assesses statistically two propositions: a) the 'stability' or 'persistency' over time of companies' technological profiles in the industry in question and b) the 'variations' in such profiles. The 'stability' or 'persistence' of a firm's technological profile over time finds its place in the broader view that technological learning within business organisations follows a cumulative path. This learning process, in other words, is not random. This view also squares with Nelson's (1991) point that firms in the same industry differ in that each firm has its own field of distinctive technological capabilities. These capabilities are firm-specific and the underlying learning processes are not readily imitable by other firms (Pavitt, 1990). In the context of this chapter, the argument of persistency relates to the idea that system integrator companies continue to maintain in-house a broad spectrum of the technologies relating to a wide range of components composing the aircraft engine despite increasingly outsourcing engine's components. This proposition can be examined statistically by testing the revealed technological advantage (RTA) distributions in the two different time periods. The second proposition refers to the changing degree of technological specialisation of the firms in the industry in question. The variation of the degree of technological specialisation can also be assessed statistically.

Table 9.4 reports on the results of the regression analysis of the RTA distribution in 1987–96 on the RTA distribution in 1977–86. The hypothesis that β is significantly different from zero can be accepted for all the companies sampled. Therefore, the technological profiles of the companies examined can be considered persistent over the two time periods examined, against the proposition that it is random. This hypothesis (test $b = 0$) is accepted at 0.01 level of significance for Company B, Company C and RRSP B, and at 0.05 level of significance for Company A and RRSP A.

According to the results presented in Table 9.4, it can also be argued that both 'persistency' and 'variation' take place during the periods examined. The test ($b = 1$) is accepted at any reasonable level of significance. In

Table 9.4 Results of company regression analysis of the RTA index in 1987–96 on the index in 1977–86

Company	*a*	*B*	*p-value (test b = 0)*	*p-value (test b = 1)*	*(1 − b)*
Company A	−0.053	0.309	0.024	0.000	0.691
Company B	−0.045	0.372	0.002	0.000	0.628
Company C	−0.006	0.405	0.000	0.000	0.595
RRSP A	−0.083	0.305	0.007	0.000	0.695
RRSP B	−0.124	0.466	0.000	0.000	0.534

particular, RRSP A displays a relatively high regression effect, $(1-b)=0.695$, indicating a relatively stronger change in its technological profile as compared to the other companies sampled. This result confirms that this RRSP has started pursuing full systems integration strategy. The magnitude of the regression effect of the Big Three also shows some variations in their technological profile. RRSP B displays the lower regression effect confirming its stable technological profile as a supplier. All in all, these companies show path-dependent technological development together with incremental change.

The test of the proposition that firm technological specialisation pattern has tended to fall calls for a test of the magnitude of the regression effect against that of the mobility effect. Cantwell (1991, 1993) argues that the breadth of firm technological specialisation increases when $(b/R)<1$. Put another way, a fall in the degree of technological specialisation takes place when the magnitude of the regression effect outweighs that of the mobility effect. The ratios (b/R) for the companies analysed are reported in Table 9.5.

Accordingly, all companies except Company A display a $b/R<1$. This result would indicate a fall or a 'broadening out' of their patterns of specialisation. According to the statistical tests reported in the table these results are not significant, however.[10] Therefore, while a fall in the pattern of specialisation (or de-specialisation) cannot be considered a strong trend, the results certainly show that the companies examined are not increasing their levels of specialisation.

6 Conclusions

This chapter has illustrated the main features of the structure of the innovation process in the aircraft engine industry highlighting the managerial implications that engine manufacturers face in terms of the technological capabilities required to co-ordinate the network of actors involved in the development of new engines. The industry is characterised by some driving forces impinging upon the in-house technological capabilities of the aircraft engine manufacturers whose combined effect

Table 9.5 Results of company regression analysis of the RTA index in 1987–96 on the index in 1977–86

Company	*R*	*(1 – R)*	*b/R*	*p-value*
Company A	0.296	0.704	1.043	0.754
Company B	0.403	0.597	0.923	0.558
Company C	0.486	0.514	0.833	0.171
RRSP A	0.351	0.649	0.868	0.294
RRSP B	0.496	0.504	0.939	0.641

'enables' and 'pushes' manufacturers to resort to suppliers to a greater extent than hitherto. The impact of these forces points to a greater division of labour between engine manufacturers and suppliers.

The patent analysis presented in this chapter showed that engine makers maintain a broad range of in-house technological capabilities. The *breadth* of these capabilities has been shown to increase over time. Along the same lines, the results of the regression analysis of the engine manufacturers' technological profiles did not display any trend towards an increased level of technological specialisation, confirming that they maintain a broad set of in-house capabilities, despite increasing outsourcing of components. Therefore, there is a trend in the industry towards a greater division of labour between engine manufacturers and suppliers. The combined effects of the driving forces are leading to a more disintegrated industry. Engine makers, however, are not focusing their capabilities on only a few technological fields and there is no trend towards greater technological specialisation. The most likely explanation is that the technological boundaries and the product boundaries of engine manufacturers differ. In other words, decisions to outsource components do not necessarily entail outsourcing technological knowledge. Component outsourcing and technology outsourcing though connected are distinct phenomena. It is argued that the scope for technology outsourcing for engine manufacturers is limited for two interrelated reasons: a) the compelling technological and product requirements for the engine integration, and b) the need to co-ordinate the network of the actors involved in the industry.

Engine manufacturers do divide up engine development tasks across a number of external suppliers, but this *task-partitioning* capability (Von Hippel, 1990) hinges on their multitechnology bases. This chapter showed that the capabilities of engine manufacturers must span a wide spectrum of technologies in order to co-ordinate from a technological viewpoint the work of suppliers, airframers, airlines and regulatory bodies. Co-ordination in the aircraft engine industry is not achieved through arms' length relationships but needs to be actively pursued by all-round knowledgeable engine manufacturers.

7 Appendix 1 Methodology

This chapter draws on data collected during a four-year field study of the aircraft engine industry. It relies on qualitative and quantitative data. Using multiple data sources allows data triangulation. Qualitative data were collected through a systematic review of the technical literature, specialised engineering journals, trade publications and interviews. Interviewees included company personnel, industry experts and academics. Technical literature and articles from specialised journals provide the basis for the discussion of the technological drivers and developments of the aircraft engine. Information was also collected via face-to-face and telephone interviews with engine makers, airframers, airlines, industry experts and regulatory bodies. This information was used to discern and describe the role of the main actors of the industry in the innovation process as well as to validate the accuracy of the quantitative analysis. Patent statistics and collaborative agreements were the main sources of quantitative data. As regards patent data, we make reference to an original data set designed by rearranging the US Patent Office classes. The database encompasses patent data of the major engine makers and suppliers of the aero-engine industry between 1977 and 1996. Patents are rearranged according to a detailed sector specific taxonomy that relates each patent to a specific engine component or subsystem. Two primary examiners of the US Patent Office and a company engineer validated the taxonomy. The taxonomy encompasses 58 sub-technological fields. By using this taxonomy, it was possible to build a technological profile of the companies under study. The companies' technological profiles are understood to reflect their *technology bases* or, in other words, their set of in-house technological capabilities. Therefore, the analysis of companies' technological profiles enables an evaluation of the dynamics of the boundaries of their technological capabilities over time. The data related to collaborative agreements are collected by searching the Securities Data Corporation (SDC) database and the DIALOG database. The data on external linkages, such as alliances, joint ventures, licensing, measure the extent of inter-firm division of labour.

7.1 The methodology proposed by Cantwell

To test the two propositions of section 5 the revealed technology advantage (RTA) distributions of each firm in two ten-year periods, namely 1977–86 and 1987–96, are compared. As described below, the RTA index reflects the firms' degree of technological advantage with respect to other companies in the same industry. Following Cantwell (1989) the Galtonian regression model is used. This statistical methodology was first used in economics to study firms' size distribution (Hart and Prais, 1956) and income distribution (Hart, 1976). Recently Cantwell has applied the same methodology to analyse cross-sectional distribution of countries' and companies' technological activities.

The RTA index reflects the relative technological advantage of one firm with respect to others across a range of identified technological fields. This index has been used to study inter-country comparisons (Balassa, 1965; Cantwell, 1989; Laursen, 1998; Soete, 1981) as well as intra-industry and inter-firm comparisons (Patel and Pavitt, 1997). The RTA of a company in a specific technological field is given by its US patent share in that field, relative to the firm's overall US patent share in all fields. In other words, the numerator of the RTA index is given by the number of US patents held by a firm in a technological field divided by the number of US patents in that technological field granted to companies in the same industry. The denominator is given by the firms' total number of US patents in all technological fields divided by the number of US patents assigned to firms in all technological fields in the industry in question. In symbols:

$$RTA_{ij} = (P_{ij}/\Sigma_j P_{ij})/(\Sigma_i\, P_{ij}/\Sigma_{ij} P_{ij})$$

where P_{ij} = number of US patents granted to firm j in sector i.

This index varies around unity so that values greater than 1 reflect a comparative technological advantage of the firm in a particular technological field in respect to other firms in the same industry, whereas values less than 1 suggest a relative technological disadvantage.

The use of this index overcomes some of the limitations of the use of patent statistics as a proxy measure of companies' technological capabilities. As regards the different propensity to patent that characterises technological fields and firms, the RTA is normalised in the numerator for inter-field variation and for international inter-firm differences in the denominator. According to Cantwell (1991), there may still be inter-field variations in inter-firm propensity to patent. Some firms may be more likely to patent in some fields than others, and *vice versa*. However, Cantwell suggests that this intra-firm variance is lower than the inter-field difference. It can therefore be "hypothesised that on relatively large numbers the propensity to patent of a given firm in any sector [i.e. technological field] cannot be expected to have any systematic bias as compared to that firm's notional average propensity to patent and the notional average propensity to patent of all firms in that sector [i.e. technological field]" (Cantwell, 1993: 221).

The regression model used to compare the RTA indices in the two time periods ($(t-1) = 1977$–86 and $t = 1987$–96) is the following:

$$RTA_{it} = \alpha + \beta RTA_{i(t-1)} + \epsilon_{it}$$

where i = technological field i; t = time period t; α, β = linear regression parameters.

The underlying assumption is that the regression is linear and the residual ϵ_{it} is independent of $RTA_{i(t-1)}$. Further, such a regression model is valid if the RTA distribution conforms to a bivariate normal distribution.[11] Also the RTA indices have been normalised in order to render them symmetric around unity, so that each RTA index varies between −1 and +1. Laursen (1998) argues that in regression analysis the RTA index must be always adjusted in a way that it becomes symmetric since an unadjusted RTA would lead to misleading results.

Following Cantwell (1989), the temporal analysis of the distribution of the RTA index revolves around the values that the β coefficient takes. To put it another way, the magnitude of β is a measure of the stability of the technological profile between the two periods in question. If $\beta < 0$ the composition of the firm's technological profile is characterised by high turbulence, the ranking of the technological fields is reversed and the prediction that the company technological profile is stable over time is proven to be incorrect. As a consequence, one can infer that firm technological learning processes are neither constrained by nor linked with existing technological skills. If $\beta = 0$ the composition of the firm's technological profile follows a random order. The stability hypothesis is instead proven when $\beta > 0$. As explained later, however, a positive value of β still allows for some gradual evolution of the firm technological profile.

When $\beta = 1$ the ranking of the technological fields remain stable. Each technological field maintains the same proportional position in the sense that the relatively more important remain more important, and the relatively less important remain less important. Where $\beta > 1$, instead, the relatively more important fields become even more important. The same trend holds for the less important fields. Where $0 < \beta < 1$ the ranking of the technological fields remains unchanged, but they move closer to one another. In other words, companies ameliorate their position in disadvantaged fields, but slip back in advantaged fields. According to Cantwell (1991) the size of $(1 - \beta)$ measures what he defines as the 'regression effect'. The magnitude of the 'regression effect' is estimated by $(1 - b)$, where b is the slope of the sample regression line.

To sum up, a test of β significantly greater than 0 is a test of the proposition that the firm technological profile is stable over the periods in question. Further, if β is significantly less than 1, then this profile tends to change incrementally. The rate of this phenomenon is measured by the size of the regression effect $(1 - b)$. Therefore, if the test of $0 < \beta < 1$ is significant, then the 'persistency' and the 'variation' propositions work together.

Cantwell argues, however, that a positive regression effect does not necessarily imply that the technological profile is broadening. He suggests that variations in companies' technological profiles and, in particular, their degree of technological specialisation, can also be evaluated by calculating the variance in the RTA index. This measure of dispersion provides an assessment of how the RTA indices are distributed around the mean. A high variance shows a high degree of technological specialisation in that a company is focused on a few technological fields and *vice versa*; a low variance indicates that the firm's technological capabilities span a broad range of fields, therefore showing a low degree of specialisation. To appreciate change in the variance of a distribution over time, Cantwell follows Hart (1976).

The variance of the RTA distribution at time is given by the following equation:

$$\sigma^2_t = \beta^2\sigma^2_{(t-1)} + \sigma^2_\epsilon$$

The square of the correlation coefficient (ρ^2) is given by:

$$\rho^2 = 1 - (\sigma^2_\epsilon/\sigma^2_t) = (\sigma^2_t - \sigma^2_\epsilon)(1/\sigma^2_t)$$

Combining the two equations:

$$(\sigma^2_t - \sigma^2_\epsilon) = \beta^2\sigma^2_{(t-1)} = \rho^2\sigma^2_t$$

In order to assess how the variance in one time period relates to the next time period, the last equation can be rewritten as follows:

$$\sigma^2_t/\sigma^2_{(t-1)} = \beta^2/\rho^2$$

Therefore, the variation in the degree of technological specialisation between two time periods as reflected by change in the variance in the RTA distribution can now be assessed by the variation in the size of the ratio β^2/ρ^2. In particular, using the estimated regression values b and R, the degree of technological specialisation will rise if $(b/R) > 1$, and it will fall if $(b/R) < 1$.

According to Cantwell (1991), the estimate of the regression coefficient (R) represents a measure of the mobility of the technological fields within the RTA distribution. A high value of R shows that the relative importance of the technological fields is relatively unchanged, whereas a low value indicates that some technological fields are moving closer to one another, others further apart. Cantwell defines $(1 - R)$ as the 'mobility effect' and argues that the magnitude of such an effect can in some cases outweigh the magnitude of the 'regression effect'. If this is the case then, although the regression effect may be significant enough to suggest a fall in the extent of technological specialisation, that is $(1 - b) > 0$, this can be offset by the size of the mobility effect, that is by a change in the proportional position of the technological fields, in symbols: $(1 - R) > 0$. Therefore, a test of the proposition that a company's extent of technological specialisation has fallen calls for an assessment of the magnitude of the regression effect alongside the mobility effect. In particular, the former should be bigger than the latter, that is: $(1 - b) > (1 - R)$, or that $(b/R) < 1$.

Notes

1 This chapter has benefited from discussions with Mike Hobday and Keith Pavitt. I would like to thank all company personnel, industry experts and US Patent Office primary examiners that gave their valuable time for interviews and Walter Garcia who gave me access to the Securities Data Company (SDC)

database. Financial support from the Targeted Socio-Economic Research (TSER) Programme of the European Commission (Research project *Corporate Governance, Innovation, and Economic Performance in the EU*, Contract no. SOE1-CT98-114; Project no. 053) is gratefully acknowledged.

2 For a comprehensive discussion of the main features of complex product systems industries see Hobday (1998). For a description of the life cycle of a complex product system see Davies (1997).

3 Interviewees underlined that new engine programmes break even after 15–20 years.

4 As confirmed by an industry expert "the reasons government [in developing countries] will do that [i.e. ask engine makers to involve national companies in the development of new engines] are very many, but essentially two. The first is the aero gas turbines are closely related to defence and therefore a country has to have the ambition in the medium or long term to have a defence capability equal to the best. The other issue is the view, totally correct view, that if you invest in very high value added technologies like the aero gas turbine, you get a spreading of the capabilities which are research, design and even management, because we are managing a very complex technology. (. . .) So many developing countries will be open to say why don't you invest in my organisation to develop gas turbine technologies for this country, because there will be spin off effects for many other people in the country."

5 It is worth noting, however, that the main reason why engine makers have entered the maintenance business is to be found in the increasing profit margins characterising this business as opposed to the nearly negative cash flow deriving from the sale of aero engines. By strengthening their position in the maintenance business, engine makers claim to be able to provide a total engine service, from physical product to engine life maintenance. In some cases the acquisition of engine maintenance companies by engine makers was part of the financial deal struck with airlines.

6 An engine's fuel consumption and reliability influence around 60 per cent of the total airline direct operating cost (DOC). The remaining 40 per cent is related to airframe costs (Todd, 1992).

7 The method of compilation of the database on which Table 9.2 is based is fully described in Prencipe (2000).

8 Companies' names have been disguised for confidentiality reasons.

9 Cantwell's methodology is fully described in the Appendix.

10 According to Laursen (1999), the statistical test for $b/R < 1$ is equivalent to an F-test of whether the variance between the two periods changes. The null hypothesis is that the variances are equal. In none of the cases presented in Table 9.5 it is possible to reject the null hypothesis.

11 The normality tests were calculated using the Microfit software package and showed that the RTA distributions analysed can be considered to be approximately normal.

References

Abernathy, W. and Utterback, J. (1975), 'A Dynamic Model of Process and Product Innovation', *Omega*, 3, 6, pp. 639–656.

Arora, A., Gambardella, A. and Rullani, E. (1998), 'Division of Labour and The Locus of Inventive Activity', *Journal of Management and Governance*, 1, 1.

Balassa, B. (1965), 'Trade Liberalisation and "Revealed" Comparative Advantage', *The Manchester School of Economics and Social Studies*, 32, pp. 99–123.

Boeing Commercial Airplanes Group (1999), *Current Market Outlook*, Seattle, US.

Cantwell, J. (1989), *Technological Innovation and Multinational Corporations*, Oxford: Blackwell.

Cantwell, J. (1991), 'Historical Trends in International Patterns of Technological Innovation', in Foreman-Peck, J. (ed.), *New Perspectives on the Late Victorian Economy*, Cambridge: Cambridge University Press.

Cantwell, J. (1993), 'Corporate Technological Specialisation in International Industries', in Casson, M. and Creedy, J. (eds), *Industrial Concentration and Economic Inequality*, London: Edward Elgar.

Chesbrough, H. and Teece, D. (1996), 'When is Virtual Virtuous: Organizing for Innovation', *Harvard Business Review*, Jan/Feb., pp. 65–74.

Davies, A. (1997), 'The Life Cycle of a Complex Product System', *International Journal of Innovation Management*, 1, 3, September, pp. 229–256.

Dierickx, I. and Cool, K. (1989), 'Asset Stock Accumulation and Sustainability of Competitive Advantage', *Management Science*, 35, 12, December, pp. 1504–1510.

Gardiner, P. and Rothwell, R. (1990), 'Design management strategies', in Dodgson, M. (eds), *Technology Strategy and the Firm: Management and Public Policy*, London: Longman.

Granstrand, O., Patel, P. and Pavitt, K. (1997), 'Multi-Technology Corporations: Why They Have 'Distributed' Rather than 'Distinctive Core' Competencies', California Management Review, 39, 4, Summer, pp. 8–25.

Hart, P.E. (1976), 'The Dynamics of Earning, 1963–1973', *Economic Journal*, 86, pp. 541–565.

Hart, P.E. and Prais, S.J. (1956), 'The Analysis of Business Concentration: A Statistical Approach', *Journal of the Royal Statistical Society*, Series A, no. 119.

Hobday, M. (1998), 'Product Complexity, Innovation, and Industrial Organisation', *Research Policy*, 26, pp. 689–710.

Laursen, K. (1998), 'A Neo-Schumpeterian Perspective on the Determinants and Effect of International Specialisation,' Unpublished PhD thesis, Aalborg University, Denmark.

Laursen, K. (1999), Personal Communication.

Mattingly, J.D., Heiser, W.H. and Daley, D.H. (1987), *Aircraft Engine Design*, Washington: American Institute of Aeronautics and Astronautics, Inc.

Miller, R., Hobday, M., Leroux-Demers, T. and Olleros, X. (1995), 'Innovation in Complex System Industries: The Case of Flight Simulators', *Industrial and Corporate Change*, 4, pp. 363–400.

Mowery, D.C. and Rosenberg, N. (1982), 'The Commercial Aircraft Industry' in Nelson, R.R. (ed.), *Government and Technological Progress*, New York: Pergamon Press.

Nakamoto, M. (1997), 'Japan Abandons Hope of Flying Solo', *Financial Times*, 10 January.

Nelson, R.R. (1991), 'Why Do Firms Differ, and How Does it Matter?', *Strategic Management Journal*, 12, 6, pp. 61–74.

Patel, P. and Pavitt, K. (1997), 'The Technological Competencies of the World's Largest Firms: Complex and Path-Dependent, but not much Variety', *Research Policy*, 26, pp. 141–156.

Pavitt, K. (1990), 'What We Know About the Strategic Management of Technology', *California Management Review*, Spring, 32, 3, 17–26.

Penrose, E. (1959, 1995), *The Theory of the Growth of the Firm*, London: Basil Blackwell.

Prencipe, A. (2000), 'Breadth and Depth of Technological Capabilities in Complex Product Systems: The Case of the Aircraft Engine Control System', *Research Policy, Special Issue on Complex Product Systems* (forthcoming).

Rolls-Royce (1997), *Market Outlook 1996–2015.*

Sanchez, R. and Mahoney, J. (1996), 'Modularity, Flexibility, and Knowledge Management in Product and Organisation Design', *Strategic Management Journal,* 17, Winter Special Issue, pp. 63–76.

Simon, H. (1962), 'The Architecture of Complexity', *Proceedings of the American Philosophical Society,* 106, 6, December, pp. 467–482.

Simon, H. (1976), 'How Complex Are Complex Systems?', *Proceedings of the Philosophy of Science Association,* 2, pp. 507–522.

Soete, L.L.G. (1981), 'A General Test of the Technological Gap Trade Theory', *Weltwirtschaftliches Archiv,* 117, pp. 638–666.

Todd, S. (1992), 'The Trent Airframe and Engine Integration to Benefit the Customer', paper presented at the Royal Aeronautics Society Conference Engine Airframe Integration, Nottingham, UK, 15–16 October.

Ulrich, K.T. (1995), 'The Role of Product Architecture in the Manufacturing Firm', *Research Policy,* 24, pp. 419–440.

Von Hippel, E. (1990), 'Task Partitioning: An Innovation Process Variable', *Research Policy,* 19, pp. 407–418.

Part IV

Strategy and management

10 An historical change in the nature of corporate technological diversification

John Cantwell[1]

1 Introduction

In this chapter historical case study evidence is presented which suggests that corporate technological trajectories tend to be generally path-dependent, but with a continual drift that changes the composition and extent of technological diversification. Cantwell and Fai (1999) had observed path-dependency in the profiles of corporate technological specialisation of 30 large firms over the 60-year period from 1930–90, in that these profiles tended to persist over time, even if they were subject to gradual or incremental change. However, that study also found some evolution and diversification in the patterns of corporate technological capabilities over time. This chapter looks in greater depth at the specific historical paths followed by four of these large firms in their corporate technological trajectories, and over the longer period 1890–1995. In doing so more can be said about the precise nature of the evolution that occurred, and about the character of changes in corporate technological diversification. What is more, the question can be addressed of whether, if profiles of corporate technological capabilities tend to persist over periods of 60 years (such that the specificities of a firm's primary technological origins can still be identified as being present 60 years later), does the same hold for periods as long as 100 years or more?

The four firms chosen were the two of the world leaders in each of the chemical and electrical equipment industries respectively. The origins of most of the present leaders in the chemical industry can be traced back to the end of the nineteenth century and even further back in the case of the German companies (Beer, 1959). The leading German firms, which were the international pioneers of in-house corporate research and development (R&D), enjoyed great early success, none more so than Bayer (L.F. Haber, 1971). The post prominent companies including Bayer merged their operations into IG Farben between 1925 and 1945, before reconstituting themselves individually again in the post-war era (as Hoechst, BASF and Bayer). Their continuing presence in an internationally leading capacity over a hundred years later constitutes a remarkable demonstration of the perseverance of technological prowess. Only slightly less remarkably, Du Pont had been the first US company to open in-house research facilities in the chemical industry, and having risen to a leading world position in the inter-war period, also has a record of success that traces back over a hundred years. Likewise, in the electrical equipment industry, the largest firms in the US and Europe trace their origins back to the nineteenth century. In terms of the longevity and the significance of their technological contributions, perhaps the two best known of these are General Electric and American Telephone and Telegraph (AT&T), whose research histories have been well documented (Reich, 1985), but both of which continue to be world leaders through to the present day.

The focus of attention here is on the long-term paths of technological development of these companies, based on the proposition that history matters, in the sense that the technological characteristics of such large companies (during the period under consideration) were heavily influenced – and constrained – by the type of technological activities that they or their predecessors had carried out in the past. This notion of organisational continuity can be supported with reference to David's (1994) explanation of the role of historical experience in forming mutually consistent expectations that facilitate coordination without the need to rely perpetually on centralised direction, and the role of the interrelatedness that tends to develop among the constituent elements of complex human organisations, as well as by the earlier concept of the central place of organisational routines as representing embedded experience in the course of evolutionary social learning (Nelson and Winter, 1982). In order to compare the evolutionary paths in the sectoral composition of the innovative activity of firms over time we require a quantitative measure of their technological activities. This chapter uses patents granted in the US to Du Pont, IG Farben (and later Bayer), General Electric and AT&T as a measure of the extent and the spread of the technological achievements of these companies. We contend that patents may be used with relatively good confidence as a proxy measure of the rate and direction of the technological change of these companies, active as they all are in science-based industries.

The chapter is divided into five sections. The next section introduces the data to be used in the analysis, discusses the suitability of using patent statistics as a measure of corporate technological activities, and briefly reviews the methodology adopted. Section 3 looks at the evolution of technological capabilities at Du Pont and IG Farben (and later Bayer) through the use of corporate patent data, and section 4 conducts an equivalent analysis of General Electric and AT&T. In the final section some summary cross-firm comparative measures of corporate technological diversification are presented and assessed, and conclusions are drawn with respect to the distinctive technological paths followed by each company.

2 The data and methodology

2.1 The companies selected

The research presented in this chapter, based on a study of four firms, is part of a wider project on long-term patterns of technological change (over a period of more than a century) of the largest US and European industrial companies. For the purposes of the wider project, two types of information have been collected manually from the *US Index of Patents* and the *US Patent Office Gazette.* First, all patents were recorded that were assigned to a selection of large US-owned and European-owned firms between 1890 and 1968. From 1969 onwards equivalent information has been computerised by the US Patent and Trademark Office (USPTO). The firms selected for the historical patent search were identified in one of three ways. The first group consisted of those firms which have accounted for the highest levels of US patenting after 1969; the second group comprised other US, German or British firms which were historically among the largest 200 industrial corporations in each of these countries (derived from lists in Chandler, 1990); and the third group was made up of other companies which featured prominently in the US patent records of earlier years (a method that proved most significant for a number of French firms that had not been identified from other sources).

In each case, patents were counted as belonging to a common corporate group where they were assigned to affiliates of a parent company. Affiliate names were normally taken from individual company histories. In all, the US patenting of 857 companies or affiliates was traced historically; together these comprise 284 corporate groups. Owing to historical changes in ownership, 17 of the affiliates were allocated to more than one corporate group over the period as a whole. Where patents have been assigned to firms, the inventor is normally an employee of the company or is directly associated with it in some other way, but occasionally independent individual inventors do choose to assign their patents to firms (Schmookler, 1966). Assignments by independent individuals were more common in the nineteenth century but, at least from the inter-war years onwards, the typical assignor was a prominent member of a corporate research laboratory, or some other similar in-house company facility. Although it is normally difficult to trace these named individuals in secondary sources on the firms concerned (as they are not usually also senior managers), the location of assignors can be checked against business history sources on the international location of activity in particular firms. Such checks on a selection of large firms have confirmed that whenever a location has been responsible for significant numbers of patents being assigned to a company, that firm did indeed have some in-house facility in the location in question at the relevant time. Companies checked in this fashion include various US firms active abroad and European companies in the US (Stocking and Watkins, 1946; Beaton, 1957; Wilkins, 1974, 1989; Chandler, 1990) including IG Farben and its predecessors (Plumpe, 1990), Du Pont and ICI (Hounshell and Smith, 1988), Courtaulds and British Celanese (Coleman, 1969), and AT&T, General Electric and the British GEC (Reich, 1985; Jones and Marriot, 1971).

The six firms that were granted the largest volume of US patents historically were, in descending order, General Electric, AT&T, Westinghouse Electric, IG Farben, RCA and Du Pont (for the years 1890–1947, the details for which are given in Tables 10.3 and 10.6 below). So as to be able to compare the long-run trends in technological specialisation of the two leading firms in each of two broadly defined industries – electrical equipment and chemicals – in this chapter GE, AT&T, IG and Du Pont are the companies selected for closer study. For the purposes of data continuity in the case of the earlier historical years, the founders of IG – namely, Bayer, BASF, Hoechst and Agfa – are treated together collectively prior to the formation of IG Farben in 1925. With the break-up of IG Farben after 1945, for the purposes of the post-war period attention is directed instead to the leading member of what had been the IG group, namely Bayer.

To construct a measure of technological specialisation of firms the first step is to devise a classification of fields of technological activity, which is derived from the USPTO patent class system. Fortunately, as these classes change the USPTO reclassifies all earlier patents accordingly, so the classification is historically consistent. This study uses the classification scheme that was in operation at the end of 1995, which is then applied backwards in time. Every patent was classified by the USPTO under at least one such class and sub-class. Although patents can be assigned to more than one field, the primary classification was used in all cases. Various broad categories of technological activity were derived by allocating classes or subclasses to common groups of activity. Patents granted to the companies included in the study were classified in this manner to a total of 23 technological sectors for each industrial group, representing the principal areas of development in each of these industries respectively. For the wider project patents have been allocated to one of the 56 fields of technological activity set out in Table 10.1. However, not all of these fields are important for the firms of a given industry, so for this study some of the less significant fields are grouped together in each industry, such that the sectoral composition across 23 areas is specifically designed to suit the analysis of patterns of specialisation in the chemical and electrical equipment industries separately. The particular disaggregation chosen for each industry is shown in Table 10.2.

2.2 Patent statistics as a measure of technological activities

Patent statistics present a potentially very rich source of empirical evidence on questions related to technological change (see Schmookler, 1966;

Table 10.1 The classification of 56 fields of technological activity

1	Food and tobacco products
2	Distillation processes
3	Inorganic chemicals
4	Agricultural chemicals
5	Chemical processes
6	Photographic chemistry
7	Cleaning agents and other compositions
8	Disinfecting and preserving
9	Synthetic resins and fibres
10	Bleaching and dyeing
11	Other organic compounds
12	Pharmaceuticals and biotechnology
13	Metallurgical processes
14	Miscellaneous metal products
15	Food, drink and tobacco equipment
16	Chemical and allied equipment
17	Metal working equipment
18	Paper making apparatus
19	Building material processing equipment
20	Assembly and material handling equipment
21	Agricultural equipment
22	Other construction and excavating equipment
23	Mining equipment
24	Electrical lamp manufacturing
25	Textile and clothing machinery
26	Printing and publishing machinery
27	Woodworking tools and machinery
28	Other specialised machinery
29	Other general industrial equipment
30	Mechanical calculators and typewriters
31	Power plants
32	Nuclear reactors
33	Telecommunications
34	Other electrical communication systems
35	Special radio systems
36	Image and sound equipment
37	Illumination devices
38	Electrical devices and systems
39	Other general electrical equipment
40	Semiconductors
41	Office equipment and data processing systems
42	Internal combustion engines
43	Motor vehicles
44	Aircraft
45	Ships and marine propulsion
46	Railways and railway equipment
47	Other transport equipment
48	Textiles, clothing and leather
49	Rubber and plastic products
50	Non-metallic mineral products
51	Coal and petroleum products
52	Photographic equipment
53	Other instruments and controls
54	Wood products
55	Explosive compositions and charges
56	Other manufacturing and non-industrial

Table 10.2 The relationship of the 23 fields of technological activity used for each industry, to the original 56 sector classification

Field	*Chemical industry* *56 sector codes included*	*Electrical equipment industry* *56 sector codes included*
1	2	2–12, 55
2	3	13
3	4	14
4	5	24
5	6	15–23, 25–30
6	7	33
7	8	34
8	9	35
9	10	36
10	11	37
11	12	38
12	13, 14	39
13	16	40
14	15, 17–30	41
15	33–41	42, 43
16	42–47	44–47
17	48	48
18	49	49
19	50, 54	50, 53
20	51	51
21	52, 53	52
22	55	53
23	1, 31, 32, 56	1, 31, 32, 56

Scherer *et al.*, 1959; Pavitt, 1985, 1988; Griliches, 1990). The learning process which generates accumulated capability in companies relies on inputs of new knowledge and inventions, and so long as the pattern of knowledge requirements thus reflects the underlying distribution of technological competence across firms, corporate patents may be used as a proxy for the underlying pattern of technological change, and not merely as a direct measure of inventions. It is argued that US patent data provide the most useful basis for international comparisons, given the common screening procedures imposed by the US Patent Office (Pavitt and Soete, 1980; Soete, 1987; Pavitt, 1988). Additionally, as the US is the world's largest single market, it is likely that firms (especially large ones), will register for a patent there after patenting in their home countries. It is also reasonable to assume that such foreign patents registered in the US are likely to be on average of higher quality or significance. US patents reveal to which firm each patent was granted, and with which type of technological activity the patent is associated.

Looking within the innovating firms themselves, the hypothesis here of path-dependence and persistence in the profiles of corporate technological specialisation comes not so much from the characteristics of the knowledge generation process (R&D) itself, but from the structure of downstream learning and problem-solving in and around production, which calls for the creation of specialised knowledge inputs in specific fields. Thus, our use of patent statistics regards them as a measure of inputs (into innovation, the creation of new commercial products and processes) and not outputs (from R&D); that is, codified knowledge inputs into the processes of problem-solving and learning in production, through which technological competence is created. Of course, this does imply that there may still be potential problems with an input-based classification scheme derived from the patent class system, given the way in which technologies from different disciplinary foundations may be integrated, and given some arbitrariness in the division between certain patent classes. We have tried to alleviate this difficulty by devising a classification scheme that groups together patent classes that are the most technologically related, as described above.

So while Schmookler (1966) used patents as a direct measure of invention as such and others (Scherer, 1983; Bound *et al.*, 1984) have since used them as an indirect (output) measure of R&D inputs, the patents granted to the largest industrial firms are used here instead as an indirect (input) measure of the pattern of technological change in these companies. In this sense patents represent knowledge inputs into the corporate learning processes that give rise to changes in production methods, the creation of which knowledge has generally been tailored to the problem-solving agenda of such learning in production. This is a valid inference so long as the knowledge requirements of the learning processes by which firms generate accumulated capabilities reflect the profile of those resultant technological competences across types of innovative activity. Just as the location of inventors that assigned patents to each firm has been checked against the known location of corporate research facilities as mentioned above, so too the sectoral distribution of corporate patenting has been checked against the more qualitative or archival evidence of business history sources on the equivalent firms. Again, we have found an approximate matching between the quantitative patterns of patenting and the qualitative accounts of the primary fields of R&D and productive expertise of the same firms (as described in Plumpe, 1995; Hounshell and Smith, 1988; Reich, 1985). In one respect what is done here is to provide a greater formalisation of propositions on the evolution of the composition of technological specialisation and the degree of technological diversification that can already be found descriptively in business history stories.

Without fully reviewing the literature on the use of patent statistics, it may be worth mentioning two of the problems that have been raised. First, the fact that companies do not patent all their inventions and therefore, any comparison may be biased in favour of those firms which rely more on patenting relative to secrecy; and second, the fact that those inventions which do get patented differ in their economic and commercial significance. With regard to the first problem, there is evidence which suggests that differences in the propensity to patent are more significant when comparing firms from different industries (Scherer, 1983). We may assume that companies in the chemical industry (or alternatively in the electrical equipment industry) have a similar attitude towards patenting, allowing for a comparison of their technological capabilities based on their patenting activity. However, we have to consider that even within a company the propensity to patent varies between technological fields. Therefore, for the comparative analysis here an indicator of relative specialisation is used rather than absolute numbers of patents, as explained below.

The second question regarding the difference in quality of patented inventions may not necessarily be a significant obstacle when assessing the breadth of a company's innovative capabilities. Since patents are not only issued on the most significant inventions but also on other related discoveries, they are useful in the analysis of general trends in the sectoral composition of technological activities (which may cover a wider spectrum than important invention alone). For instance, a major shift in the level of a company's patenting in a particular sector, relative to the aggregate level, is likely to indicate a shift in the focus of its technological efforts. Consequently we may conclude that despite differences in the "quality" of individual patents, comparisons between rival companies across the entire distribution of their respective patenting can shed light on the composition or spread of the technological expertise of firms. Other evidence confirms the suitability of patent data as a measure of corporate technological effort, particularly in inter-firm comparisons within an industry (Griliches, 1990). They are available, they go back over a hundred years, and allow for a technological classification at a greater level of detail than any other measure of technological activity (such as R&D statistics).

The business histories of the firms studied here can also be cited to show how patenting mattered to them as part of their strategy, and with respect to the construction of technology exchange arrangements with other large firms in their respective industries (see Cantwell and Barrera, 1998). Reich (1977) discusses the importance of patents to the struggle to control radio that included both GE and AT&T. Plumpe (1990) shows that the level of IG Farben's patent applications in Germany was consistent with its research and development (R&D) activities, which gives us an indication of the company's reliance on patents. In addition, IG Farben's negotiations with Standard Oil, which led to the establishment of a joint venture in the US, together with the activities of the US subsidiary of IG, General Aniline and Film, confirm how these patents had to be extended to the US market. However, since we will be using data on patents granted to these companies in the United States, it should be allowed that Du Pont, being a US company, was more prone to patent in its home country than would have been IG Farben. This is another reason for using relative rather than absolute numbers.

2.3 The indicators of corporate technological specialisation derived from patenting

Arguments such as those just considered, and other issues that have been well documented demonstrate the need for caution in the use of patent statistics (Basberg, 1987; Pavitt, 1988; Griliches, 1990; Archibugi, 1992; Patel and Pavitt, 1997, 1998). However, a number of the difficulties in the use of patent data have been avoided in our approach through relevant disaggregation and the construction of an appropriate index. Inter-industry differences in patenting propensity are reduced as the chapter deals with intra-industry comparisons only, although admittedly the industrial groups are defined very broadly (but so too is the span of activity of the very large companies under consideration). It is recognised that inter-sectoral (across technological fields) or inter-firm differences in the propensity to patent may arise, but these are controlled for here by the use of the Revealed Technological Advantage (RTA) index (Cantwell, 1989, 1993; Cantwell and Andersen, 1996; Patel and Pavitt, 1997, 1998). The RTA is an indicator of a firm's technological specialisation across a spectrum of technological activity relative to that of other firms in the same industry. The RTA of a firm in a particular field of technological activity is given by the firm's share in that field of US patents granted to all companies in the same industrial group, relative to the firm's overall share of all US patents assigned to all firms in the industry in question. If P_{ij} denotes the number of US patents granted in a particular industry to firm i in technological activity j, the RTA index is defined as:

$$RTA_{ij} = (P_{ij}/\Sigma_i P_{ij})/(\Sigma_j P_{ij}/\Sigma_{ij} P_{ij})$$

The index varies around unity, such that a value in excess of one shows that the firm is specialised in that field of activity in relation to other firms in its industrial group. In this manner inter-sectoral differences in the propensity to patent are normalised in the numerator of the RTA index, and inter-firm differences are normalised in the denominator. There still remains the possibility of intra-firm and intra-sectoral differences in the propensity to patent, but it is likely that the respective variances of these two factors are systematically lower than the inter-firm and inter-sectoral differences.

The degree of technological diversification of the firm is measured by the inverse of the coefficient of variation of the RTA index, CV_i, across all the relevant fields for the firm. Therefore, for firm i in each period considered, the proxy DIV_i for technological diversification will be the reciprocal of the CV_i. In particular:[2]

$$DIV_i = 1/CV_i = \mu_{RTA_i}/\sigma_{RTA_i}$$

where σ_{RTA_i} is the standard deviation and μ_{RTA_i} is the mean value of the RTA distribution for the firm i.

3 Technological development at IG Farben and Du Pont

A central proposition here is that, to a great extent, the research traditions of the companies which joined in the formation of IG Farben in 1925 regulated the subsequent technological development of the new company, and are likely to be reflected as well in the path of its descendants. The major German chemical companies such as Bayer, BASF and Hoeschst had their origins in the dyestuffs industry, one of the most dynamic chemical sectors at the turn of the century. These companies managed to bridge the gap between industrial and academic chemistry by incorporating and organising research within the dye workplaces. Consequently, they had accomplished great innovative and technical achievements prior to their amalgamation into IG Farben. Certainly in the first part of the twentieth century, the technological supremacy of these companies was still unchallenged (Beer, 1959). These German companies had traditionally dominated the world dyestuffs market, including in the US. Furthermore they had established barriers to entry which proved very difficult to circumvent. These seemed to be the case when, with the outbreak of the First World War, the US market was cut off from German imports. Lacking a research tradition in this area, American companies found it almost impossible to replicate the broad range of dyes which the Germans had introduced.

It seems that after the First World War, dyestuffs had nevertheless lost relative importance, and the German chemical companies expanded into other areas of activity, such as nitrogenous fertilisers, plastics, photographic products and synthetic materials (L.F. Haber, 1971). However, the 1926 figures for IG Farben's research staff show that as much as 76 per cent of the labour employed at the companies laboratories was still concentrated in dyestuffs and dyeing processes research; with about 9 per cent of the research staff engaged on the newer fields of pharmaceuticals, synthetic fibres and photographic chemicals (Plumpe, 1990). Other technologies gaining ground on dyestuffs included cleaning agents and other compositions (coatings and plastics in particular), and coal and petroleum research (the oil from coal hydrogenation process).[3] Yet the fastest-growing technologies from the 1930s were those grouped under synthetic resins and fibres. By the 1930s the chemical industry seems to have built upon organic chemistry to move into synthetic materials, photographic chemistry and petrochemicals.

By contrast, Du Pont's origins had been in the explosives business. Its first research laboratory (which opened in 1902) had been established to deal with the problems inherent in the manufacturing process. However, a threat to the company's monopolistic position in the smokeless powder market seems to have prompted the need for diversification. This move was influenced by the company's excess capacity following the expansion of production during the First World War, and for which alternative uses would have to be found in peace time. With cash available after the war, and based on its experience with cellulose technology (used in the manufacturing of explosives), the company expanded into related areas mainly through the acquisition and further refinement of firms and technologies (Hounshell and Smith, 1988). Following this strategy, by the time of IG Farben's merger, Du Pont had broadened its areas of activity. In addition to explosives, the company had diversified into paints (Duco being a major innovation), silk, leather and cellulose. As with explosives, these products were based on nitrocellulose technology. The company had bought its way into the production of cellophane and developed moisture-proof cellophane, a successful new product. In addition, Du Pont had finally accomplished the production of dyestuffs following a major struggle to circumvent the barriers established by the German companies (which involved the government's establishment of a higher import tariff in the years following the war). R&D expenditures in 1926 give us an idea about the extent of this diversification – roughly 15 per cent of research spending was into explosives, 25 per cent in general chemicals, 27 per cent in paints and related chemicals, 19 per cent in dyestuffs and 6 per cent in plastics (Hounshell and Smith, 1988).

Comparing the evolution of the German companies with that of Du Pont prior to 1926, it appears that their technological strategies had been different (Dornseifer, 1989, 1995). Whereas the German firms had relied more on internal generation of innovation (through their strong in-house research), Du Pont had relied more on external sources, i.e. acquisitions. Lacking a research tradition in areas outside its core technology, Du Pont took advantage of the strengths of its organisation to incorporate those acquired technologies and develop them further (Chandler, 1990). By contrast, IG Farben's predecessors had continued to rely on the internal dynamism of the research organisations that they had built.

Table 10.3 presents evidence on US patents granted to the largest chemical firms. In absolute terms (see last row) US patenting activity in the chemical sector experienced sustained growth throughout 1890 to 1947, with the partial exception of the period 1920–24, when there was a fall attributable to the effects of the war. The position of the German dyestuffs companies (here amalgamated under IG Farben) is even more remarkable than the high shares, given that, as mentioned above, US companies had a higher propensity to patent their innovations in the US. Indeed, Du Pont lagged behind in second place until the late 1930s. This overwhelmingly commanding position of IG Farben (in what follows this name also applies to its predecessors prior to 1925) was particularly

Table 10.3 Percentage share of US patenting of large chemical and petrochemical companies

	1890–1919	*1920–24*	*1925–29*	*1930–34*	*1935–39*	*1940–47*	*Average 1890–1947*	*1991–95*	*Average 1890–1995*
Chemical firms									
IG Farben	56.22	11.37	28.86	30.75	18.74	5.58	19.81	N.A.	2.64
Hoechst	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	8.47	4.01
Bayer	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	8.39	5.57
BASF	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	6.02	2.79
Du Pont	7.17	15.19	8.99	11.61	19.13	17.46	15.27	7.95	9.17
Dow Chemical	1.26	5.03	2.37	5.12	3.47	4.94	4.09	7.10	6.04
Union Carbide	7.53	15.68	7.58	3.66	4.73	4.16	5.05	1.41	3.59
Allied Chemical	4.76	13.81	6.69	6.87	4.34	2.35	4.44	0.08	1.50
ICI	1.82	1.54	1.86	4.36	4.07	2.61	3.13	2.66	2.87
British Celanese	0.40	2.11	3.08	6.37	8.10	3.89	4.93	N.A.	0.87
Celanese Corp	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	0.34	0.86
Swiss IG	5.80	5.04	5.20	3.38	3.33	2.89	3.56	N.A.	N.A.
Ciba Geigy	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	5.06	4.25
Sandoz	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	0.72	0.88
Total Chemicals (%)	96.75	82.05	77.60	81.84	78.12	66.78	76.26	80.74	74.19
Oil firms									
Standard Oil NJ	0.77	4.14	5.91	5.68	4.90	9.45	6.45	N.A.	N.A.
Exxon	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	3.32	5.20
Shell	0.13	0.24	0.63	1.47	4.00	5.38	3.42	3.62	3.52
Total Oil (%)	3.25	17.95	22.40	18.16	21.88	33.22	23.74	19.26	25.82
Total Number	4,518	1,231	2,692	8,079	11,398	17,906	45,824	37,033	343,703

Source: US Index of Patents, Patent Gazette and computerised data from the US Patent and Trademark Office.

Notes
Prior to 1926 IG Farben's and ICI's figures correspond to the aggregate of their predecessor companies; a similar procedure applies to Swiss IG.
N.A. = Not applicable.

apparent in the period prior to the First World War. However, the figures for the 1920–24 and 1940–47 periods may be somewhat underestimated, since after the two wars the Alien Property Custodian confiscated thousands of German patents, which had not yet been assigned to the relevant companies. Nevertheless, note that although IG Farben was dissolved in 1945, the relevant period allows for the inclusion of two additional years (to 1947) during which the confiscated American subsidiaries of IG Farben were still patenting.

3.1 The evolution of technological capabilities in IG Farben and Bayer

Table 10.4 presents the cross-field RTA index over time for the IG group and latterly for Bayer. As explained earlier, the RTA index shows the firm's share of patenting in a given technological field (among patents granted to all large firms in the chemical industry), relative to its equivalent share of total chemical industry patenting in all fields for each period considered. It can be seen that, in spite of the fact that IG Farben's research remained heavily concentrated in organic chemistry (as that of its predecessor companies had been) as shown by an RTA value consistently above one, changes began to occur to its profile of technological specialisation in other parts of the cross-sectoral distribution. There was even some decline in related bleaching and dyeing processes after the merger that constituted the IG group in 1925.

Looking back to the turn of the twentieth century, it can be seen that Table 10.4 provides evidence that is entirely consistent with what is already known about the early development of the chemical industry, and of the large German firms in the chemical industry in particular. That their histories were essentially coincident at that stage reflects the dominant position in the industry of the German leaders. The industry began with the development of artificial dyestuffs in the 1870s, from which it moved into photographic chemicals and synthetic fibres in the early years of the twentieth century. The predecessors of IG Farben led the way, as is shown by the RTA values above one in 1890–1919 in Table 10.4. In the 1920s and 1930s the IG group diversified further into fertilisers (listed here under agricultural chemicals) and pharmaceuticals. Following the formation of IG in 1925 synthetic resins and fibres steadily gained in importance in the group's profile of technological effort, the RTA rising from 0.45 in 1925–29 to 1.14 in 1940–47. The latter may partly reflect the company's research into synthetic rubber which led to the development of PVC (Freeman, 1982). In addition, intensification of research in photo-chemicals (from 1.92 to 2.65 over the same period) seems to have been associated with developments in related product areas, namely an involvement in photographic equipment (here included under the other scientific instruments category, the RTA for which was well above 1 throughout 1925–47). In this case technological diversification was linked to product

Table 10.4 Evolution of patterns of technological specialisation at IG Farben, 1890 to 1995

	IG Farben						*Cumul.*	*Bayer*	*Cumul.*
Technological sectors	*1890–1919*	*1920–24*	*1925–29*	*1930–34*	*1935–39*	*1940–47*	*1890–1947*	*1991–95*	*1947–95*
Distillation processes	0.34	0.80	1.01	0.36	0.60	0.58	0.42	1.33	0.74
Inorganic chemicals	0.58	0.84	0.96	1.16	0.73	0.62	0.97	0.81	0.48
Agricultural chemicals	0.47	2.40	0.90	1.30	0.99	0.22	0.92	1.96	1.53
Chemical processes	0.50	0.42	0.88	0.63	0.68	0.61	0.59	0.56	0.61
Photographic chemistry	1.45	7.21	1.92	2.40	3.00	2.65	1.95	2.48	3.26
Cleaning agents and other compositions	0.64	0.14	0.59	0.81	0.63	0.52	0.56	0.57	0.51
Disinfecting and preserving	0.00	0.00	0.00	0.00	0.00	1.71	0.17	0.33	0.41
Synthetic resins and fibres	1.58	0.34	0.45	0.96	0.90	1.14	0.70	1.41	1.41
Bleaching and dyeing processes	1.53	4.38	1.44	0.82	0.94	1.27	1.16	1.01	0.88
Other organic compounds (including dyestuffs)	1.33	1.96	1.30	1.33	1.35	1.33	1.48	1.23	0.91
Pharmaceuticals	0.92	1.55	1.14	0.93	1.28	0.97	0.96	0.86	1.31
Metals	0.49	0.72	0.57	0.60	0.46	0.36	0.45	0.40	0.48
Chemical and allied equipment	0.38	0.18	0.64	0.53	0.44	0.39	0.47	1.11	0.90
Mechanical engineering nes.	0.13	0.29	0.52	0.36	0.25	0.20	0.24	0.38	0.53
Electrical equipment nes.	0.07	0.00	0.07	0.33	0.61	0.93	0.28	0.37	0.38
Transport equipment	0.34	0.00	0.34	0.53	0.78	0.00	0.39	0.37	0.51
Textiles, clothing, leather	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.42
Rubber and plastic products	0.11	0.42	0.29	0.49	0.44	0.31	0.29	0.76	0.78
Non-metallic mineral and wood products	0.26	0.39	0.09	0.43	0.50	0.31	0.32	0.58	0.56
Coal and petroleum products	1.17	0.00	1.08	0.95	1.58	2.72	1.30	0.38	0.29
Professional and scientific instruments	0.06	0.48	1.56	1.62	2.62	1.88	1.46	0.98	2.39
Explosive compositions and charges	0.07	0.00	0.00	0.00	0.06	0.00	0.05	0.00	0.01
Other manufacturing	0.10	0.00	0.00	0.17	0.17	0.89	0.21	0.26	0.20

Source: As for Table 10.3.

diversification into the photographic sector, as represented by the Agfa branch of the group, this and other parts of the IG group having developed the complementary technological expertise in photographic chemistry.

One noteworthy diversification feature of the inter-war period is that coal and petroleum research reached an all-time high in the period following the merger (particularly from the late 1930s). This confirms other evidence about IG Farben's renewed interests in coal liquefaction, which had been initiated at one of the company's predecessors (Beer, 1959). While this may have originally been commercially inspired in the 1920s and early 1930s when other chemical firms followed suit in investing in the apparently promising field of oil from coal, most other large firms that had experimented with this possibility divested from the area during the 1930s as the early promise was disappointing. This helps to explain how IG's RTA in the field rose from 1.08 in 1925–29 to 2.72 in 1940–47. The reason seems fairly clear – by this stage IG Farben had become obliged to assist in the Nazi war effort, and as is well known the principal German military weakness was that it lacked its own oil supply.

Perhaps the most remarkable part of the IG story comes from updating the account to consider the subsequent profile of technological specialisation of its largest successor company, Bayer. In this context we focus on a comparison of the pattern of technological specialisation of the IG Farben group as a whole over 1890–1947 with that of Bayer over 1947–95, but with an eye on the position of Bayer in the most recent sub-period, 1991–95, to see whether there are any substantive shifts in the pattern of specialisation that appear to have emerged in the latest years. A rationale for comparing two very long-term periods of 1890–1947 and 1947–95 is itself the belief that the knowledge base of firms is cumulative and incremental (Nelson and Winter, 1982; Rosenberg, 1982; Cantwell, 1989). What comes out of this comparison is indeed a picture of the most remarkable continuity. The oldest strength in dyestuffs has held up and indeed even reasserted itself most recently (an RTA of 1.23 in 1991–95), while the new developments that had emerged early in the twentieth century and been either reinforced or established as a strength in IG Farben in the inter-war period remain evident in Bayer today. Thus, consider the RTA values in 1947–95 in synthetic resins and fibres (1.41), photographic chemistry (3.26) and instruments (2.39); pharmaceuticals also stands at 1.31, but this advantage has been eroded recently (0.86 in 1991–95). In contrast, the inter-war specialisation in oil-related chemicals has disappeared (an RTA in the Bayer years of 0.29), driven as it was more by external military demands than by the specificities of internal capabilities and commercial logic. In contrast, what had been for IG in the 1930s the newly emergent strength in fertilisers and agricultural chemicals has successfully reappeared in Bayer (an RTA of 1.53 in 1947–95, and 1.96 in 1991–95).

3.2 The evolution of technological capabilities at Du Pont

Looking at the evolution of Du Pont's technological specialisation (Table 10.5), through to 1947 the company preserved its founding strength in the field of explosives. However, given its incredibly high degree of focus on explosives (an RTA of 11.16 in 1890–1919), it was almost inevitable that growth would take the form of – to some extent – moving away from its original research activities in and around explosives and allied technologies (chemical and distillation processes, cellulose, silk and leather with textile applications – with RTAs in 1890–1919 of 1.76, 5.40 and 13.49 respectively), initially into rubber and plastics (2.70 in 1890–1919), and then into synthetic resins and fibres (3.05 in 1925–29). The emergence and subsequent rise of the development of synthetic materials in the 1920s and 1930s seems to be for Du Pont the most striking phenomenon of the inter-war period. This confirms other evidence regarding the company's research into polymers which eventually led to the discovery of nylon, the first synthetic fibre and Du Pont's most successful product.[4]

By contrast with IG Farben, organic chemistry was never an area of comparative strength at Du Pont, and it emerged to respectability in this field (an RTA of 0.99 in 1935–39) only after the First World War. Since this was not a traditional area of research for the company, its moderate catching up partly reflects the company's cooperative agreement with the ICI (after 1929), a central objective of which was to enable these partners to better match the industry leader, IG Farben (see Cantwell and Barrera, 1998). A sustained position in rubber and plastic technologies through the inter-war years reflects in part the rise in Du Pont's research in polymers leading to the discovery of neoprene (Hounshell and Smith, 1988). An interesting feature hidden by aggregation in Table 10.5 is the growth of the development of textile and clothing machinery (within mechanical engineering), which may have spun off from the interest in synthetic fibres, and particularly nylon.

What is most striking from a comparison with IG Farben is that while Du Pont began with a much more focused spectrum of technological specialisation early in the twentieth century than that of IG, reflecting its later start and smaller size, it had become notably more diversified than IG by the 1940s. This again can be related to the strategy of acquisitions rather than internal growth. Over 1890–1947 as a whole, Du Pont held a technological specialisation among others in cleaning agents and compositions (an RTA of 1.61), chemical processes (1.20), synthetic resins and fibres (1.81), disinfecting and preserving (1.09), textiles and leather (1.15), non-metallic mineral products (1.77), rubber and plastic products (1.43), distillation processes (1.08) and of course in explosives technologies (3.14). Within chemical processes, the most important technologies were coating processes, adhesive bonding and chemistry and electrical and wave energy. Cleaning agents and other compositions included paints

Table 10.5 Evolution of patterns of technological specialisation at Du Pont, 1890 to 1995

Technological sectors	*1890–1919*	*1920–24*	*1925–29*	*1930–34*	*1935–39*	*1940–47*	*Cumul. 1890–1947*	*1991–95*	*Cumul. 1947–95*
Distillation processes	5.40	1.80	3.24	1.08	0.87	0.82	1.08	2.80	1.48
Inorganic chemicals	0.49	0.63	0.71	0.85	1.16	1.16	0.87	0.91	1.35
Agricultural chemicals	0.00	0.00	0.00	1.03	0.49	1.04	0.78	0.57	1.18
Chemical processes	1.76	1.25	0.81	0.76	1.26	1.20	1.20	1.26	1.15
Photographic chemistry	0.00	0.00	2.47	0.52	0.50	1.06	0.97	1.82	1.50
Cleaning agents and other compositions	1.98	1.51	2.48	1.71	1.52	1.33	1.61	0.90	1.21
Disinfecting and preserving	0.00	0.00	0.00	2.82	0.00	1.64	1.09	1.05	0.62
Synthetic resins and fibres	0.00	0.77	3.05	2.29	1.39	1.53	1.81	1.06	1.19
Bleaching and dyeing processes	0.00	0.39	0.32	0.75	0.73	0.85	0.73	0.49	0.82
Other organic compounds (including dyestuffs)	0.18	0.63	0.85	0.82	0.99	0.87	0.80	0.70	0.78
Pharmaceuticals	0.00	0.77	1.32	1.43	0.73	0.72	0.85	0.27	0.29
Metals	0.96	0.72	0.92	0.81	0.68	0.74	0.78	1.10	1.03
Chemical and allied equipment	3.16	1.98	1.40	0.87	0.99	0.82	1.03	0.86	1.06
Mechanical engineering nes.	3.04	1.15	0.38	0.75	0.59	0.61	0.73	1.57	1.23
Electrical equipment nes.	0.14	0.05	0.08	0.19	0.45	0.64	0.29	2.56	1.05
Transport equipment	6.75	3.60	2.16	0.00	0.51	0.38	1.00	0.78	1.69
Textiles, clothing, leather	13.49	3.60	0.00	0.00	1.48	0.38	1.15	6.25	1.26
Rubber and plastic products	2.70	0.95	1.23	0.97	0.97	1.47	1.43	2.79	1.70
Non-metallic mineral and wood products	1.04	1.75	1.39	2.14	1.39	1.64	1.77	1.88	1.68
Coal and petroleum products	0.54	0.95	0.43	0.69	0.97	0.75	0.78	1.74	1.56
Professional and scientific instruments	1.35	0.36	0.20	0.24	0.25	0.32	0.33	1.00	0.71
Explosive compositions and charges	11.16	4.02	5.34	4.50	1.87	1.78	3.14	0.56	2.70
Other manufacturing	8.34	3.47	3.84	1.43	1.29	0.88	1.69	0.95	1.09

Source: As for Table 10.3.

and lacquers, with "Duco" (the trademark product) being its most important innovation in this field (Hounshell and Smith, 1988).

However, despite a path that emphasised technological diversification at Du Pont compared to greater consolidation among the IG group, Du Pont's corporate technological trajectory from 1900–47 was in many respects even more coherent in its direction than that followed by IG. The early moves away from explosives mainly represented the development of nitro-cellulose technologies – cellulose (used in the manufacturing process of explosives), silk and leather, chemical processes (including coating and bonding) and paints. From here came the development of cellophane. Then, having worked with rayon and cellulose acetate textile fibres, the company was well placed to diversify into (and to lead) the synthetic fibre revolution (Hounshell and Smith, 1988).

Much of this structure was then preserved in the post-war period. In 1947–95 (and in 1991–95) Du Pont retained an RTA greater than one in distillation processes, chemical processes, synthetic resins and fibres, textiles, clothing and leather, rubber and plastic products. However, although this remained true also of explosives in 1947–95 as a whole (an RTA of 2.70), it is striking that by 1991–95 this original primary source of strength had finally lapsed (the RTA value standing at 0.56). Conversely, to a greater extent than in the post-war experience of Bayer, new strengths have emerged in Du Pont in 1947–95 in mechanical processes (an RTA of 1.23 in 1947–95 and 1.57 in 1991–95), electrical equipment (1.05 in 1947–95 and 2.56 in 1991–95), and coal and petroleum products (1.56 in 1947–95 and 1.74 in 1991–95). The latter emergent strength in oil-related chemicals may be somewhat ironic given Bayer's post-war retreat from that field, but in Du Pont it can be traced back to the development of polymer intermediates that derived from the long tradition in explosives (Hounshell, 1995). So perhaps some residue of Du Pont's path-dependent history stemming from its beginnings in explosives remains through to the present day after all.

4 Technological development at GE and AT&T

As has been seen already in the case of chemicals, the science-based industries that began towards the end of the nineteenth century were characterised by growth through horizontal diversification into technologically related fields. However, vertical diversification into related mechanical fields mattered too, as in the case of IG's move into photographic equipment, and Du Pont's move into textile machinery. Nevertheless, horizontal science-related diversification was the essential theme of corporate technological trajectories in the chemical industry. In comparison, the development of vertically integrated systems was relatively more important in the electrical equipment industry, broadly defined. The electrical equipment industry focused from the outset on the design of complex and interrelated technological systems, of which certain components might lie either ahead (salients) or behind (reverse salients) the general front of development at any point in time, whereby progress in other parts of the overall system is either facilitated or constrained (Aitken, 1985; Hughes, 1983, 1989).

While in the chemical industry the largest German companies were the world leaders, in the electrical industry that role was taken up by the largest US firms. The firms examined here were associated with the founding of the two central planks of the industry – namely, electrical lighting, power, traction and related machinery (in the person of Edison, whose role is discussed by David, 1991), and the telephone (in the person of Bell). General Electric was formed in 1892 from the merger of the Edison General Electric Company and the Thomson-Houston Electric Company, while AT&T was originally a subsidiary of American Bell set up in 1885, which with financial reorganisation in 1899 became the holding company for the entire Bell group (Reich, 1985). The original overlap between these two branches of the industry lay in electrical devices and systems, and in some general machinery. This overlap illustrates how the leading firms in this industry were concerned to establish integrated systems, and not the (perhaps interconnected range of) more narrowly defined products that were typical in the chemical industry. The connection between the two segments of the industry became much sharper from the inter-war years onwards with the development of the radio, and subsequently the television. The radio was the primary focus of growth in the electrical equipment industry in the inter-war period, and both parts of the industry made critical contributions to this new area of development.

Table 10.6 shows the comparative patenting records of the leading firms in the electrical equipment industry. It shows how AT&T (Bell) was the leading research organisation and the dominant corporate patenter in the 1920s (which made it the highest ranked patenting firm in any industry), but that at other times – before the First World War and once again from the 1930s onwards – this role fell to GE. The early 1920s saw a substantial growth and diversification of research at AT&T, which gave rise to the establishment of Bell Telephone Laboratories in 1925, the formation of which gave a further impulse to R&D in the company (Maclaurin, 1949; Nobel, 1979; Reich, 1985). Westinghouse Electric was not far behind the big two, while RCA was set up by GE in 1919 to take over the assets it had acquired of American Marconi in the nascent radio industry. By 1921 Westinghouse Electric and AT&T had also entered into a partnership with RCA in the radio industry, which therefore of course was also a partnership with GE in the development of radio systems (Reich, 1977). During the post-war period while GE has remained the industry leader the others have gradually declined somewhat (and in the case of AT&T been broken up), and large firms from other countries have caught up. The German firm Siemens is a prime example, but there are also the newer Japanese companies that have not been considered here.

Table 10.6 Percentage share of US patenting of large electrical equipment companies

	1890–1919	*1920–24*	*1925–29*	*1930–34*	*1935–39*	*1940–47*	*Average 1890–1947*	*1991–95*	*Average 1890–1995*
General Electric	49.71	21.52	25.21	28.53	27.21	26.97	30.90	23.58	25.26
AT&T	20.17	34.65	34.26	25.96	20.32	19.81	24.02	13.58	16.94
Westinghouse Electric	23.72	37.64	29.85	21.44	15.24	19.09	22.45	8.00	15.20
RCA	1.66	1.72	2.54	8.86	19.37	19.50	10.78	0.30	9.71
ITT	0.05	0.43	0.78	2.07	1.39	5.95	2.31	2.61	5.11
Siemens	2.43	1.52	2.45	4.12	3.62	1.39	2.59	14.40	7.26
AEG	0.45	0.43	1.57	2.87	6.38	2.36	2.54	0.26	1.27
Total number	13,057	4,883	9,524	12,003	12,005	18,503	70,025	19,184	241,069

Source: As for Table 10.3.

4.1 The evolution of technological capabilities at GE

Given the complex systems nature especially of that part of the electrical business in which GE was active, and given what is known about the breadth of interest of GE in particular from the beginning across the range of electric lighting, power and transport components, it is hardly surprising that the evidence on the spread of GE's technological specialisation set out in Table 10.7 shows that it was far more diversified in its range of expertise in 1890–1919 than were our other large companies. Although this high initial span of corporate technological diversification is indeed partly attributable to the systems nature especially of this segment of the electrical equipment industry from the start, it may also have something to do with relatively wide inventive interests of Edison, and his comparative advantage as an inventor in the design and construction of electromechanical systems (Reich, 1985). This is akin to David's (1991) assessment of the significance of the individual personality of Edison as an influence on historical paths, in this case helping to establish GE as an innovator across a broad front, which has remained as a feature of GE's capabilities (compared to its major competitors) through to the present day.

This having been said, GE embarked on a further technological diversification in the final decade of the 1890–1919 period (Reich, 1985), and this is encompassed in the aggregation of the years 1890–1919 into a combined period for the purposes of comparison with other companies (for which change was concentrated in the inter-war years). The earliest strengths in electric lighting, power and traction are here reflected in RTA values greater than one for 1890–1919 in illumination devices, electrical lamp manufacturing equipment, general electric equipment, other machinery and industrial equipment, vehicle (components) and other transport equipment. Other areas of GE technological advantage are best related to developments that came in the early part of the twentieth century. An RTA greater than unity in metallurgy can be related to the development of ductile tungsten filaments for incandescent electric lighting, while that in chemicals may relate to advances in heat insulation and refrigeration (Reich, 1985).

What is most striking about GE's subsequent corporate technological trajectory is its high degree of path-dependency and persistence, even across the very wide front of capabilities over which it operated. Almost all the primary fields of advantage in 1890–1919 were also areas of advantage for GE in 1940–47 (including illumination devices, electric lamp manufacture, chemicals and pharmaceuticals, metallurgical processes, other machinery and industrial equipment, other general electrical equipment, motor vehicles and engines, other transport equipment, building materials and coal and petroleum products). Perhaps even more remarkably, GE continued to enjoy an RTA greater than one in all these fields in

Table 10.7 Evolution of patterns of technological specialisation at General Electric, 1890 to 1995

Technological sectors	*1890–1919*	*1920–24*	*1925–29*	*1930–34*	*1935–39*	*1940–47*	*Cumul. 1890–1947*	*1991–95*	*Cumul. 1947–95*
Chemicals and pharmaceuticals	1.14	1.09	0.93	1.04	1.19	2.09	1.40	2.48	1.82
Metallurgical processes	1.21	2.14	1.15	1.12	1.39	1.21	1.21	1.89	1.35
Miscellaneous metal products	0.89	1.43	1.03	0.98	1.24	1.12	1.03	0.97	1.36
Electrical lamp manufacturing equipment	1.61	1.69	1.27	1.42	1.75	1.54	1.46	0.45	1.06
Other machinery and industrial equipment	1.41	1.25	0.89	0.93	1.41	1.15	1.22	1.60	1.26
Telecommunications	0.04	0.16	0.13	0.11	0.11	0.17	0.11	0.17	0.16
Other electrical communication systems	0.33	0.46	0.84	1.11	0.80	0.62	0.64	0.54	0.56
Special radio systems	0.00	1.60	0.60	0.24	0.28	0.20	0.24	0.64	0.31
Image and sound equipment	0.19	0.07	0.37	0.43	0.11	0.16	0.23	0.28	0.30
Illumination devices	1.30	1.55	1.62	1.51	1.37	1.02	1.28	0.90	1.12
Electrical devices and systems	1.01	1.37	1.33	1.26	1.08	1.20	1.15	0.59	1.06
Other general electrical equipment	1.14	1.21	1.68	1.52	1.56	1.45	1.44	0.88	1.43
Semiconductors	0.00	0.00	0.79	1.28	0.64	0.48	0.61	0.33	0.46
Office equipment, computers, and other data processing	0.13	0.20	0.75	0.61	0.18	0.18	0.30	0.47	0.44
Motor vehicles and engines	1.73	1.55	1.26	1.11	1.38	1.69	1.92	0.75	1.50
Other transport equipment	1.10	0.77	0.97	1.07	1.33	1.05	1.34	2.30	1.44
Textiles, clothing and leather	2.01	0.00	3.97	0.00	1.05	1.48	1.03	0.00	0.96
Rubber and plastic products	1.01	0.62	0.91	0.50	1.02	0.55	0.76	2.07	1.22
Building materials	1.16	1.39	1.72	0.95	1.79	1.58	1.35	2.27	1.55
Coal and petroleum products	2.01	0.00	3.97	2.04	1.47	1.01	1.66	2.83	1.91
Photographic equipment	1.44	0.00	0.57	0.98	0.46	0.56	0.72	0.20	0.41
Other instruments and controls	1.25	1.28	1.04	1.13	1.14	1.10	1.16	0.88	0.90
Other manufacturing and non-industrial	1.37	0.91	0.79	1.20	1.58	0.85	1.13	2.08	1.33

Source: As for Table 10.3.

1947–95! However, in its original core field of lighting it had declined by 1991–95. Thus, by this last period, GE's RTA in illumination devices had fallen to 0.90, while in electric lamp manufacturing equipment it had dropped as low as 0.45. No doubt lighting is not as central to new development in the electrical equipment industry now as it once was, but given the overall forcefulness of GE's technological path-dependency over a wide range of activities, this retreat from its historical origins is noteworthy, even though it has taken the best part of a century to reach that turning point away from the past.

4.2 The evolution of technological capabilities at AT&T

AT&T (Bell Telephone as it was) began with a much sharper focus in its technological specialisation than that at GE, concentrating its efforts on the telephone, and on related technologies. This is readily apparent from Table 10.8, and from a comparison of Table 10.8 with Table 10.7. In 1890–1919 the company was primarily focused on its origins in telecommunications (an RTA value of 4.50), together with the closely allied fields of other electrical communication systems (3.68) and image and sound equipment (3.12). Also, it had established a related base in metal product technologies (an RTA of 1.22), no doubt given the need to work on the detailed development of telephone receivers, transmitters, cables and the like. Between them, these four fields of technological endeavour were the only ones out of the 23 areas of activity under consideration in which AT&T held RTA values greater than one in 1890–1919. In contrast, GE had an RTA above unity in no less than 16 out of 23 fields over the same period (see Table 10.7).

From the 1920s onwards, and especially after the formation of Bell Laboratories in 1925, AT&T was engaged in a substantial technological diversification largely in support of (rather than away from) its continuing core interests in telecommunications (Reich, 1985). This theme is again well illustrated in Table 10.8. In 1925–29, AT&T had added to the fields in which it held an RTA value above one (among others) the three areas of metallurgical processes (1.08), rubber and plastic products (1.33) and office equipment and other data processing (1.40). These three new fields of strength are likely to have been related to respectively the firm's development in the 1920s of metallic contacts for telephone switching apparatus and the properties of magnetic materials, enamel and phenol-fibre insulation, and telephone and telegraph transmission parameters (Reich, 1985). In 1930–34 an RTA above one was further attained in other machinery and industrial equipment (then 1.04), representing again a recognition of the role of vertical systems integration in the direction of diversification in the electrical equipment industry.

By 1940–47 all these new fields just referred to continued to hold an RTA greater than unity in AT&T – metallurgical processes at 1.80,

Table 10.8 Evolution of patterns of technological specialisation at AT&T, 1890 to 1995

Technological sectors	*1890–1919*	*1920–24*	*1925–29*	*1930–34*	*1935–39*	*1940–47*	*Cumul. 1890–1947*	*1991–95*	*Cumul. 1947–95*
Chemicals and pharmaceuticals	0.34	0.61	0.85	0.87	0.87	0.73	0.71	0.82	0.72
Metallurgical processes	0.41	0.48	1.08	1.54	1.38	1.80	1.27	0.86	1.20
Miscellaneous metal products	1.22	0.70	0.69	1.50	1.82	1.22	1.21	0.30	0.85
Electrical lamp manufacturing equipment	0.28	1.57	0.47	0.18	0.82	0.36	0.47	0.16	0.37
Other machinery and industrial equipment	0.37	0.53	0.75	1.04	1.02	1.40	0.90	0.42	0.95
Telecommunications	4.50	2.53	2.32	2.26	1.95	2.15	2.65	2.77	2.77
Other electrical communication systems	3.68	2.21	1.28	1.09	1.83	2.04	1.94	1.12	1.48
Special radio systems	0.35	0.70	1.02	0.93	0.47	0.48	0.58	0.20	0.63
Image and sound equipment	3.12	2.48	1.77	1.43	1.50	1.05	1.59	0.86	1.00
Illumination devices	0.42	0.59	0.56	0.35	0.39	0.58	0.44	0.08	0.39
Electrical devices and systems	0.73	0.64	0.70	0.71	0.91	0.73	0.74	0.99	0.92
Other general electrical equipment	0.15	0.15	0.24	0.35	0.34	0.40	0.26	0.95	0.45
Semiconductors	0.00	2.89	0.00	0.39	0.62	0.51	0.45	1.19	1.04
Office equipment, computers, and other data processing	0.31	0.75	1.40	1.07	1.12	0.98	0.95	0.99	1.13
Motor vehicles and engines	0.18	0.43	0.53	0.09	0.12	0.00	0.21	0.00	0.17
Other transport equipment	0.12	0.15	0.07	0.32	0.15	0.29	0.14	0.00	0.20
Textiles, clothing and leather	0.00	2.89	0.00	0.64	1.41	0.00	0.76	0.00	0.80
Rubber and plastic products	0.17	0.38	1.33	2.11	1.09	1.93	1.41	0.69	1.19
Building materials	0.51	0.51	0.43	0.89	0.99	1.13	0.80	0.55	0.73
Coal and petroleum products	0.00	0.00	0.00	0.32	0.00	0.00	0.12	0.00	0.28
Photographic equipment	0.71	0.00	1.67	1.23	0.82	0.00	0.83	0.00	0.63
Other instruments and controls	0.32	0.61	0.58	0.87	0.77	0.69	0.65	1.18	0.86
Other manufacturing and non-industrial	0.65	1.09	1.34	1.00	1.27	1.14	1.10	0.26	0.43

Source: As for Table 10.3.

machinery and industrial equipment at 1.40 and rubber and plastic products at 1.93 – but with the partial exception of office equipment and data processing at 0.98. Needless to say the established advantage was retained through to 1940–47 in telecommunications (2.15), other electrical communication systems (2.04), image and sound equipment (1.05) and metal products (1.22). In other words, over a combined period of well over 50 years AT&T preserved its core technological competence, but effectively built around it. As has been commented upon already, AT&T was also involved as a major contributor to the development of the inter-war radio industry. However, while it had moved substantively into special radio systems (an RTA of 1.02 in 1925–29) and various instrument technologies (0.87 in 1930–34), these never became its relative strength compared to its major rivals (and most notably compared with RCA, of course). Even in image and sound equipment there was a significant relative decline in the 1940s (from 1.50 in 1935–39 to 1.05 in 1940–47), following the advent of commercial television in the US and the new focus of experimentation that this provided (Abramson, 1995).

In essence, AT&T's technological profile persisted also into the post-war period. In the years 1947–95 considered together, AT&T retained its indicator of positive corporate technological specialisation in telecommunications (2.77), other electrical communication systems (1.48), image and sound equipment (1.00), as well as in metallurgical processes (1.20) and rubber and plastic products (1.19), but had lost its position in metal products (0.85). Key strengths persist all the way through to the latest period of 1991–95 in its core fields of telecommunications (2.77) and other electrical communication systems (1.12). However, by 1991–95 the company had witnessed some decline of its relative capabilities in image and sound equipment (0.86) and metallurgical processes (0.86), and a clear fall in metal products (0.30) and rubber and plastic products (0.69). Replacing these areas, AT&T now has advantages in instruments (1.18) and semiconductors (1.19), for which the antecedents had been laid in the inter-war years, but on which a relative focus of development attention emerged only recently. Yet despite some shift in the overall composition of its technological trajectory, AT&T's continuing strong concentration on its telecommunications origins (2.77) is evident.

5 Diversification revisited, and some conclusions

The evidence seems to confirm that all the large firms considered here followed specific and path-dependent corporate technological trajectories, in that the distinctive characteristics of their early years exercised an influence on the composition and breadth of their subsequent technological capabilities, and the direction in which they evolved. Despite the fact that these large companies broadened their areas of research, until at least the post-war period they remained specialised in those fields which had been their original stronghold. However, Du Pont and GE seem to have experienced a more radical departure from their original core technology than did IG Farben (and later Bayer) and AT&T. Nevertheless, even the extension of Bayer's and AT&T's research activities also led to a gradual diversification into some other related areas of strength. It is noticeable that the intensification of research in certain key areas appears to have spun off allied innovations in other fields. This underlines the importance of interrelatedness of technology, whereby a major technological breakthrough tends to generate further innovations in connected fields, a feature of particular significance for firms in the science-based industries. It also helps to show the usefulness of patent statistics as a means of tracing the historical paths followed by large firms when considered across their entire distribution, as important patents are unlikely to be isolated while unimportant ones may be. While the patterns described here are entirely consistent with the qualitative evidence of business histories, they add some precision by facilitating clearer comparisons between the positions and paths of firms operating in similar industries.

Having commented on the extent of corporate technological diversification and how it evolved historically in each of our individual company descriptions of paths of specialisation, it is time to summarise these trends through an examination of our more formal indicator of diversification DIV, the reciprocal of the coefficient of each company's RTA distribution across fields (as explained above). The values of this indicator are set out in Table 10.9. The first row of the table, concerning 1890–1919, affirms

Table 10.9 Evolution of corporate technological diversification, 1890 to 1995

Period	*IG Farben*	*Bayer*	*Du Pont*	*GE*	*AT&T*
1890–1919	1.04	N.A.	0.71	1.64	0.66
1920–24	0.57	N.A.	1.06	1.35	1.07
1925–29	1.23	N.A.	1.00	1.32	1.33
1930–34	1.27	N.A.	1.14	2.03	1.59
1935–39	1.10	N.A.	2.00	2.01	1.71
1940–59	N.A.	0.79	2.68	1.87	1.65
1960–64	N.A.	0.83	1.90	1.42	1.37
1965–68	N.A.	0.91	2.66	1.68	1.09
1969–72	N.A.	0.91	2.63	1.87	1.16
1973–77	N.A.	0.95	1.98	1.41	1.15
1978–82	N.A.	1.34	1.58	1.31	1.19
1983–86	N.A.	1.34	1.50	1.36	1.32
1987–90	N.A.	1.50	1.46	1.20	0.89
1991–95	N.A.	1.31	1.17	1.28	0.98
1890–1995	0.89	1.15	2.56	2.04	1.52

Source: As for Table 10.3.

Note
N.A. = Not applicable.

what has already become clear from the discussion of Tables 10.5 through to 10.8. That is, corporate technological diversification was much more pronounced from the outset in general electrical systems (as represented by GE, with a DIV value of 1.64 in 1890–1919) than it was in chemicals (1.04 in what became the IG group combined, and a still more concentrated 0.71 in Du Pont), but telecommunications was more like the latter than the former (with a DIV as low as 0.61 in AT&T for the equivalent period).

By the end of the inter-war period both Du Pont and AT&T had largely caught up with the span of diversified technological development at GE. Thus, in 1935–39 Du Pont's DIV value had risen as high as 2.00, and that of AT&T to 1.71, as against a value of 2.01 in the case of GE. IG Farben was the firm out of step in this respect, in that while it had been gradually diversifying through to 1930–34, at which stage it remained more diversified than Du Pont (a DIV value of 1.27 as against 1.14 for Du Pont), in the later 1930s what appeared to be its natural commercial path became distorted by the need to be attuned to the military objectives of the new German government. The fall in IG's DIV value in 1935–39 (to 1.10) was particularly associated with its further move into oil-related chemicals, exactly at the time when Du Pont was diversifying heavily into a range of new chemical processes following (and associated with) its successful transition into synthetic resins and fibres.

Bringing the story closer to the present day, there tends now to be less difference between large firms in the scope of their technological diversification, compared to the inter-company variety of diversification that was often observed in the past. By 1991–95 the DIV measure seems to have converged among firms to a range of around 1.0 through to 1.3. Compared to the long-term historical average value of DIV (for 1890–1995 as a whole) this represents a rise for Bayer (to 1.31 in 1991–95, as opposed to 1.15 in its own post-war history, or even 0.89 for the IG group in earlier times), a fall for AT&T (from 1.52 as a long-term average through to 1.32 in 1983–86, and then 0.98 in 1991–95, although the sharpness of this recent structural shift reflects the break-up of AT&T and the greater focusing of its remaining business), but a significant decline for Du Pont (1.17 in 1991–95 vs 2.56 in 1890–1995) and GE (1.28 in 1991–95 vs 2.04 in 1890–1995).

Looking across companies and over time the general trend that is observed is of a steady initial increase in technological diversification historically, followed by a renewed concentration in more recent times. The three of our four companies with the greatest continuity of historical identity (Du Pont, GE and AT&T) describe this pattern most clearly, in that the DIV values with which they began in 1890–1919, and those with which they finished in 1991–95, were both well below their respective long-term averages for DIV in 1890–1995 as a whole. If one allows for the specificities of the experience of IG Farben in its later years (its contribution to the

German war effort), and for the smaller size of Bayer which was only part of the original group and the recovery of the German chemical industry in the early post-war period, one can also see an historical trend towards diversification, from a DIV value of 1.04 in 1890–1919 through to 1.27 in 1930–34 and then to 1.34 in Bayer in 1978–82. Although Bayer's DIV value did not decline after 1978–82, it has seen no further sustained increase since that time (standing at 1.31 in 1991–95).

While in the early post-war years there was some continuation of the inter-war diversification trend (into e.g. photographic chemistry) in both Du Pont and Bayer, from around 1970 Du Pont has refocused its technological efforts (with a fall in DIV from 2.63 in 1969–72 to 1.17 in 1991–95). In comparison the reversal of the diversifying trend began earlier in the post-war period in the electrical equipment industry, with some moderate refocusing of technological efforts in GE until around 1970 (the DIV indicator fell from 2.01 in 1935–39 to 1.87 in 1969–72), and in AT&T until the mid-1980s (a drop from 1.71 in 1935–39 to 1.32 in 1983–86, having been as low as 1.16 in 1969–72). Since then there has been a clearer refocusing upon a more closely related set of technological activities in GE from around 1970 (from 1.87 in 1969–72 to 1.28 in 1991–95) and in AT&T following its break-up (from 1.32 in 1983–86 to 0.98 in 1991–95).

Some explanation can be offered for the apparent switch in the long-term direction of corporate technological diversification in at least this group of the largest firms (in terms of their patent volume), away from pro-diversifying change and towards an increasing focus of effort. In the first phase of the growth of large industrial companies, from around the end of the nineteenth century through to the Second World War, product diversification and technological diversification were much more closely connected to one another, through attempts to realise the joint economies of scale and scope (as documented in depth by Chandler, 1990). In the second phase of such growth since 1945, and especially since around 1970, corporate technological diversification has acquired a new motive apart from the simple support of product or market diversification. That is, in more recent times the primary motive has become the potential rewards from rising technological interrelatedness between formerly largely separate and discrete branches of innovative activity. These are new and more dynamic economies of scope, associated with continuous knowledge spillovers between allied fields of learning, and with the creation of new and more complex technological combinations.

While for many smaller companies this shift of motives has meant a new impulse towards greater technological diversification than in the past to incorporate what have become the most closely related areas to their own core business, in some giant firms the greater potential inner benefits of interrelatedness has meant instead a refocusing of efforts around that combination of their established areas which have become most closely related (Cantwell and Santangelo, 2000). Thus, the drivers of corporate technological diversification have shifted from the coverage of related products and markets in the first phase of large company growth, to the relatedness to be found in innovative activity itself, and in the construction of new technological combinations in the second phase in the growth of large firms. So technological diversification associated with a steady movement outwards into new markets and technologically related products has been gradually replaced by often more focused combinations of technological activity to capture the fruits of interrelatedness in the competence creation process itself.

Meanwhile, path-dependency has prevailed throughout the last hundred years or so of the corporate technological trajectories of these large firms, but it is a path-dependency accompanied with the gradual drift that is associated with most stochastic processes. The gradual drift away from the initial competence base of a large firm implies that while the direction of corporate technological diversification may be explicable ex post (as argued by Breschi, Lissoni and Malerba in Chapter 3, this volume, it constructs a coherent and not a random set of new combinations), it is not predictable ex ante with any degree of precision or reliability. Bayer has continued with IG Farben's traditions in dyestuffs, photographic chemistry and fibres through to the present day, but Du Pont has eventually moved away from its historic origins in explosives. AT&T continues to hold its primary position in electrical communication systems, but GE has eventually moved away from illumination devices and lamp manufacture. Taken together these large company technological histories show how corporate technological trajectories have the typical property of path-dependency with some continual drift, and not a strong kind of "lock-in" configuration of the kind sometimes proposed in the context of other discussions of path-dependency and its implications.

Notes

1 The author is grateful for the support of the UK Economic and Social Research Council, who funded the project on long-term technological change in the largest US and European firms on which this chapter draws, and to Pilar Barrera, who worked with him on that project. He is also grateful for the help of Jane Myers and Jim Hirabayashi at the US Patent and Trademark Office.

2 The CV measure has often been used as well in the analysis of business concentration across firms within an industry, as opposed to concentration or dispersion across sectors within a firm (see Hart and Prais, 1956). It is worth noticing that alternative measures could be used (e.g. the Herfindhal index) but that for a given number of firms or sectors (N), there is a strict relationship between the Herfindhal index (H) and the coefficient of variation (CV) (Hart, 1971). The relationship is: $H = (CV^2 + 1)/N$.

3 There is evidence that during the inter-war period there was a close overlap between oil and petrochemical research in the chemical industry (Freeman, 1982).

4 "Nylon became far and away the biggest money-maker in the history of the Du Pont Company" (Hounshell and Smith, 1988, p. 273).

References

Abramson, A. (1995), *Zworykin: Pioneer of Television*, Urbana, IL: University of Illinois Press.

Aitken, H.G.J. (1985), *The Continuous Wave: Technology and American Radio, 1900–1932*, Princeton, NJ: Princeton University Press.

Archibugi, D. (1992), "Patenting as an indicator of technological innovation: a review", *Science and Public Policy* vol. 19, pp. 357–368.

Basberg, B.L. (1987), "Patents and the measurement of technological change: a survey of the literature", *Research Policy* vol. 16, pp. 131–141.

Beaton, K. (1957), *Enterprise in Oil: A History of Shell in the United States*, New York, NY: Appleton-Century-Crofts.

Beer, J.J. (1959), *The Emergence of the German Dye Industry*, Urbana, IL: University of Illinois Press.

Bound, J., Cummins, C., Griliches, Z., Hall, B.H. and Jaffe, A.B. (1984), "Who does R&D and who patents?", in Z. Griliches (ed.), *R&D, Patents and Productivity*, Chicago, IL: University of Chicago Press.

Cantwell, J.A. (1989), *Technological Innovation and Multinational Corporations*, Oxford: Basil Blackwell.

Cantwell, J.A. (1993), "Corporate technological specialization in international industries", in M.C. Casson and J. Creedy (eds), *Industrial Concentration and Economic Inequality: Essays in Honour of Peter Hart*, Aldershot: Edward Elgar.

Cantwell, J.A. and Andersen, H.B. (1996), "A statistical analysis of corporate technological leadership historically", *Economics of Innovation and New Technology* vol. 4, pp. 211–234.

Cantwell, J.A. and Barrera, M.P. (1998), "The localisation of corporate technological trajectories in the interwar cartels: cooperative learning versus an exchange of knowledge", *Economics of Innovation and New Technology* vol. 6, pp. 257–290.

Cantwell, J.A. and Fai, F.M. (1999), "Firms as the source of innovation and growth: the evolution of technological competence", *Journal of Evolutionary Economics* vol. 9, pp. 331–366.

Cantwell, J.A. and Santangelo, G.D. (2000), "Capitalism, profits and innovation in the new techno-economic paradigm", *Journal of Evolutionary Economics* vol. 10, pp. 131–157.

Chandler, A.D. (1990), *Scale and Scope: The Dynamics of Industrial Capitalism*, Cambridge, MA: Harvard University Press.

Coleman, D.C. (1969). *Courtaulds: An Economic and Social History (Volume II: Rayon)*, Oxford and New York, NY: Oxford University Press.

David, P.A. (1991), "The hero and the herd in technological history: reflections on Thomas Edison and the battle of the systems", in P. Higonnet, D.S. Landes and H. Rosovsky (eds), *Favorites of Fortune: Technology, Growth and Economic Development Since the Industrial Revolution*, Cambridge, MA: Harvard University Press.

David, P.A. (1994), "Why are institutions the 'carriers of history'?: path dependence and the evolution of conventions, organizations and institutions", *Structural Change and Economic Dynamics* vol. 4, pp. 205–220.

Dornseifer, B. (1989), "Research, innovation and corporate structure: Du Pont and IG Farben in comparative perspective", Harvard University Graduate School of Business Administration Working Paper, Spring.

Dornseifer, B. (1995), "Strategy, technological capability and innovation: German enterprises in comparative perspective", in F. Caron, P. Erker and W. Fischer (eds), *Innovations in the European Economy Between the Wars,* Berlin: de Gruyter.

Freeman, C. (1982), *The Economics of Industrial Innovation,* London: Frances Pinter.

Griliches, Z. (1990), "Patent statistics as economic indicators: a survey", *Journal of Economic Literature* vol. 28, pp. 1661–1707.

Haber, L.F. (1971), *The Chemical Industry: 1900–1930,* Oxford: Oxford University Press.

Hart, P.E. (1971), "Entropy and other measures of concentration", *Journal of the Royal Statistical Society* Series A, vol. 134, pp. 73–85.

Hart, P.E. and Prais, S.J. (1956), "The analysis of business concentration: a statistical approach", *Journal of the Royal Statistical Society* Series A, vol. 119, pp. 150–191.

Hounshell, D.A. (1995), "Strategies of growth and innovation in the decentralized Du Pont company 1920–1950", in F. Caron, P. Erker and W. Fischer (eds), *Innovations in the European Economy Between the Wars,* Berlin: de Gruyter.

Hounshell, D.A. and Smith, J.K. (1988), *Science and Corporate Strategy: Du Pont R&D, 1902–1980,* Cambridge: Cambridge University Press.

Hughes, T.P. (1983), *Networks of Power: Electrification in Western Society, 1880–1930,* Baltimore, MD: Johns Hopkins University Press.

Hughes, T.P. (1989), *American Genesis: A Century of Invention and Technological Enthusiasm,* New York, NY: Viking.

Jones, R. and Marriot, O. (1971), *Anatomy of a Merger: A History of GEC, AEI and English Electric,* London: Cape Ltd.

Maclaurin, W.R. (1949), *Invention and Innovation in the Radio Industry,* London and New York, NY: Macmillan.

Nelson, R.R. and Winter, S.G. (1982), *An Evolutionary Theory of Economic Change,* Cambridge, MA: Harvard University Press.

Nobel, D.F. (1979), *America by Design: Science, Technology and the Rise of Corporate Capitalism,* New York, NY: Alfred A. Knopf.

Patel, P. and Pavitt, K.L.R. (1997), "The technological competencies of the world's largest firms: complex and path-dependent, but not much variety", *Research Policy* vol. 26, pp. 141–156.

Patel, P. and Pavitt, K.L.R. (1998), "The wide (and increasing) spread of technological competencies in the world's largest firms: a challenge to conventional wisdom", in A.D. Chandler, P. Hagström and Ö. Sölvell (eds), *The Dynamic Firm: The Role of Technology, Strategy, Organization, and Regions,* Oxford and New York, NY: Oxford University Press.

Pavitt, K.L.R. (1985), "Patent statistics as indicators of innovative activities: possibilities and problems", *Scientometrics* vol. 7 (1–2), pp. 77–99.

Pavitt, K.L.R. (1988), "Uses and abuses of patent statistics", in A. van Raan (ed.) *Handbook of Quantitative Studies of Science Policy,* Amsterdam: North Holland.

Pavitt, K.L.R. and Soete, L.L.G. (1980), "Innovative activities and export shares: some comparisons between industries and countries", in K.L.R. Pavitt (ed.), *Technical Innovation and British Performance,* London: Macmillan, pp. 38–66.

Plumpe, G. (1990), *Die IG Farbenindustrie AG. Wirtschaft, Technik und Politik 1904–1945,* Berlin: Duncker & Humblot.

Plumpe, G. (1995), "Innovation and the structure of the IG Farben", in F. Caron, P. Erker and W. Fischer (eds), *Innovations in the European Economy Between the Wars,* Berlin: de Gruyter.

Reich, L.S. (1977), "Research, patents and the struggle to control radio: a study of big business and the uses of industrial research", *Business History Review* vol. 51, pp. 208–235.

Reich, L.S. (1985), *The Making of American Industrial Research: Science and Business at GE and Bell, 1876–1926*, Cambridge and New York, NY: Cambridge University Press.

Rosenberg, N. (1982), *Inside the Black Box: Technology and Economics*, Cambridge and New York, NY: Cambridge University Press.

Scherer, F. (1983), "The propensity to patent", *International Journal of Industrial Organisation* vol. 1, pp. 107–128.

Scherer, F.M., Herzstein, S.E., Dreyfoos, A.W., Whitney, W.G., Bachmann, O.J., Pesek, C.P., Scott, C.J., Kelly, T.G. and Galvin, J.J. (1959), *Patents and the Corporation: A Report on Industrial Technology Under Changing Public Policy*, Boston, MA: J.J. Galvin (privately published).

Schmookler, J. (1966), *Invention and Economic Growth*, Cambridge, MA: Harvard University Press.

Soete, L.L.G. (1987), "The impact of technological innovation on international trade patterns: the evidence reconsidered", *Research Policy* vol. 16, pp. 101–130.

Stocking, G.W and Watkins, M.W. (1946), *Cartels in Action*, New York, NY: Twenty Century Fund.

Wilkins, M. (1974), *The Maturing of Multinational Enterprise: American Business Abroad from 1914 to 1970*, Cambridge, MA: Harvard University Press.

Wilkins, M. (1989), *The History of Foreign Investment in the United States to 1914*, Cambridge, MA: Harvard University Press.

11 Multi-technology management

Ove Granstrand

1 Introduction

1.1 How proper is the diversification fashion?

Fashions and fads plague management thinking, and to some lesser extent – hopefully – management practice. It is in fact a significant challenge to members of corporate boards and top management to avoid being overly fascinated by fashions and fads. These may very well build on some sound ideas but are then typically oversold by a host of preachers among fame-driven scholars, money-driven consultants and stock-traders and novelty-driven managers (often at higher levels!) and media, all jockeying for advantages. Diversification, with its converse specialization, is one particular example of a strategic issue being heavily subjected to fashionable thinking. An average corporation's list of product offerings has been lengthened and shortened like women's skirts over the years, at least in the Western industrialized world. In the 1960s and 1970s conglomerate diversification US-style came into vogue, based on ideas of attaining attractive growth and risk dispersion through applying various management skills across a portfolio of businesses, acquired or home-grown, related or unrelated, financed externally or internally via a corporate capital market. For this strategy, it was perfectly proper to use the by now fairly well-known divisionalized organization structure, pioneered by General Motors and Du Pont already in the 1920s, as well as recent advantages in management accounting. As it gradually became clear that the promises held out were not materializing and conglomerate profits soured under over-taxed management, 'survival of the fattest' became an issue and the fashion pendulum started to swing to the other extreme. In the 1980s and 1990s, specialization became fashionable (in the West), dressed in terms like 'back to basics', 'stick to the knitting', 'focus on core business', 'be lean and mean', 'slim the organization', downsizing, outsourcing, demerging etc. Stock prices came increasingly to reinforce this management fashion (and discount conglomerates) as the financial markets and ownership concerns developed and occupied an increasingly large share of minds among corporate boards and top management.

However, as is well known, stock prices at times do not reflect the real economy very well, so how have the conglomerates and the specialized companies fared economically over the years? In other words, what has been the relationship between degree of diversification (or specialization) and economic performance over the years? As a rule, the US-inspired type of conglomerates of the 1960s and 1970s did not perform very well (International Telephone and Telegraph (ITT), Philips, Siemens etc.) with General Electric as still (as of 2002) outstanding exception confirming the rule. On the other hand many Japanese companies diversified successfully in the 1980s (Canon, Hitachi, Toshiba etc.).

Specialization in the 1980s and 1990s improved economic performance in many cases of Western companies which, under the influence of fashionable management thinking had become overdiversified in one way or another (with too many unrelated products and/or markets). In other cases, specialization or too little diversification jeopardized the company's long-term economic performance, making it too vulnerable to downturns in business cycles or special markets or patent positions, possibly leading to a merger and acquisition (M&A) restructuring (as for Astra-Zeneca in pharmaceuticals). Also many Japanese companies had become overdiversified, mostly as a result of previous diversification successes, and were pressured to de-diversify in the Japanese economic crisis of the 1990s (Gemba and Kodama 2000).

Thus, business histories offer many lessons but do not show a clear, overall picture. In fact economic research has not found any significant connection between diversification (or specialization) and economic performance in terms of profitability (see especially Montgomery 1994, Ravenscraft and Scherer 1987).

However, diversification is a mixed bag of various strategies, including conglomerate diversification into more or less unrelated businesses, as well as diversification into businesses that are highly related product- or marketwise in terms of shared resources or other synergies. Moreover, the benefits (economies) associated with shared resources and synergies do not end up automatically on the profit-and-loss (P/L) account but have to be reaped through active management. But what kinds of guidelines are there for company boards and management to judge the proper type and amount of diversification?

1.2 Purpose and outline

The purpose of this chapter is to answer this question by penetrating a particular type of diversification related to technology and presenting some guidelines on how to manage this type of diversification successfully. In so doing, we need to distinguish between product diversification, commonly understood as extending the range of products (outputs) of a company, and technological diversification, i.e. extending the range of technologies (inputs) a company uses together with other resources for its output products. As will be seen below, recent research has shown that technological diversification has a strong, positive impact on growth of sales, but likely also on growth of expenditures on research and development (R&D) and technology acquisition – in turn giving management an incentive to utilize the company's technologies for diversifying into new product businesses, i.e. to undertake a technology-related product diversification. The chapter will first briefly illustrate the processes of product diversification as well as technological diversification, then present and explain some results from studies of company diversification strategies and their economic performance. Finally, the chapter will focus on a number of management skills or capabilities needed to successfully manage technology-related diversification processes.

1.3 Literature

A quick account of literature on diversification in general, mostly then focusing on product and market diversification, mostly in a US context, would include classic studies of large corporations such as Ansoff (1957), Penrose (1959), Gort (1962), Chandler (1962, 1990) and Rumelt (1974).

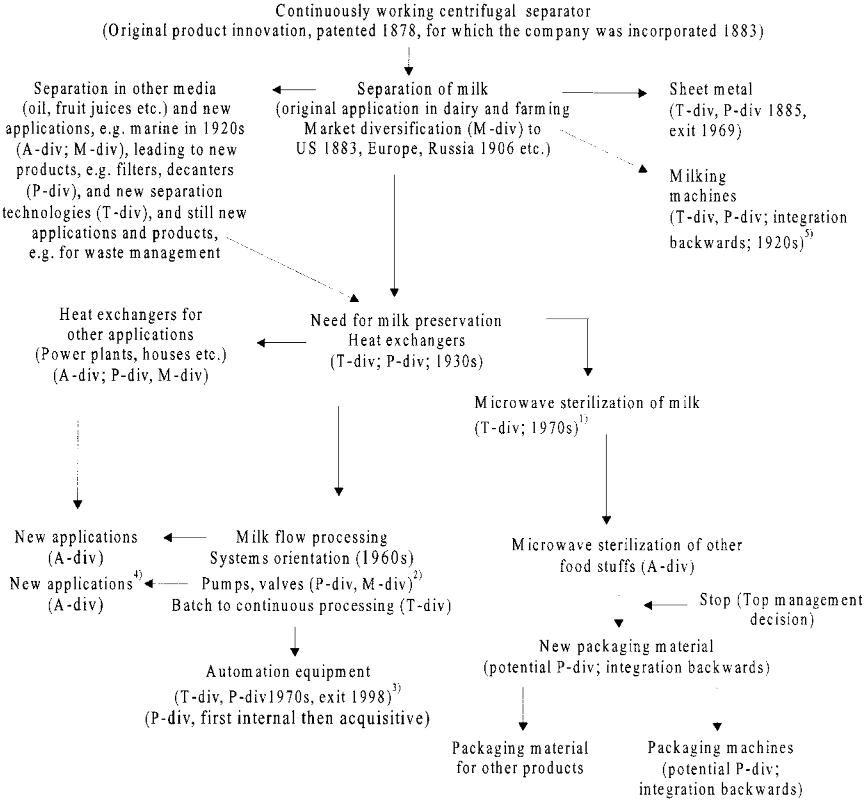
More recent studies, still in a US context, are Ravenscraft and Scherer (1987), Scott (1993) and Markides (1995). Literature surveys are given by Ramanujam and Varadarajan (1989), Montgomery (1994) and also management handbooks such as as Hitt *et al.* (2001). Essentially, the literature so far gives a mixed verdict regarding the virtues of product diversification in terms of economic performance, apart from pointing out the average underperformance of unrelated conglomerate diversification.

Literature on technological diversification is of more recent origin and has, in fact more of a non-US orientation. Kodama (1986) studied technological diversification at industry level in Japan, Pavitt *et al.* (1989) at company level in the UK, Granstrand (1982) and Granstrand and Sjölander (1990) at company level in Sweden, followed up by Oskarsson (1993), Patel and Pavitt (1994) and Granstrand *et al.* (1992, 1994, 1997) for samples of large corporations in Europe, Japan and the US. Essentially, this literature has pointed out the prevalence and nature of technological diversification and its association with economic growth and diversification in general. The literature on this topic has then grown considerably and is surveyed and elaborated in Chapter 2 (this volume).

2 Empirical findings

2.1 Cases of corporate and technological diversification

Diversification occurs at various levels in industry. A number of not very well defined levels could be discerned, e.g. levels corresponding to different sector levels (e.g. manufacturing, vehicles, cars), product area (e.g. passenger cars), product line (e.g. station wagon) and product variant or model (e.g. blue, 2003, turbo).[1] At corporate level, Figure 11.1 illustrates some types of diversification in the evolution of a particular firm. The company Alfa-Laval has a long, diversified history of which



Legend
A-div =Application diversification (application = physically similar user situations)
M-div =Market diversification (segments, regions) (market segment =behaviorally similar customers)
P-div = Product diversification (= extension of the range of product areas)
T-div = technology diversification (= extension of the range of technologies)

Notes
1) Not significant diversification for sales growth. Included as an illustrative example here of top management deciding to stop further diversification.
2) Major related acquisitions 1969, 1971.
3) P-div first through internal development, then through acquisitions (a common feature in other instances of P-div as well). Divested to ABB 1998, due to insuffient A-div to cover rising R&D costs.
4) Two major types - sanitary (incl. food and health) and industrial. Industrial pumps and valves exitted 1980s and 1990s.
5) Further P-div into various areas of farm equipment

Figure 11.1 Diversification tree – case of Alfa-Laval AB (as of 2000).

Figure 11.1 can only give a very incomplete picture. For example, the company was acquired by the packaging group Tetra Pak in 1991 (for 16 BSEK, media said), then divested in 1998, although without its liquid food processing business area, which had become integrated into Tetra Pak after the acquisition, while other areas had not. The technologies – originally for centrifugal separation of milk, through mechanical engineering related to metal forming, material science and precision engineering – then evolved (diversified) over the years, largely devoted to processing mostly liquid (rather than air or material) flows, i.e. flow processing, for which a portfolio of fairly general-purpose products was developed (separators, heat exchangers, pumps, valves etc.).

Market-pull development of new technologies and then technology leveraging (technology push) into new applications, often involving initiatives and ideas from users, then leading into new but related product areas, has been a general driving force. Mostly the successful product diversifications have been technology related in this way rather than market related. (Cases of the latter have occurred when customers have asked to be supplied with other complementary products in their flow process. In order to ensure sufficient economies of scale and scope, diversification policies have been implemented saying that at least X percent of the value of an order should relate to core products defined in technology terms.) However, diversifications have often had many relations and it is difficult to classify them as being related only in a single dimension. The diversification tree in Figure 11.1 is rather a complex diversification network. The four main types of diversification that could be discerned are the two traditionally recognized ones – product diversification into different product areas (P-div), leading to a multi-product company (MPC), and market diversification (M-div), including internationalization as a special case, leading to a multi-national company (MNC), and then two newly recognized ones – technological diversification (T-div), leading to a multi-technology company (MTC), and application diversification (A-div), leading to a range of applications for technologies within a product area. More types could of course be identified and labelled, e.g. business diversification (including services as well as products) and resource diversification (including knowledge in general and technology in particular).

Application diversification is not generally recognized in the literature as a diversification type but is generally recognized as an important phenomenon. Business histories provide ample cases of companies with new technologies and products finding and developing a range of applications over time, often in unexpected ways with unexpected successes, sometimes even overshadowing the original application. Examples are mobile phones – migrating from car phones to pocket phones or an old drug finding new medical indications as with beta blockers, originally developed and used for heart rhythm disorders, then migrating also into treatment of hypertension.

Interaction between these types of diversification processes over time provides a significant impetus to the dynamics in corporate evolution. For example, new technologies are developed or acquired (T-div) for a new product (P-div) in a specific application, as a kind of market-pull-process. The technologies thus acquired can be adapted to new applications (A-div) and/or further developed for new products (P-div), possibly requiring still more new technologies (T-div). At the same time new markets (in terms of new market segments and market regions rather than applications) are entered (M-div), bringing the company into contact with new customer groups having new requirements and ideas, leading to new products, technologies and applications and so forth. However, in cases of resource constraints different types of diversification may become adversary when competing for the same resources. For example, it has proven to be very risky to perform product diversification concurrent with market diversification (internationalization in particular), critical resources then being managerial competence and attention.

In a study of diversification processes in eight large, European MNCs[2] (Granstrand 1982) it was found that:

1 Raw material based companies were historically early product diversifiers, incentivized thereto mainly by physical by-products in raw material processing, while late internationalizers. Product innovation based companies were early and fast internationalizers while being product specialized, with product diversification growing (sometimes accidental rather than strategic, often with external impulses) in the post-war boom of the 1950s and 1960s, mainly through acquisitions, producing some failures (due to lack of competence, management and market demand), leading to de-diversification on average in the 1970s. The two world wars had on average spurred both growth and diversification (e.g. through import substitution).

2 The continuity and path-dependence were high in the evolution of the companies, and more so at higher levels of diversification (sector, product area) where corresponding product life cycles then are longer. Shifts in core business or dominant business had occurred but all companies (with century long histories on average) had stayed in their original sector and most of them in their original product area. Diversification had thus been rooted in most cases, and in general related in some way with existing resources and technologies, spurred by combinatorial opportunities in generic technologies and generic products (as with materials, chemicals and universal machine elements such as electric motors, lamps, bearings and separators), spurred also by systems orientation in industrial marketing, hampered but however, by top management's unwillingness to integrate forwards and thereby start competing with powerful industrial customers. For companies with generic (general purpose) products, typically

universal machine elements, the degree of diversification into various product areas was low while product differentiation within a product area was high, sometimes clearly uneconomically high (as when SKF's different foreign subsidiaries had developed extensive ranges of bearing variants to serve all types of their domestic customers). Leading, invention-based engineering companies such as Alfa-Laval, Philips and SKF thus ran the risk of overspecializing in a product area and overdiversifying within that area.

3 Product diversification strategies had been mixed, changing and controversial, while internationalization strategies had been steadily embraced by top management.

4 Diversification through acquisitions was a preferred mode, except in R&D intensive companies. Using R&D for product diversification had indeed occurred before the Second World War but gained momentum in the post-war era, during which corporate R&D also grew, internationalized and diversified. In general there was a close, although lagged, connection between growth, diversification and internationalization at company and R&D level, i.e. R&D grew, diversified (technologically) and internationalized eventually as the company did in terms of sales in various product areas and foreign markets.

5 Additions to, as well as shifts in, the dominant core technology of almost all corporations were found, e.g. generation shifts from carbide engineers to polymer technologists at KemaNobel (later merging into Akzo-Nobel); a series of generation shifts in electrical engineering from vacuum tubes to transistors to integrated circuits to microcomputers at Philips; chemistry, biology, electronics and systems engineering being integrated in mechanical engineering at Alfa-Laval; material scientists being promoted at SKF; metallurgists and chemists being added to the 'the mining people' at Boliden; biologists and mechanical engineers being promoted at Iggesund (pulp and paper); a transition from chemistry to biology taking place at Astra; and mechanical engineers being supplemented by various other types of engineers (electrical, chemical, engineering physics etc.) at Volvo. These changes in the portfolio of technological competencies depended on external technological developments and internal conditions such as the rise of advocates or opponents among management and technologists. Both companies and products thereby became technologically diversified, although not necessarily technologically advanced, i.e. companies and products became multi-technological ('mul-tech') rather than 'hi-tech'. In connection with technological diversification the need for new technologies grew, leading to growth of both in-house R&D and external technology acquisition through various means, in turn making in-house R&D a means also for accessing and absorbing external R&D.

6 Four different types of technological diversification were discerned.

First, there was a diversification of competencies pertaining to the core technologies of a corporation, for instance, the differentiation of polymer technology or tribology. This was a kind of 'ordinary' specialization within a technology of decisive importance to the corporation. Second, there was a diversification pertaining to adjacent technologies. These adjacent technologies could concern supporting technologies such as automation technology in production, surface chemistry for lubrication in a part of a product or materials technology. Corporate R&D often diversified into adjacent technologies through an initial stage of perception of product problems followed by attempts to solve them by extending internal knowledge, often amateurishly, or acquiring external R&D services. Third, there was substitution among different technologies, such as the transition from chemistry to biology in pharmaceutical research. Fourth, a new technology was 'picked up' for exploration because of its potential benefit to the corporation, e.g. because it could create entirely new businesses (e.g. KemaNobel acquired polymer technology and Astra went into antibiotics). Often these new technologies were science related, emerging, and possibly generic, technologies, for which the implementation in products and/or processes was not yet clear. Entry into these could proceed through internal exploratory work (e.g. Ericsson experimenting with computers in the 1950s and 1960s) and/or external acquisition of personnel, licenses, projects or companies. Of these four types – (1) differentiation of and specialization within a core technology, (2) expansion into adjacent technologies, (3) substitution of technologies and (4) involvement in new and so far unrelated technologies – the first three are product related, while the fourth is not (for the time being, at least). Thus, most but not all types of technological diversification could be said to be related to products (and their production processes) already existing in the companies.

7 The diversification into a new technology for new kinds of businesses was quite often evolutionary, with a progression through adjacent or substituting technologies. For example, the need to preserve milk led Alfa-Laval into heating and cooling, in turn leading to heat exchangers, microwaves, the preservation of other types of food and finally a new packaging technology. Alfa-Laval then decided not to go into packaging (see Figure 11.1). The concept of evolutionary chains is too simplified, though. Rather, technologies advance along some lines, may then rest until combined with some other technologies, and may then advance a bit further.

Finally, any typology of diversification of technology and R&D is vague, since conceptions of a technology are diffuse and changing. Confluences and combinations occur. Strictly speaking, technological diversification should be considered to decrease if a combination of two technologies gains coherence and recognition. For example, many corporations started to encounter different environmental problems in the 1970s and developed counter-measures in the form of corrective technologies. New competences had to be acquired, and perceptions of which technologies were adjacent and relevant changed rapidly. Hence the kind of technological diversification triggered by environmentalism is hard to classify. It may not even be considered a diversification at all after environmental technology became recognized as a specific technology. Thus, when assessing type and degree of diversification, changes in the underlying typology create classification and measurement problems.

2.2 Survey of diversification strategies for growth

Oskarsson (1993) explored whether certain corporate diversification sequences were associated with high sales growth. Observations of 57 large multinationals worldwide were classified according to sequences of diversification and specialization of technologies, products and markets. Four main patterns of strategic behavior were identified:

a Fourteen companies[3] pursued a diversification sequence of, first increased technological diversification (T-div), then product diversification (P-div) and market diversification (M-div) in this or reverse order. These companies were called ‘aggressive diversifiers’.
b Nineteen companies[4] pursued a sequence of first increased technological diversification, then either product specialization followed by market diversification or the reverse. These companies were called ‘stick to the knitting’ companies.
c Five companies[5] pursued a strategy sequence of increased technological diversification followed by product diversification concurrent with market specialization. These companies were called ‘market specializers’.
d Eight companies[6] specialized both product-wise and market-wise and sometimes even technology-wise. These were called ‘defenders’.

Eleven companies had selected four other strategic sequences, all of them either growing slowly or declining. They had neither rapid increase nor decrease in diversification.

The ‘aggressive diversifiers’ had significantly higher sales growth (in 1980–1990) and expanded their technology base, product base and market base significantly more.

Canon was the company with the fastest growth of all the 57 companies between 1980 and 1990. Canon also followed an ‘aggressive diversifier’ strategy, see Figure 11.2. The Canon case also illustrates three different types of diversification: first, concurrent (and indeed risky as it was) diversification (into copiers); second, technology-related business

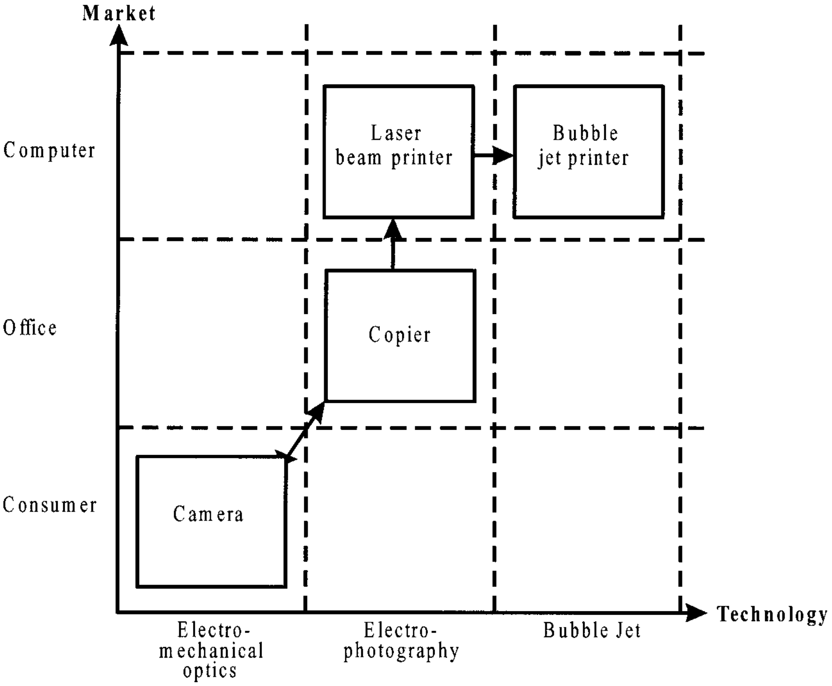


Figure 11.2 Canon's diversification trajectory.

Source: Yamaji (1994).

(product, market) diversification into laser beam printers, exploiting the competence in electro-photography; and third, business-related technological diversification into bubble jet printers, exploiting the competence and position in the printer industry.

A qualitative model of diversification in general is given in Figure 11.3. Oskarsson (1993) tested a simplified and modified (due to lack of data on feedback) version of this model for 1980–1990 with results shown in Figure 11.4.

Technological diversification at firm level was thus an increasing and prevailing phenomenon in all three major industrialized regions, Europe, Japan and the US. This finding has also been corroborated by Patel and Pavitt (1994).

Moreover, technological diversification was a fundamental causal variable behind corporate growth. This was also true when controlled for product diversification and acquisitions.[7] Technological diversification was also leading to growth of R&D expenditures, in turn leading to both increased demand for and increased supply of technology for external sourcing.

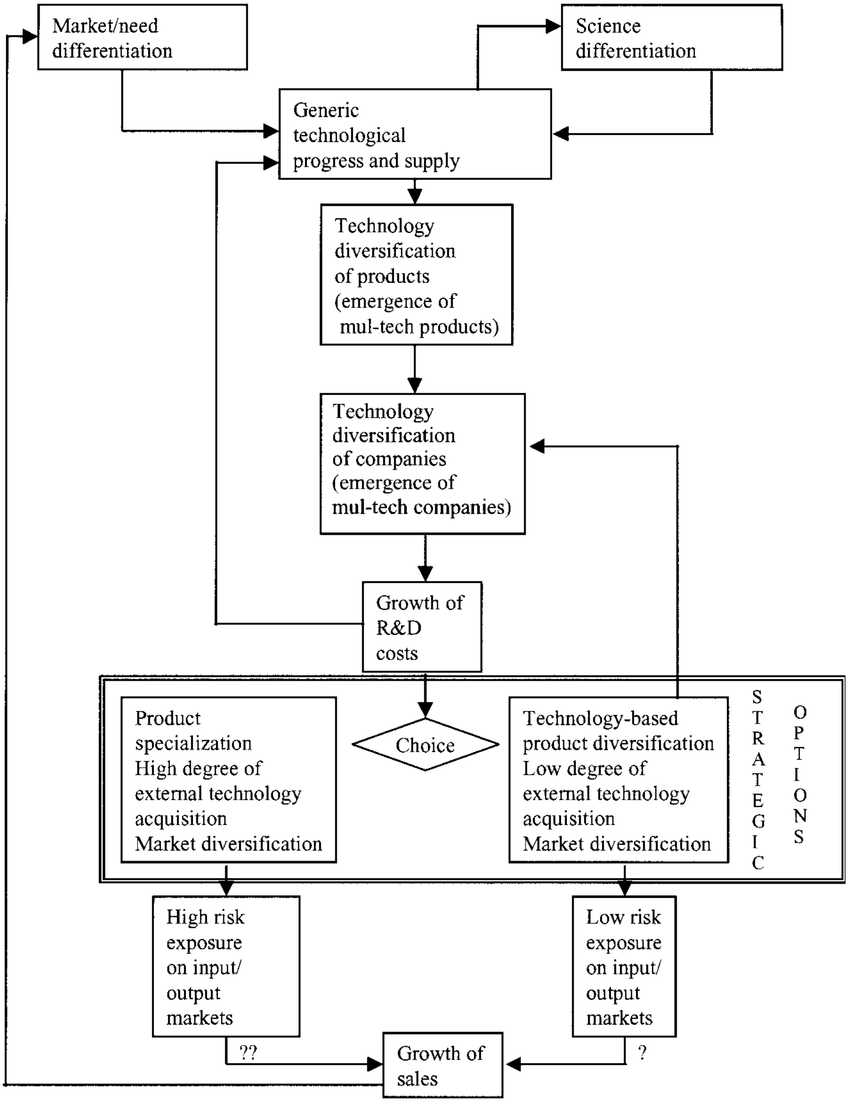
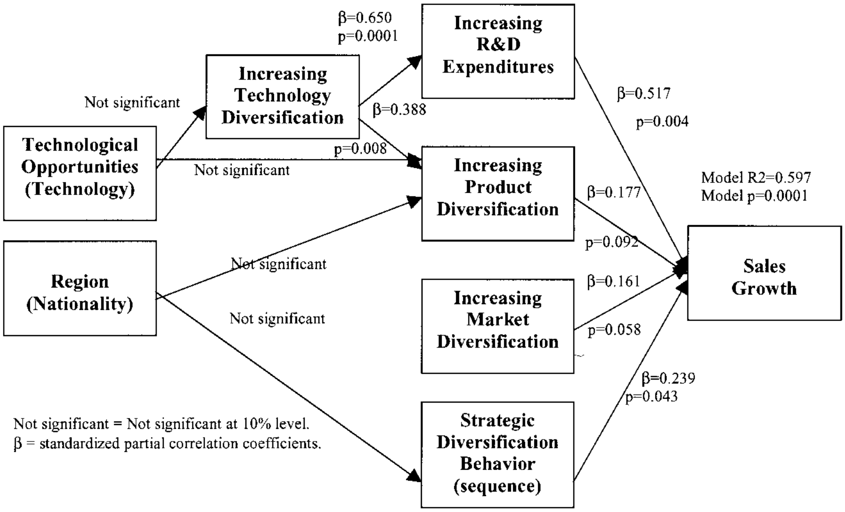


Figure 11.3 A strategic choice for technology management in 'mul-tech' companies.

Source: Granstrand *et al.* (1992).

These findings were not readily explainable in terms of received theories of the firm. Without going into detail about the pros and cons in using received theories to describe, explain and predict the behavior of technology-based firms, taking idiosyncrasies of technology as a special



Not significant = Not significant at 10% level.
β = standardized partial correlation coefficients.

Figure 11.4 A test of a model for growth and diversification ($N = 55$).
Source: Oskarsson (1993).

type of knowledge into account, one can note that technological diversification does not feature at all in received theories. Moreover, most theories do not explicate the dynamics and heterogeneity of technology, and many restrict their focus to process technology. (For an elaboration on these theoretical issues, see Granstrand 1998.)

3 Analysis

3.1 Diversification dynamics

At a given point in time a multi-product multi-technology corporation (MPC/MTC) comprises several products (or businesses) and several technologies, constituting the product base and the technology base respectively for the corporation. These bases are linked to each other, e.g. as in Table 11.1 (built on an actual case in the Saab Corporation, reported in Granstrand and Sjölander 1990). For each product there is then an associated technology base, comprising the product and process technologies to that product, and to each technology there is an associated product base, comprising the range of products for that technology. The more technology-product couplings, the more synergies there may be. For example, one could note in Table 11.1 that:

a The technology base of product P_2 is highly technologically diversified, i.e. P_2 is clearly a ‘mul-tech’ product, while P_9 is not.

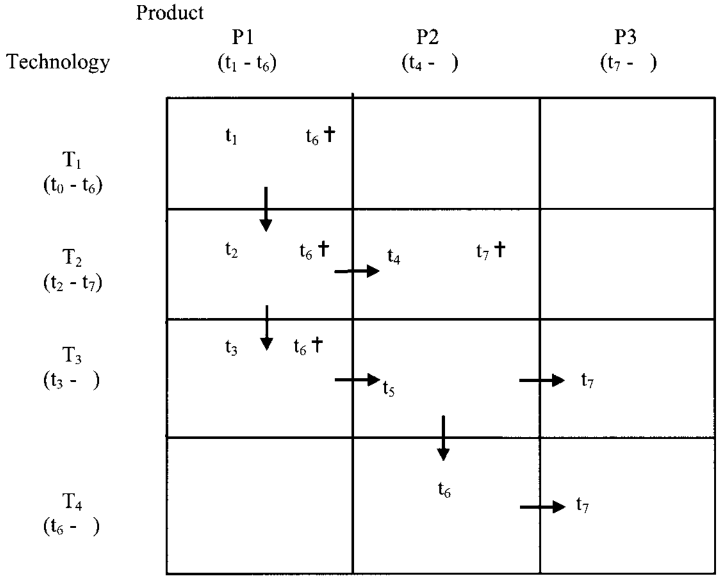
Table 11.1 Corporate structure in terms of its technology/product matrix

Technology	*Product area*									
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}
Electronic hardware	X	X	X	X	X	X	X	X	X	X
Man/machine communication		X	X	X	X	X	X			
Electronic packaging	X	X				X				
Micro-mechanical design		X	X	X	X	X	X			
Software		X	X	X			X			X
Computer communication		X		X		X				
Electro-optics		X	X			X	X	X		
Infrared technology	X	X				X		X		
Microwave technology					X	X		X		
Laser technology		X					X			
Hydro-acoustics		X		X						
Image processing					X	X		X		
Artificial intelligence		X	X	X	X	X	X			
Systems technology		X	X	X	X	X	X	X		X

b Electronic hardware is a generic technology, while hydro-acoustics has a narrow applicability in the product base of the corporation.

How has an MPC/MTC developed such a coupled technology-product structure (TP structure)? For a given product new customer requirements and technological opportunities create an incentive for making transitions in the technology base of the product, which leads the company to develop or acquire new technologies through technological diversification, then being product-related. Possibly some existing technologies may then be divested as well. The new set of technologies may then give the company an incentive to diversify into a new product area, that is, to engage in technology-related product diversification, in turn possibly requiring still more technologies to be developed or acquired.

Figure 11.5 illustrates this stepwise feature of corporate evolution in principle over time – with time points t_0, t_1 etc., and an arrow denoting entry into a TP-combination and † denoting exit (divestment or de-diversification from a TP-combination). It may of course also happen that a technology is developed or acquired at a point in time for exploratory (or accidental!) reasons without yet being related to a specific product.[8] This holds for research activities by definition. Similarly, although more rare, there may be company products without any in-house technology for the time being. In Figure 11.5 the company enters a new technology at time t_0 but does not implement it in a product until time t_1. The product diversification process is then rooted in P_1 until time t_6. In P_2-related technological diversification, technology T_4 is then assumed to substitute for T_2 but with a lag.



Legend:

↓	T-div, i.e. entry into a technology area (mostly associated with economies of scope)
→	P-div, i.e. entry into a product area (mostly associated with economies of scale, possibly also product related economies of scope)
†	Exit from a technology-product combination
$t_0, t_1, t_2 \ldots$	time points

Figure 11.5 Evolution of a company in terms of changes in its technology/product matrix over time (t).

The combined TP-base thus shifts over time, just as the customer base may do in accordance. Product invention-based companies in electrical and mechanical engineering (such as Alfa-Laval above) then often display a kind of 'rooted' diversification, sticking to the original product area (at least for a long time), while diversifying into others. A kind of 'floating diversification' on the other hand is common for a raw material-based company or a chemical company over long periods of time, in the sense that the company diversifies away (i.e. exits) from its original product area. For the latter type of companies, physical by-products in extraction and processing play an important role in the diversification process. When physical resources are depleted or subjected to diminishing returns, the incentives to stay in the related product areas go away. On the other hand, if a company's resources are subjected to increasing returns, as is often the case with knowledge in general and technology in particular, the incentives to stick to the original product area or core business remain.

The diversification dynamics has so far been analyzed for product and technological diversification. Other diversification types exist (M-div, A-div) and there are various sequential and concurrent patterns of diversification as shown by Oskarsson (1993), presented in the preceding section. The analysis could be extended to these cases, since similar principles and similar basic types of economies are involved, which will be dealt with next.

3.2 Economies of diversification

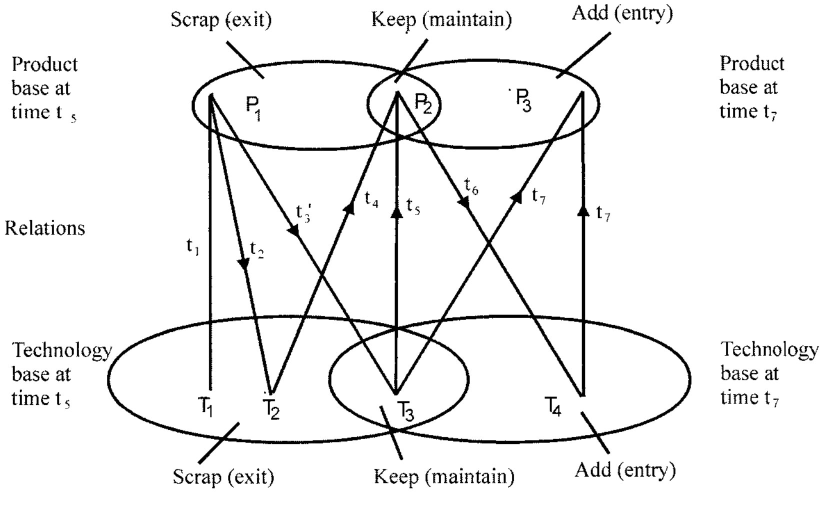
Technological diversification as an empirical phenomenon with its causes and consequences has only recently gained attention among researchers[9] The key role apparently played by this variable in corporate evolution, as described above, is a new finding for which any explanation at this stage must be tentative. Tentative modelling as presented above, emphasizes progress in science and technology (S&T) together with differentiation of both S&T fields and market needs. This view is closely related to the view that an expanding set of opportunities technological as well as business opportunities is a major factor in a number of phenomena. Penrose (1959) treated technology and industrial R&D as one (out of several) important source of new opportunities for product diversification in general. Scherer (1980) identified technological opportunity as the most important factor behind differences in innovativeness between different industries. In fact, it may be argued that technological opportunities are generated in a fundamentally important and inexhaustible way through the combination and recombination of various technologies, new as well as old. Such a process of combinations and recombinations could be considered to lie at the heart of the invention and innovation processes, in which technologists, managers and markets filter out technically and economically infeasible combinations.

In the process of taking advantage of technological opportunities, technological diversification at the corporate level may lead to four different but complementary types of economies of diversification: economies of scale, scope, speed and space (the four Ss behind diversification). First, there are static as well as dynamic economies of scale. Static economies of scale accrue to the extent that the same, or close to the same, technologies can be used in several different products with minor adaptation costs. Since exploiting knowledge in various applications is typically characterized by small and decreasing marginal cost for each additional application, while the fixed cost of acquiring the knowledge is substantial, the static economies of scale are significant when a technology has a wide applicability to many different product areas in a corporation (which is the case for generic technologies by definition). Moreover, as is well known, knowledge is not consumed or worn out when applied. On the contrary, knowledge is typically improved through learning processes when applied several times, which also allows for dynamic economies of scale in technology-related product diversification or technology-related application diversification. Second, different technologies have a potential to cross-fertilize other technologies, yielding new inventions, new functionalities and increased product and/or process performances when combined. This cross-fertilization yields economies of scope, but not primarily the kind of cost-related economies of scope in production that arise from shared inputs, and thus are special cases of economies of scale. This second type of economies of scope of technological diversification depends on the specific technologies that could be combined or integrated. Such economies of scope also vary over time, depending upon the different intra-technology advancements over time. Third, combining technologies mostly requires some technology transfer, and (under certain conditions) intra-firm technology transfer is faster and more effective than inter-firm, giving rise to early mover advantages in a multi-technology corporation (MTC). These advantages, related to speed and timing, can be labelled economies of speed. Fourth, many regions in the world are multi-technological, i.e. they are technologically diversified, e.g. the Silicon Valley area or the Tokyo area, regions that also mostly have diversified eminent universities. These regions generate a stream of technological and business opportunities, which are localized and poorly codified, at least initially. An MTC is then better positioned to take advantage of these opportunities through building close external linkages in different areas. These economies, related to location, agglomeration and geographical coverage in general, can be labelled economies of space.

According to the empirical findings above, technological diversification leads not only to sales growth but also to growth of R&D expenditures, however. Tentatively, the reason is that a larger number of technologies is involved, which means that a larger amount of coordination and integration work is needed, apart from the cost of acquiring each new technology, as difficulties arise in connection with conducting multidisciplinary R&D. These difficulties are widely reported and typically involve conflicts between professional subcultures in science and technology, not-invented-here (NIH)-effects and other innovation barriers (see below and, for more detailed accounts, Granstrand 1982).[10] Thus, in order to reap net benefits from technological diversification leading to growth of both sales and R&D expenditures, the integrative skills of both technologists and managers become decisive.

3.3 Diversification analysis

Above we have in fact identified two contrary but complementary types of diversification as having a strong economic potential – diversification into new technologies, then mostly related to existing products, and diversification into technology-related products. The first type, P-related T-diversification, corresponds to a shift in the technology base or portfolio of the company, while the latter, T-related P-diversification, corresponds to a shift in the product (business) portfolio. These two shifts could in principle take place independent of each other, still being economical; but when they combine over time as shown in Figure 11.6, economic benefits can be strongly enhanced. In fact, it could be argued that a crucial dynamic factor in corporate evolution is the interdependence or interaction over time between *business-related resource diversification* and *resource-related business diversification* of which P(T)-related T(P)-diversification is a special but important case. These latter terms then include other possible types of X-related Y-diversification, where X and Y could refer to products, markets, technologies or applications, or other types or mixes of types of input (resources) and output (businesses) characteristics. One could even let both X and Y refer to sets of outputs or both refer to sets of inputs, but then there usually is an implicit understanding of an underlying resource relation or connection. For example, entering new product areas from existing market positions could be characterized as a case of



Legend:

⬭ Base (set) of products and technologies of the company at a specific point in time

Figure 11.6 Evolution of a company in terms of changes in its product and technology bases.

M-related P-diversification and entering new markets with existing products as case of P-related M-diversification as was originally done in the early literature on diversification.

Finally, one has to keep in mind that the concept of relation or relatedness, which has been and still is a central concept in diversification analysis, is so universal that a diversification move can be characterized in many ways in terms of what is related to what. Any diversification move is made for a set of reasons, including motives, and its outcome may change character over time, in intended and unintended ways. For example, many product diversifications have been unintended consequences of major M&As, thus being M&A-related, if nothing else. Multi-inventive entrepreneurs easily give rise to diversifications, then being inventor-related, perhaps without any other resource-relatedness. Seen in this way, totally unrelated diversifications do not exist.

The economies of scale, scope, speed and space associated with resource-related product diversification change over time and must be continually assessed and monitored, also relative to other companies. For example, diversification into a new product P_2 (e.g. light trucks) might initially share a lot of resources, including technologies, with an existing product P_1 (e.g. passenger cars), but over time the resource sharing may very well decrease as the new product gradually needs more specialized resources, for example in production. Such resource divergence may perhaps lead to the point where divestment of some technology or product has to be considered, due to losses of scale and scope advantages relative to other suppliers. Not seldom, resource divergence is reacted to too late, leading to over-diversification.

The opposite may also occur. Two initially fairly unrelated products, e.g. computers and telecom equipment in the 1950s, may over time 'come closer' in their resource requirements, e.g. through sharing new technologies (e.g. integrated circuits), or serving similar new customer segments.[11] This kind of resource convergence (with technological convergence as a special case) may then at some point justify diversification one way or the other, through mergers, acquisitions, alliances or organic growth, depending upon the resource position and resource acquisition costs relative to other companies. The resource positions and acquisition costs for different companies are typically asymmetric and uncertain, which makes the direction of diversification important but difficult to assess, especially in early stages of convergence, prompting for experimental diversifications. (The convergence of computers and communications is a major case in point.) Figure 11.7 illustrates these two cases. Over longer periods of time both resource divergence and convergence may occur, e.g. due to technological changes in general.

The changing resource bases for different product generations or versions may be similarly illustrated as in Figure 11.8. A company operating in a product area may have to offer its customers both an old and an

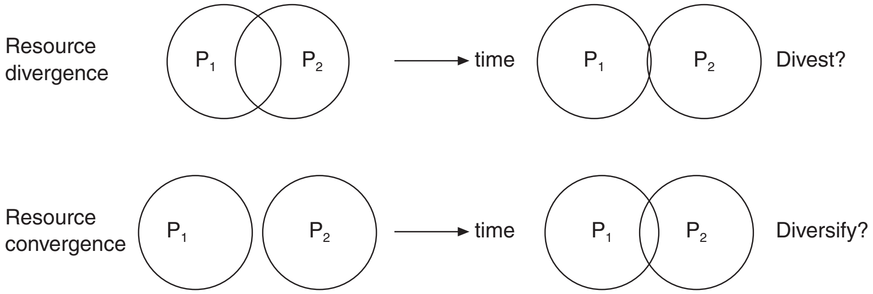


Figure 11.7 Changing resource-relatedness over time for two products P_1 and P_2.

upgraded new product generation for some time but then eventually has to scrap or divest the old generation. Scrapping obsolete competences is often associated with considerable difficulties, since a number of people, including managers, will be threatened thereby, trying all kinds of defensive behaviour, essentially resulting in organizational inertia (or core rigidities in the terms of Leonard-Barton 1995), costs and delays. This is not least the case when old technical competencies (technologies) embedded in engineering subcultures have to be phased out (see below). Scrapping resources also involves scrapping some old relations, i.e. scrapping some relational capital, which is difficult. For example, scrapping some customer relations, built up through single-minded corporate campaigning about ‘listening to our customers’, leading to bias for current ones, is difficult and costly in the short term but even more costly in the long term if not undertaken (see Christensen 1997).

A company wanting to enter the product area is not plagued with these costs, but if it is a new start-up company it must, on the other hand, to acquire all necessary resources if it wants to independently launch a new product generation. An existing company, operating in other product areas but attempting to diversify into the product area under consideration with a new product generation, typically based on some new technology, also has to acquire new resources but can at the same time draw on some of its old resources in so far as the diversification attempt is resource-related.

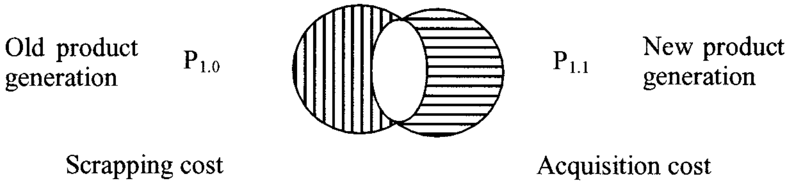


Figure 11.8 Resource bases for different generations of a product P_1.

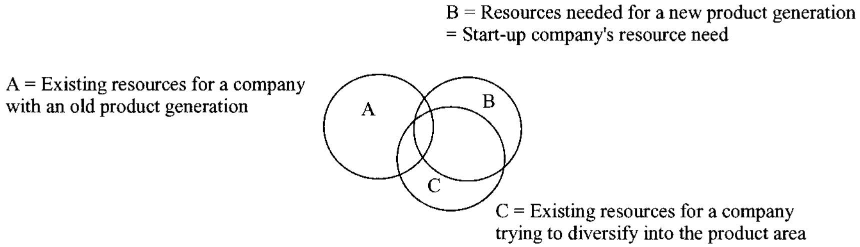


Figure 11.9 Resource bases (including technology bases) for an incumbent (A), a start-up (B) and a product diversifier (C).

Thus, depending upon the resource acquisition cost, the resource-scrapping cost and the synergies between the new product generation and existing resources, either the start-up company (e.g. for mobile handsets or palmtops), or the existing company (e.g. in telecom industry) already operating in the product area or the existing company (e.g. in computer industry) diversifying from outside into the product area will have a relative cost advantage; see Figure 11.9.

4 Critical abilities in management of technology and product diversification

The question is now how the economic benefits could be reaped by proper management of these dynamic shifts in inputs and outputs or, in other words, these diversification processes (including de-diversification, i.e. divestment). Of course a complete answer cannot be given since management is so multidimensional and contingent upon specific company situations. Some general observations plus some lessons from a few cases may serve as guidelines for further management thinking. The first case concerns how the Swedish telecom giant Ericsson successfully managed the shift or transition in the technology base for its telecom switching products, i.e. a case of product-related technological diversification. The second case deals with how the Swedish auto and aerospace company Saab attempted to leverage a number of its numerous military-related technologies through internal technology transfer to a number of new product areas, collected in a special high-tech group called Saab Combitech. This is then a case of mainly technology-related product diversification. (For further details of the cases, see Granstrand and Sjölander 1990.) Both cases point at the criticality of managing conflicts, especially conflicts between subcultures associated with different technologies. This issue will therefore be dealt with specifically.

4.1 Managing technology assembly

As seen above, technology-related product diversification typically involves procuring some new resources while drawing on some existing technologies. Procuring new technologies can be done in various ways – by in-house R&D, by alliances or acquisitions on external technology markets, or simply through technology intelligence. Either strategy requires specific management abilities, e.g. in cooperating with lead users, competitors, suppliers or universities. External sourcing requires in general technology forecasting (foresighting), identifying, valuing, accessing, transferring and integrating new technologies, the latter then often encountering difficulties like NIH effects. At the same time internally available technologies have to be internally identified, transferred and adapted to the new product, which may very well encounter difficulties, not least in a large corporation. The saying: 'Wenn Siemens wusste was Siemens weiss' is indeed relevant here.[12] Sometimes it may even be simpler (faster, cheaper) to source a piece of technology externally than to go and find it in large, diversified organizations like Siemens, Philips or General Electric and then to overcome internal technology transfer barriers.

All in all, there is a *technology assembly problem*, or more generally *a competence or knowledge assembly problem*, to deal with in technology-related product diversification. This also holds true for product-related technological diversification. In the latter case, however, there is also the problem of managing obsolete resources, and in particular competences and technologies that are embedded in managers and personnel. Their self-interests produce not only inertia, active resistance and political manoeuvring but also distortion of information, often even without guile. Top managers and board members are dependent upon internal expertise in judging new product and technology prospects, and all expertise is framed in their own competence. (This is why it is sometimes risky to promote a technologist or scientist, who has successfully specialized in one specific area, to a position as general technology manager.) As diversifying competence for an individual is difficult (costly) and time-consuming, to say the least, an important goal discrepancy or principal-agent problem arises between the board (principal) and the internal expertise (agent). It is then important for top managers and the board to complement internal expertise and judgments with external ones, e.g. in the form of external technology audits, technical due diligence, scientific advisory boards or technical alliance advisors. However, this possibility is limited by secrecy needs (sometimes corporate boards are simply very leaky and top management cannot bring the issue to the board) and in a highly specific and uncertain situation with limited availability of experts.

Figure 11.10 summarizes some general management abilities in managing technology assembly in connection with a technology transition or technology base shift. Three main categories of technology management

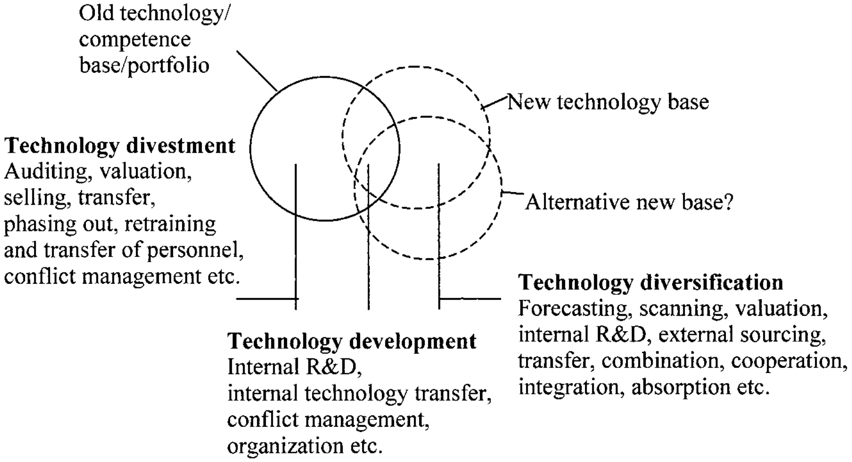


Figure 11.10 Managing technology assembly in connection with a technology base shift.

Note
There are many terms for similar concepts used in the figure, e.g. divestment is associated with exit, scrapping, destruction and substitution.

abilities are then involved in a general case – technology divestment, technology development and technological diversification through various strategies (in-house R&D, buying/selling companies/projects/licenses/services, joint ventures and scanning or intelligence), in turn requiring valuation, transfer, integration etc. Management of technology transitions (base shifts) and internal technology transfer and integration in particular will be illustrated in the company cases to follow.

4.2 Managing product-related technological diversification into digital switching in Ericsson[13]

For over a century Ericsson, as a fairly specialized but highly internationalized company in telecom, has managed a number of transitions into new technologies successfully (with some exceptions), pertaining to both switching and transmission of phone calls. The transition into computerized (stored program control) switching in the 1950s to 1980s was particularly successful, leading to the so-called AXE system, which provided a strong technological position for subsequent development of mobile communications (voice and data), in turn very successful as has been widely recognized. The latter development was then a case of technology-related business diversification (with several new products – base stations, handsets etc.), as well as a case of a technological transition from wired (cable) to wireless (radio) transmission in the access part of a telecom network (besides the transition from copper cable to optical fiber in the trunk lines of the network).

In the case of managing a series of technological transitions, it is of interest to ask which are the critical managerial abilities and whether these abilities have improved over time, that is, whether there has been any long-term managerial learning or development of management capabilities. In the case of transitions into new switching technologies in telecom (into register control in the 1920s, into crossbar technology in the 1940s and later into stored program control – the AXE system), several critical managerial abilities can be identified in Ericsson. First is the ability to perform environmental scanning (including technology and competitor scanning, intelligence and forecasting) and to produce technological, industrial and market forecasts. It is doubtful whether the precision in forecasts of technological developments and their impacts has improved over the years, that is whether there has been any managerial learning in this respect over the series of transitions. Certainly the awareness that the sources of innovations and competition are often outside the company's industry (as traditionally defined) has improved as well as the responsiveness to signals about emerging technologies and potential competitors (or joint venture partners).

Second, the ability to assess the proper rate, direction and form of strategic competence diversification is critical. There is a long process, perhaps 20–30 years, from the first signals of an emerging technology (e.g. discovery of semiconductivity) to the commercial success of a new product generation based on it. All the time the technology develops, technological options proliferate and the competitors' technological approaches and positions change. Several general strategies or responses are feasible in a situation with an emerging technology, such as:

a to improve the old technology in the existing product generation (producing what is sometimes called 'the sailing effect');
b to develop a new generation based on some version of the new technology;
c to develop a hybrid generation, based in part on both the old and the new technology, as a 'gap-filler';
d to introduce the new technology in an evolutionary manner in the existing generation (e.g. piecemeal replacement of transistors with integrated circuits);
e to skip the emerging technology and jump to the next-next technology (has been attempted but never with success in the telecom sector);
or finally
f to do nothing (wait and see).

When and how to introduce the new technology (if at all) and when and how to exit the old technology are crucial timing decisions. The experience in Ericsson suggests that the building of competence for these decisions ought to be done at the outset in an experimental manner without a precise business plan and involving good technologists, young and old. (The latter may be difficult if the product with the old technology is simultaneously successful on the market.)

A third critical ability in connection with technological transitions is the ability to handle conflicts. It is almost axiomatic that such transitions involve conflicts. This should be recognized as natural rather than pathological in the organization. Some conflicts derive from confrontations between different professional subcultures associated with different scientific and technological disciplines involved in a transition. Sometimes, as in the Ericsson case, these conflicts could be mitigated by a strong corporate culture and/or a consensus-seeking problem-solving engineering culture. Some conflicts are associated with power struggles among managers, whose power is based on knowledge in a certain technology. Some conflicts have good effects, e.g. increasing motivation as in some 'guerrilla' development work ('skunk work') in a large company, but conflicts may often turn out to be disastrous. (Probably the different conflicts in Ericsson's long-standing competitor ITT during the latter half of the 1970s went far enough to delay R&D work on its System 12 competing with the AXE.) The ability by managers (and board members) to handle conflicts has probably not developed very much, if at all, over the years. For several reasons, managers often avoid dealing with conflicts until it is too late, when conflicts have become overly person-oriented rather than issue-oriented, productive communications break down, tensions and struggles prevail, resources are wasted and speed in decision-making is lost.

Fourth, organizational ability is important in connection with technological transitions. The scale of the old must eventually to shrink, while the scale of the new has to grow. Thus, major shifts and renewals of resources, personnel, power, attention and so on have to be made. At the same time, the new always runs a risk of being killed by the old. To organize the work on the new technology, separate from that on the old, in a semi-autonomous organization has often proved to be a viable organizational solution. It is not only a way of separating the new from the old, but also gives possibilities of combining the advantages of large and small organizations. In the Ericsson case, the formation of Ellemtel, a joint venture company with the Swedish telecom operator (later named Telia), proved to be highly successful and done at what seems in, retrospect, the right time. The special connection with the Swedish telecom operator as a lead user gave Ellemtel advantages in addition to the advantages of separation and small/large combination. Although there are drawbacks associated with this kind of organizational solution as well, it seems on the whole as if the managerial ability to organize for innovation has improved over the years. Also the employment of a divisionalized organizational form (M-form) represents a managerial innovation in general.

A fifth managerial ability concerns how to work with parallel approaches in R&D, and when and how to divest or redirect some approaches and concentrate R&D resources on a major design direction for a new product generation. (A related question here is whether management or markets provide the most efficient selection environment in the terms of Nelson and Winter (1982).) It is doubtful whether the managerial ability to diversify and then focus R&D work has improved. At the same time increasing R&D costs, increasing possibilities to combine different technological options (due to a general accumulation of S&T advances) and rather constant R&D times (as in the Ericsson case) increase the importance of this ability.

4.3 Managing internal technology transfer in Saab Combitech

Now let us turn to some critical managerial abilities in managing intra-company technology transfer as they have become evident in the case of Saab – a large European civil and military aircraft manufacturer, merged with the heavy truck company Scania in the early 1970s and then demerged in the 1990s. In a corporate restructuring in the 1980s, Saab Combitech was formed as a large subsidiary, housing a number of technologies and products outside but related to core businesses, for the purpose of diversification, cross-utilization and cross-fertilization (combination) of technologies (see Table 11.1 above).

Combining technologies in R&D work always involves the problem of how to manage professional subcultures. It is then of importance that these subcultures rest on some commonalities in communication, values, problem-solving approaches etc., that is to say, that there is some kind of overarching professional culture or corporate culture. The development and sustenance of a corporate culture is facilitated by common historical roots and traditions of various businesses, and coherence in vision, goals and explicit strategies. If this is not fulfilled to a certain degree, the combination of technologies in a multi-business structure has limited chances of success. This is even truer in a multinational setting in which there are national culture differences as well. Thus, multi-technology management in MNCs is compounded by cultural differences in two dimensions, differences that have to be subdued by an even stronger corporate culture.

It is moreover important that there exists a well conceived and implemented technology transfer policy, supported by the various business managers. The experience from Saab Combitech also points to the need for incorporating strategic perspectives and responsibilities into the technology transfer function, together with operative and tactical ones. This is facilitated by a corporate technology officer or a Vice President Technology with joint staff/line function with direct executive responsibilities for group strategic projects, ventures and new technology-based firms, together with staff responsibility for supporting the chief executive officer and the various business managers in the strategy development process.

Developing managerial abilities in an MTC such as Saab Combitech takes time and needs a great deal of experimentation. This can hardly be done if the overall profitability is low or poor. Therefore, healthy businesses, projects and ventures are needed at the outset.

To sum up, critical managerial abilities for managing internal technology transfer in an MTC such as Saab Combitech are:

1 the ability to manage subcultures and to resolve conflicts;
2 the ability to identify and exploit commercially sound, technological opportunities, which often are triggered by technology combinations or technology fusion;
3 the ability to spot, monitor and take strategic action on changes in competition and technological development; and
4 the ability to experiment with new managerial routines and policies, to evaluate the effects and to act according to the analysis.

Finally, an overall experience from Ericsson as well as Saab. Technologists often consider the growth of S&T to be the basis of progress. On the other hand, business management, strongly influenced by short-term financial and marketing knowledge, tends to consider S&T as one among several contributing factors in doing successful business. In this latter top-down view of S&T, technologists are simply there to implement business strategy. Companies with this type of view will most probably have difficulties in creating balanced technology strategies that are coherent with business strategies. In order to integrate the technologist perspective more thoroughly into a balanced, interactive process of strategic development, and to facilitate the managerial learning process at top management level, MTCs need to incorporate technologists with executive powers in their top management ranks, similar to what large Japanese MTCs have done.

4.4 Managing conflicts among engineering subcultures

4.4.1 Cultural structure

The culture associated with S&T is sometimes presumed to be homogeneous, but is in fact heterogeneous with several subcultures, not seldom in conflict with each other. Scientists and technologists certainly share some basic values and beliefs about the benefits of their work and their methods and what is legitimate in thinking and language. However, at the same time, differences in these respects between disciplines, as well as between generations, are marked. Such differences within an overall S&T culture seem to produce intermittent reorientations rather than smooth, cumulative evolution. Individual scientists and technologists build up conceptions that ossify and obstruct intellectual reorganizations. Science and technology groups are formed on the basis of similarities in educational background and shared conceptions and language. Individuals tend to socialize in at least one group, their social skills improve, they become tied to interests, and they defy fundamentally new conceptions. As a result, disciplines expand and contract, amalgamate (fuse) and split up (diversify), and this is accompanied by generation changes, breakthroughs of new knowledge and, not least, by conflicting interests.

S&T subcultures are typically associated with S&T professions, such as chemists, biologists, mining engineers, mechanical engineers, electrical and electronics engineers, and physicists. These categories correspond to the structure of graduate education, as well as to some extent to the structure of industrial branches or sectors (which graduate engineering education is supposed to serve). The formation of subcultures also seems to take place to a large extent during graduate education or in the early years of professional life when large parts of an individual's professional *'Weltanschauung'*, language and base for socialization are formed.

The subcultural features formed during graduate education are then often reinforced when the young professional goes into a corporation, due to the structural correspondence between universities and different sectors of industry. The inertia of the educational system in universities then tends to produce a strong and enduring sectoral barrier to change in industry.[14]

4.4.2 Cultural change

Social differentiation into different cultures is neither hierarchical nor permanent, and an individual or a corporation may be associated with several cultures having multiple and temporary connections of various strengths. An individual may belong to a subculture in S&T but also to a corporate culture and to a regional culture. Her cultural memberships may change as well. Individuals are also carriers of culture, and a corporate culture may be altered as the result of changes within individuals and among corporate personnel.

In considering cultural change, three connected processes are of relevance here:

a the formation and change of cultures;
b the association of an individual with a culture;
c the association of a culture with a corporation.

To discuss each of these processes in depth would be beyond the scope of this chapter. The role of graduate education has been noted above. In a second-order analysis, one may take as a starting point the observation that social differentiation is clustered (i.e. social differences are not evenly distributed but patterned). The clustering of social differences in language, beliefs and values in problem-solving among professionals is influenced by the individual's need to reduce uncertainty in connection with her pattern of communication, which she can only partially influence. Interpersonal variations are a great source of uncertainty and this may be reduced by conforming to a certain language and to certain standards and norms of behavior. Consider, for instance, the use of mathematical-logic standards of reasoning among S&T professionals or the standard way of assigning the burden of proof to the one who makes a statement or proposes a change. Individuals, however, differ in their capacities to process information and handle uncertainty associated with interpersonal variations. Their needs to reduce uncertainty differ, as well as the manners in which uncertainty is reduced. Moreover, different needs of different individuals become dependent upon each other, which may mutually reinforce a social clustering.

Thus, there are several determinants behind the formation of cultures and the association of an individual with different cultures pertaining to different segments of her life situation. The strength of this association differs between individuals and also changes with time. A high learning capacity makes a professional less dependent upon her discipline-oriented knowledge as acquired by formal education, and may therefore permit her to be more problem-oriented and less inclined to associate with a certain professional culture. A university researcher may feel associated with S&T in general, but with academic research in particular and even more with academic research within her own field. Problems in connection with too weak an association of university researchers with the culture of industrial R&D are often witnessed.

The third process, the association of a culture with a corporation, is of main concern here. The focus is especially on change associated with professional subcultures, as encountered in the corporations studied. On the one hand, a corporation is associated with different cultures through its personnel. On the other hand, a specific corporate culture is often formed, a culture which may retain its basic characteristics even if turnover of personnel is high. Since a culture reduces variations and uncertainty for its members, it may be instrumental in coordination and communication. A culture may also be instrumental in preserving a power structure. Management has possibilities to influence language, ideology, beliefs and myths in the corporation and thereby influence the corporate culture to the benefit and convenience of themselves. Thus, there are several motives behind the formation of a corporate culture. However, a culture may also act as a barrier to change, as can be seen from the cases studied.

Focusing on changes of professional subcultures in three of the corporations studied, summarized in Table 11.2, one may discern a number of factors of primary influence behind such changes. Although it is extremely difficult to separate such factors and assess their influence,

Table 11.2 Examples of subcultural transformations in the company histories of Astra, Boliden and Alfa-Laval from the 1960s–1970s

Change involving a subcultural transformation	*Factors of primary influence*
Astra	
Transition from a chemistry orientation to a biology orientation	Corporate origin Top and R&D management behavior Recruitment Technological change
Boliden	
Integration of chemistry into the mining orientation	Top management behavior Recruitment and promotion Corporate strategy Technological change
Alfa-Laval	
a Integration of economics into the engineering orientation b Transition from component orientation to systems orientation	Top management behavior Recruitment Corporate strategy Internal conceptualizers Technological and market change Product troubles
c Integration of electronics into the mechanics orientation	R&D management behavior Independent subsidiary action Recruitment Technological change

certain indications are worthwhile to consider. The most frequently encountered factors are, on the one hand, technological and market changes and, on the other hand, top management behavior, corporate strategy, recruitment and promotion. The latter group of factors directly involves top management. This indicates that top management plays a primary role in cultural change in the corporation, and that strategy formation, recruitment and promotion are important instruments in bringing about that change. In this sense a top manager in a large corporation may act in an important manner as a 'cultural entrepreneur'. This does not always have to be the case, though. In some cases a corporate managing director has hindered or slowed down a cultural change initiated internally or externally.

Concerning the instruments for bringing about a cultural change, strategy formation, recruitment and promotion certainly are important. These instruments may, of course, be used in different ways. Thus, for example, Boliden promoted a mining man as head of a new chemical division of the corporation to be able 'to lift it up' in the corporate power structure. Astra heavily relied on recruitment of new competence, which was natural considering the total dominance of chemists at the time. (It is a fundamental fact that a specialized professional in one field cannot be converted into a specialized professional in a different field overnight, or even over some years.)

A cultural entrepreneur may use other instruments as well. To restructure communications through organization and location is a tangible way of acting. He may also act in a more intangible way on the level of fundamental elements in a culture, such as influencing language and values, creating symbols and rituals, strengthening ideologies and nurturing myths.

However, the dynamics of cultural change as discussed here, involve more factors than just a cultural entrepreneur, a concept that is often used in oversimplified explanations. Although there are instruments for management that influence a culture, it would be naive to consider a culture as something which could be created and managed totally at will. Cultural change has, for instance, a prehistory in which external changes and internal conflicts are influential. The whole process of change, which may last over some decades, is characterized by disorder and uncertainty and the outcomes may vary. Starting from the situation of a dominant culture in a corporation, with a new culture emerging, four types of outcome may be discerned:

- amalgamation of cultures;
- transition to new dominance;
- ordered coexistence;
- rejection of emerging culture and regression to old culture.

Of the above, amalgamation (for instance, at Alfa-Laval), transition (for instance, at Astra) and the role of new generations of professionals are important. A new generation may change and amalgamate values and beliefs previously associated with two subcultures or disciplines, and a new generation may be needed to subdue an old subculture. Ordered coexistence of two subcultures (for example, at Boliden) may be accomplished both by hiring new professionals with weaker subcultural association and by structuring organization and management.

Finally, some comments may be made about the general trend to incorporate biological competence in industry. It is a response partly to threats from technological side effects and partly to opportunities in the advancing life sciences. Neglecting, for the moment, the many confluences of scientific disciplines in advanced natural sciences, one may make the following rough description. Chemists and others have been engaged in designing resistant compounds; they have been utilizing 'aggressive' methods and have applied rude measures to achieve certain effects and suppress others. To a different extent, biologists utilize processes in nature (for example, by enzyme technology, microbiological extraction, biological control in agriculture, molecular biology in medicine and genetic engineering) and by these means it is possible to tailor outcomes more precisely. A naive but illustrative simplification would be to view the change as turning from fighting with nature to manipulative cooperation with nature. This change may lead to the establishment of a new subculture of biologists in parts of industry. Likewise, the transition to electronics has led to the dominance of electronics people in parts of industry. If there were to be a confluence of biology and electronics (c.f. bio-chips) in the decades to come, it would probably cause resistance to change among these new subcultures. The reasoning behind such a forecast then has supporting evidence in psychology and sociology concerning individual and group behavior in information processing, problem-solving and socialization.

5 Summary and conclusions

5.1 Multi-technology management

Diversification into new types of businesses and resources is an old phenomenon and an inherent feature in corporate evolution, subjected to much controversy as well as to fashion-oriented management. Despite this, diversification has only fairly recently been analyzed in the literature, with inconclusive results as to the impact of product diversification on economic performance. However, more recent research has focused on a new type of diversification into multiple technologies, i.e. technological diversification, which so far has proven to be strongly associated with growth of sales as well as with growth of R&D expenditures and external technology sourcing, especially when combined with product and market diversification. As a result, products become increasingly multi-technology ('mul-tech' rather than 'hi-tech'), and corporations develop into MNC/MPC/MTC combines.

In order to reap the economies involved in technological diversification, a number of critical management abilities have been identified, so far only through case studies. Thus, critical abilities in multi-technology management are to manage technology assembly, technology transitions, technology transfer and conflicts. Conflicts among managers and personnel are deeply involved in innovation and diversification into new technologies, not least the conflicts associated with engineering subcultures. In contrast to 'hi-tech' management, 'mul-tech' management thus has to focus on sourcing, assembling and exploiting an ever-changing portfolio of various technologies for customer-oriented business development, rather than to focus on in-house R&D of a narrow range of proprietary advanced technologies, which possibly may be over-performing for many market segments and applications.

5.2 Managing diversification dynamics

Some general conclusions regarding successful diversification management could finally be formulated. First, at strategic level, technology-related product diversification as well as its converse, product-related technological diversification, must be clearly recognized as a venue toward growth and profitability, but with strong emphasis on strong relatedness involving clear economies of scale, scope, speed and space. Often these two types of diversification are best managed in a dialectic fashion, that is, one giving rise to the other in a sequence rather than concurrently, in order to reduce risks. That is, a product may require new technologies for new features and enhanced performance in order to meet new competition. Once these – probably expensive – technologies have been acquired and integrated, one must ask whether there then could be an opportunity for technology-related product diversification. If so, still more technologies may be needed in a next phase and the diversification process continues, often over long periods of time, which requires sustained diversification strategies. Of course, uncertainty and entrepreneurialism may lead to temporary overdiversification and business failures, but the diversification–specialization pendulum must not be allowed to swing to extremes. This is very much a strategic challenge to top management and the corporate board, since commitments and sunk costs creates inertia in the organization – at the same time as short-sighted pressures from investors and others, particularly in downturns, create a momentum for divestment decisions, difficult to reverse. The issue is then not so much what is the core business or the core competence, but how distributed competences can be enhanced, leveraged and integrated for developing new valuable businesses (see Granstrand *et al.*, 1997). To formulate a simple but powerful vision for the direction of long-term diversification in the corporation is often helpful. Good examples are the C&C (Computers and Communications) vision of NEC and Toshiba's E&E (Energy and Electronics) vision. However, it must also be kept in mind that, despite its long-term nature, the economic lifetime of such a vision is limited.

5.3 Managing quasi-integrated corporate innovation systems

Second, at structural level, the suitability of the divisionalized organizational structure is commonly recognized for large, diversified corporations. With technology-related business divisions operating on a short-term P/L account, a rationale arises for centralizing some R&D and technology acquisition operations. In addition, internally competing technologies may have to be organizationally separate to some degree, just as some new business development activities may have to, in order not to be choked by dominant business divisions and day-to-day operations. The suitability of such an organizational structure with semi-autonomous units for R&D on radical new technologies, new business development and corporate venturing is by now fairly well recognized. However, there is a wide spectrum of quasi-integrated structural solutions and strategies for such units, regarding at what level they should be organized, how economic performance should be evaluated, how they should source ideas and ventures internally and externally, preferred entry and exit stages and modes, preferred interfaces with the rest of the organization, management reporting and accountability etc. To go further into this, beyond a note of awareness, would however exceed the scope of this chapter.

5.4 Corporate entrepreneurship

Third, at a more operational level, technology management for diversification must have a commercial and entrepreneurial orientation. Technology has to be managed as an asset that can be built-up (procured) in various ways, not only through traditional in-house R&D but also through alliances and various forms of external sourcing, requiring commercial skills. The technology asset can also be exploited in various ways, not only through traditional downstream investments in production and marketing but also through alliances, spin-offs, divestment and technology marketing. These latter strategies have become increasingly attractive after the strengthening of intellectual property rights and financial markets in the 1980s. Technology exploitation therefore has come closer to corporate venturing, thus calling for commercial skills beyond mere buying technology and interfacing R&D with marketing people in a traditional way. This is probably the most important type of extension of traditional R&D management into modern technology management.

Notes

1 The resulting diversity of firms and products is actually bewildering; see e.g. Petroski (1994) and Sanderson and Uzumeri (1997) for good illustrations at product, line and variant levels. In a large MNC with general-purpose products such as bearings or separators, having a variety of user situations in various industries and countries, thousands and thousands of product variants occur in perhaps hundreds of product and component areas.

2 The companies were Alfa-Laval (engineering), Astra (pharmaceuticals), Boliden (mining), Iggesund (pulp and paper), KemaNobel (chemicals), Philips (electronics), SKF (engineering) and Volvo (engineering).

3 3M, Astra, ABB, Canon, Digital Equipment, Honda, Kyocera, Matsushita, Motorola, NEC, Sandoz, Sony, Toshiba and Toyota.

4 BASF, Bayer, Electrolux, ESAB, DuPont, Ford, Glaxo, General Motors, Hitachi, IBM, Kodak, Rhone Poulenc, Pharmacia, L'Oréal, Nobel, Ericsson, Unilever, Volvo and Xerox.

5 Sumitomo, Sanyo, Merck, Nippon Steel and Siemens.

6 General Electric, Aerospatiale, ICI, FAG, Thomson CSF, Olivetti, Texas Instruments and Philips.

7 This finding has later been confirmed also by Gambardella and Torrisi (1998) for 32 of the largest European and US electronics firms.

8 If a technology is licensed out without being implemented at all in a proprietary physical product, it is still related to a particular business.

9 Incidentally no reference is made to technological diversification in the surveys of diversification literature by Ramanujam and Varadarajan (1989) and Montgomery (1994), nor in general surveys of strategy literature, e.g. Hitt *et al.* 2001.

10 If N is the number of important technologies, some of which have mutual relations giving rise to combination costs, the R&D costs at product level could specifically be hypothesized to depend quadratically on N, that is, R&D costs $= a + bN + cN^2$. If some of all the possible multilateral interdependence relations among the N technologies are assumed to contribute roughly equally to R&D costs, then these costs would hypothetically grow exponentially, i.e. R&D costs $= a * \exp(bN)$, as a result of technological diversification. The often observed progressive rise in R&D costs in a product area over time, or over successive product generations, could thus be explained, at least partially, by technological diversification, with the shape of progressive growth being somewhere between quadratic and exponential growth.

11 For this type of analysis the concept of technological distance has been developed; see Granstrand 1994.

12 The saying is sometimes attributed to the former chairman Karl-Heinz Kaske of Siemens, but the origin is unclear within Siemens (which in itself illustrates the saying).

13 This section builds on a series of about 30 interviews in Ericsson in the mid-1980s, reported in Granstrand and Sjölander (1990).

14 This circumstance may partially explain the phenomenon of innovation by invasion as described by Schon (1967), that is, how whole sectors of industry are invaded by new technologies outside their traditional fields.

References

Ansoff, H.I. (1957), ‘Strategies for diversification’, *Harvard Business Review,* 35/5, 113–124.

Chandler, A.D. (1962), *Strategy and Structure: Chapters in the History of the American Industrial Enterprise* (Cambridge, MA: MIT Press).

Chandler Jr., A.D. (1990), *Scale and Scope – The Dynamics of Industrial Capitalism* (Cambridge, MA and London: Belknap Press of Harvard University Press).

Christensen, C.M. (1997), *The Innovator’s Dilemma: When new technologies cause great firms to fail* (Boston, MA: Harvard University Press).

Gambardella, A. and S. Torrisi (1998), ‘Does technological convergence imply convergence in markets? Evidence from the electronics industry’, *Research Policy,* 27, 447–465.

Gemba, K. and F. Kodama (2000), ‘Diversification Dynamics of the Japanese Industry’. Working paper, RCAST, University of Tokyo (mimeo).

Gort, M. (1962), *Diversification and Integration in American Industry* (Princeton, NJ: Princeton University Press).

Granstrand, O. (1982), *Technology, Management and Markets* (London: Frances Pinter Publishers).

Granstrand, O. (ed.) (1994), *Economics of Technology. Seeking Strategies for Research and Teaching in a Developing Field* (Amsterdam: North-Holland).

Granstrand, O. (1998), 'Towards a theory of the technology-based firm', *Research Policy*, 27/6, 465–489.

Granstrand, O. and C. Oskarsson (1994), 'Technological diversification in MUL-TECH corporations', *IEEE Transactions on Engineering Management*, 41/4, 355–364.

Granstrand, O. and S. Sjölander (1990), 'Managing innovation in multi-technology corporations', *Research Policy*, 19/1, 35–60.

Granstrand, O., E. Bohlin, C. Oskarsson and N. Sjöberg (1992), 'External technology acquisition in large multi-technology corporations', *R&D Management*, 22/2, 111–133.

Granstrand, O., P. Patel and K. Pavitt (1997), 'Multi-technology corporations: why they have "distributed" rather than "distinctive core" competencies', *California Management Review*, 39/4, 8–25.

Hitt, M.A., R.E Freeman and J.S. Harrison (eds) (2001), *Handbook of Strategic Management* (Oxford: Blackwell Publishers Ltd).

Kodama, F. (1986), 'Technological diversification of Japanese industry', *Science*, 18/7, 233, 291–296.

Leonard-Barton, D. (1995), *Wellsprings of Knowledge. Building and Sustaining the Sources of Innovation* (Boston, MA: Harvard Business School Press).

Markides, C.C. (1995), *Diversification, Refocusing, and Economic Performance* (London, England and Cambridge, MA: The MIT Press).

Montgomery, C.A. (1994), 'Corporate diversification', *Journal of Economic Perspectives*, 8/3, 163–178.

Nelson, R.R. and S. Winter (1982), *An Evolutionary Theory of Economic Change* (Cambridge, MA: The Belknap Press).

Oskarsson, C. (1993), Technological Diversification – the Phenomenon, Its Causes and Effects, PhD dissertation, Department of Industrial Management and Economics, Chalmers University of Technology, Göteborg, Sweden.

Patel, P. and K. Pavitt (1994), 'Technological competencies in the world's largest firms: characteristics, constraints and scope for managerial choice', STEEP Discussion Paper No. 13, Science Policy Research Unit, University of Sussex.

Pavitt, K., M. Robson and J. Townsend (1989), 'Technological accumulation, diversification and organisation in UK companies 1945–1983', *Management Science*, January 35/1, pp. 81–99.

Penrose, E. (1959), *The Theory of the Growth of the Firm* (Oxford: Basil Blackwell).

Petroski, H. (1994), *The Evolution of Useful Things* (New York, NY: Vintage Books, Random House Inc.).

Ramanujam, V. and P. Varadarajan (1989), 'Research on Corporate Diversification: A Synthesis', *Strategic Management Journal*, 10, 523–551.

Ravenscraft, D.J. and F.M. Scherer (1987), *Mergers, Sell-Offs, and Economic Efficiency* (Washington, DC: The Brookings Institution).

Rumelt, R.P. (1974), *Strategy, Structure and Economic Performance* (Cambridge, MA: Harvard Business Press).

Sanderson, S.W. and M. Uzumeri (1997), *Managing Product Families* (Chicago, IL: Irwin).

Scherer, F.M. (1980), *Industrial Market Structure and Economic Performance* (Chicago, IL: Rand McNally).

Schon, D.A. (1967), *Technology and Change, The New Heraclitus* (New York, NY: Delacorte Press).

Scott, J.T. (1993), *Purposive Diversification and Economic Performance* (New York, NY: Cambridge University Press).

Yamaji, K. (1994), 'Market economy and intellectual property oriented management', Speech at LES International Conference in Beijing, 7 May.

12 Summary and conclusions

John Cantwell, Alfonso Gambardella and Ove Granstrand

Corporate technological diversification, as the contributions in this book set out to illustrate, is a multifaceted and complex issue and research in this area branches out in a variety of directions, driven by a host of questions. While technological diversification has come into the spotlight as an emerging research area quite recently, the phenomenon has been developing in large firms over a much longer period of time as discussed in the historical overview provided in Chapter 10 by Cantwell in this book. It is therefore not surprising that the state of knowledge is so far mostly focused on uncovering and describing the complexity and determinants of corporate technological diversification and its implications for other research areas, such as economic performance, internationalisation, alliances and managerial issues. As is also characteristic of an emerging field, the existing work reflects a continuing refinement and search for new methodology as the concepts under investigation get defined more succinctly and consensus builds over how the problem can be distinguished from other related issues. The purpose of this chapter is to tie together some of the major insights of the work presented in this volume amidst all the complexity, and also to outline the areas into which future research efforts may be usefully heading. In the course of our discussion, we highlight six key themes.

(i) The dual role of information and communications technology (ICT)

The most basic insight that emerges across all the contributions to the volume is that technological capabilities are diversifying in large multi-product firms and the extent of this type of diversification has surpassed the other 'classic' types of diversification, namely product and market diversification. This brings the 'multi-technology corporation' centre stage (Pavitt *et al.,* 1989; Granstrand *et al,* 1997). A closer look beneath the rather sweeping statement that technological diversification has been gathering pace, reveals that this dispersion of corporate competencies has not evenly affected firms' efforts in all technologies, and has taken different forms depending on the industry and its past development. As Mendonça shows in Chapter 8 in this volume ICT, drugs and biotech, and materials technology seem to be the areas in which the greatest diversification has taken place.

The key importance of ICT to the now more complex management of innovation in MNCs is that it enables firms to better exploit their corporate technological diversification across national boundaries, as well as across business areas. This owes to the dual role of ICT as being both a means of combining fields of knowledge creation that were previously kept largely apart, and a managerial process technology that lowers internal coordination costs, and thus may extend the potential boundaries of firms. Other aspects of the first facet of ICT are discussed below – the greater facility to develop related combinations of formerly separate lines of technological development. With respect to the second facet, the methods of managing more complex combinations and greater diversity have also improved. Thus, the social technology of management practice has itself developed to facilitate technological diversification (see Chapter 11 by Granstrand in this volume). This implies the feasibility of the kind of organisational structure that is needed to sustain a more diverse firm, and one that is more flexible and potentially adaptable.

(ii) A paradigm shift away from the pursuit of related but separate avenues of innovation, and towards an integration of paths so as to more fully develop the potential for complementarities between technologies and business areas

However, while this use of ICT has led many smaller firms to extend the breadth of their technological diversification to create new combinations, in some of the very largest MNCs the extent of technological diversification has been reduced, so as to better focus on the most promising possible combinations from among the broader initial dispersion of innovative activity that such companies have inherited from the past (Cantwell and Santangelo, 2000). The particularly pronounced trend towards a wider dispersion of innovative effort in ICT seems to be evidence of a paradigm shift in the general conditions for innovation and growth, according to the neo-Schumpeterian perspective upon long-term techno-socio-economic change (Freeman and Perez, 1988). However, empirical investigations also show that industries differ in the propensity of their firms to diversify into technologies that lie in complementary or non-primary fields for the industry.

While the expanded contribution of ICT is a widely acknowledged feature of the so-called ‘new economy’ or a new paradigm, with its associated need for more general and multiple skills on the part of the workforce, the greater significance of business process re-engineering and the more frequent changing and reconstitution of firm boundaries may not have been so widely appreciated. The new paradigm is one of continual experimentation over the right mix at the firm level, seeking out the most productive combinations of business areas and technologies. It might also be noted that this shift casts further doubt on the traditional finance perspective on diversification. In the finance perspective on the subject, diversification is believed to be a means of reducing risk by holding a portfolio of alternative lines of activity, but this has always been a misleading conceptualisation of the diversification of firms (as opposed to that of financial investors). The diversification we observe in firms is deliberately combinatory as part of a business strategy, and has become increasingly so. In the finance perspective we should observe diversification into unrelated assets, whereas what we actually observe is the reverse, diversification into related assets and the establishment of patterns of corporate coherence (Teece *et al.*, 1994), and this is now found increasingly as a means of developing new structures of relatedness between in-house activities.

(iii) External technology acquisition as an increasingly significant means of knowledge combination

In addition to differences in the types of technologies that are being added to existing competencies, there also are differences in the sources from which these are coming. Firms rely on some combination of generating new technological knowledge gradually internally, together with the external capabilities that they access through inter-company alliances, networks that include cross-licensing arrangements and informal exchanges, as well as through acquisitions. This combination of external and internal knowledge generation is of increasing importance, as in order to engage in inter-company interaction fruitfully, firms must maintain an adequate diversification of their in-house technological efforts, since the closer that knowledge is to the proprietary interests of a firm the more likely that it will only be shared in return for something else that is probably technologically complementary, which is what each firm needs to join the relevant corporate club (Cantwell and Barrera, 1998).

In technology-based corporate clubs the rationale is knowledge exchange, which to be warranted requires a sufficient diversity of capabilities among the members of the club, but in order to benefit from the exchange each recipient requires an adequate span of absorptive capacities. A special case in which these conditions are met occurs when a group of firms each contribute to a wider and complex technological system, and so necessarily maintain some overlapping lines of innovation, although these are normally approached in each case slightly differently from their own particular vantage points. The need to possess an adequate absorptive capacity in order to realise the potential for knowledge exchange implies that the spectrum of a firm's diversified internal capabilities will be at least as wide as the breadth of external capabilities on which it is able to draw in practice, through its membership of inter-company clubs or alliances. Indeed, as a general rule the spread of internal diversification will be much wider than the span of external sources of diversified capabilities that it can actively utilise in its own innovative efforts (see Giuri, Hagedoorn and Mariani in Chapter 5 in this volume).

Despite these general trends that have affected all companies to a greater or lesser extent, variations across firms in diversification profiles can be explained from an historical perspective by looking at the specific research tradition and distinctive characteristics that have come from the early years of individual companies, which through path-dependent technological evolution create more or less favourable conditions for internal knowledge diversification. Despite the idiosyncrasies of individual firms there seem to be industry-specific drivers that regulate the direction and form of technological diversification as well. For example, the pharmaceutical (except biotech) and petrochemical sectors enter into less technological alliances, than do the ICT, automotive and aerospace sectors.

While the descriptive work outlining the sectoral differences in the patterns and extent of corporate technological diversification is now far along, our understanding of the underlying reasons is still in the early stages and is one of the major fields of future research. The basic determinants of the direction and shape of a firm's composition of technological diversification can be linked to the complexity of the product, the production process and of the supporting underlying science. As has been illustrated here in the case of the aerospace and pharmaceutical industries (see Chapter 6 by Pammolli and Riccaboni and Chapter 9 by Principe), a rise in complexity leads both to a widening of the technological base of manufacturers, but also to an increase of division of innovative labour between the different groups of players (to follow the terminology of our authors, between the 'coordinators' or 'developers' on the one hand and the 'suppliers' or 'originators' on the other).

(iv) A shift towards a recombinant kind of technological diversification that is non- or pre-product-related

At a more fundamental level the drivers of an increased corporate technological diversification can be traced to a changing institutional form of innovation per se. Until about 1970, as described by Chandler (1990) there was a direct interleaving between economies of scale and scope. Large firms grew by diversifying their technological base basically by moving horizontally from one field to a related one, and in the process diversified their product markets in similar proportion, and together this combined diversification supported (and was supported by) a rise in the scale of output. Most growth took the form of the joint attainment of increased scale and greater scope as diversification and growth of output went hand in hand. Thus, in the early years of their growth, large firms tended to move steadily upwards along a positively sloping size-diversification frontier, the position of which was given for most firms by the then prevailing scale-based paradigm. The size-diversification frontier is a linear relationship that is represented by plotting a measure of technological diversification against the log of size, since firm sizes are known to be approximately lognormally distributed (see Fai and Cantwell, 1999; Cantwell and Santangelo, 2000).

However, in more recent times the position of the size-diversification frontier has shifted quite markedly, which helps to show how the relationship between technological diversification and growth has become less direct than in the past. Across firms the size-diversification frontier has tended to shift upwards (so the average extent of technological diversification has risen, controlling for size). While at one time the growth of output, product and technological diversification were all parts of a common process as firms sought out the benefits of greater scale through an extended scope, corporate technological diversification has shifted to become more of an objective in its own right, a means of creating the potential for future growth rather than simply itself a reflection of current growth. Technological diversification is now more bound up with a prior experimentation, a bringing together of technologically complementary fields so as to facilitate innovation and hence growth. Put another way, the economies of scope associated with corporate technological diversification are now more the dynamic economies from an increased capacity to learn and to innovate, and less the static economies of bringing together an already obviously related set of assets so as to be able to mutually increase the range of exploitation of each of them. (See Chapter 11 by Granstrand.)

The size-diversification frontier has also rotated so that the very largest firms have tended to reduce the diversity of their technological profiles (Fai and Cantwell, 1999). There is now an impetus for firms to achieve a minimum threshold degree of technological diversification to take advantage of greater interrelatedness, but the combinations constructed by the firm must also be coherent enough to focus upon potential linkages in which the interrelatedness or technological complementarity of activities is at its greatest. The increasing significance for firms of technological interrelatedness, convergence and fusion is one aspect of this historical shift, associated with a change in paradigm.

In this context a techno-economic paradigm is a system of scientific and productive activity based on a widespread cluster of innovations that represent a response to a related set of technological problems, relying on a common set of scientific principles and on similar organisational methods (Dosi, 1984). The old paradigm until around 1970 was based on energy and oil-related technologies, and on mass production with its economies of scale and specialised corporate R&D. In recent years this has gradually been displaced by a new paradigm grounded more on the economies of scope as distinct from scale, and derived from the interaction between flexible but linked production facilities, and a greater diversity of search in R&D. In general, as hinted at by Schumpeter, innovation embodies the creation of a kind of 'superadditivity' of new combinations being more than the sum of their parts, and these combinations have become not only more numerous and varied, but sometimes entail a temporary or fluid kind of combination for the purposes of experimentation, as suggested under theme (ii) above. So the modern increase in technological interrelatedness provides a new potential, which has tended to increase the scope and rate of innovation.

(v) Increased technological interactions between actors in innovation due both to greater interrelatedness and an increase in the number of contributors to innovation
A further reason for the increased extent of technological interactions within and between firms lies in the more sophisticated modern system of production and R&D, and the greater breadth of players providing through their search activities a wider variety of technological opportunities. With a fatter lower tail in the distribution of innovative actors there is a greater tendency for firms to try and hedge their bets across a wider range of technological options, and a need for firms to become more outward-looking as discussed under theme (iii) above. A rise in the significance of technological interactions has resulted as well from the more intensive linkages between science and technology that typify the current techno-economic paradigm, which paradigm relies on flexibility through computerisation and diversity through experimentation with new combinations that of necessity draw upon a wider range of disciplines (and hence on a wider range of science). Firms increase the returns on their own R&D through suitably adapting their underlying tacit capability so that they can more intensively absorb and apply the complementary knowledge acquired from other locations or from other firms in their own internal learning processes.

Another major area of continuing research will inevitably be associated with the effects rather than the causes of diversification, i.e. what impact technological diversification has on a variety of factors. As with the determinants of corporate technological diversification, the connections with economic performance, internationalisation, external technology acquisition including that achieved through alliances, managerial issues and product diversification are quite complex and typically not always unidirectional from a longer term perspective.

First there are several interactions and connections between the three major types of corporate diversification, i.e. with regard to technology, markets and products. Technological diversification is still positively even if now less directly related to product diversification and vice versa, as argued earlier, and both types of diversification are subject to certain resource constraints in terms of management and organisational capabilities. The relationship between technological diversification and the internationalisation of production is also a complex one, in that it is mediated by the accumulation of competence and competence creation in the multinational firm. It has also changed in nature over the years, from being an historically negative relationship (a choice between greater diversification in established markets and entry into new markets) when most international investments were market-seeking, to a positive one in the most recent period (there being a complementarity between extending the competence base of the multinational firm at home and abroad) when a rising share of international investments are technology or asset-seeking (see Chapter 4 by Cantwell and Piscitello in this volume).

Second, overall corporate technological diversification seems to have a positive impact on performance, which may be the reverse of the apparently often negative relationship between product diversification and performance, although the latter is still not conclusive (see also Chapter 2 by Torrisi and Granstrand). However, the positive effect of technological diversification for the firm is moderated by the coherence of technological diversification and the source of the diversification. In general, firms that focus on a few technological fields in their internal and external diversification effort and have a large number of outside alliances perform better (see Chapter 5 by Giuri, Hagedoorn and Mariani). The type of diversification most likely to be conducive to performance also depends on the role of the individual firm in the innovatory network in certain industries. Firms that have a coordinating function in the network tend to benefit from a wider horizontal technological spread as opposed to the specialist firm that benefits from a more vertical pattern of diversification.

(vi) The unpredictability of longer term variations in technological opportunities and of patterns of corporate technological diversification across industries

The complexity of the relationship between corporate technological diversification, performance and inter-firm collaboration is further increased by the recent findings that in the chemical industry licensing is becoming a means of gaining value from technological surplus and thus it is positively influenced by technological diversification (see Chapter 7 by Cesaroni). An important area for future research will be to establish whether the tendencies that have been identified here are generalisable across industries or whether some are more industry-specific and, if so, what are the reasons for any differences. It will also be valuable to uncover the underlying processes that link together these various aspects of corporate behaviour, or so as to say, to open the 'black box' of mechanisms within the firm.

There is always some chance or random element to success or failure in innovation, and where or by whom success is achieved. Key inventions or scientific breakthroughs occur from time to time, but in a fashion that is partially exogenous to the prevailing economic and social conditions, and even to past technological accumulation (which may have constituted the necessary setting of the scene for a critical new invention as argued by Usher, but is not in itself sufficient to ensure that a critical act of insight follows quickly). Each such radical breakthrough opens up a new branch of research with potentially multiple impacts, but depending upon the nature of what has been discovered certain industries will have been provided with a greater fillip to their innovation than others. The cross-industry set of technological opportunities varies quite markedly over time, and the way in which it does so involves some element of human creativity that implies uncertainty over what will be achieved, when, and which new directions it will open up.

There is undoubtedly uncertainty as well over the evolving structure of technological interrelatedness, which may move in the direction of some new combinations rather than others, and which it requires the processes of search and experimentation to reveal. We might speculate here that the strength of the historical path-dependency in corporate technological trajectories may have been weakened by the detachment of technological diversification from having been largely a reflection of (past or contemporary) product diversification, and towards technological diversification becoming instead itself a means of experimentation with potential new combinations for the future, as argued under theme (iv) above. If technological diversification evolves according to which combinations yield the greatest opportunities for a given industry, then firms may be led more readily into new business directions. This underlines the significance of the point made by Cantwell in Chapter 10 in this volume, that the path-dependency of corporate technological trajectories is subject to a gradual historical drift, and it suggests that the random or drift element may become relatively more significant and create a faster pace of change in profiles of corporate technological specialisation.

Developing further the methodology used, while standardising it rather more and applying it more consistently across future studies, will assist in confirming and solidifying the results that have emerged from our various directions of exploration, as well as helping to clarify sometimes apparently contradictory findings. The preferred method of choice in research related to corporate technological diversification is patent data analysis and its use has been increasingly perfected over the years, with most researchers more fully aware of both its potential and its limitations. However, as Breschi, Lissoni and Malerba (in Chapter 3) and other authors discuss in this volume, there are differences between a variety of indicators commonly used in the past, and this may be the reason for some occasionally conflicting results and inconclusive findings. Future research, especially on the relatedness of knowledge and inter-firm and cross-sector technological spillovers, will require refinements and perhaps a more sophisticated combination of indicators in research methodology.

Overall, were one to attempt to put the insights of all the contributions in just one statement, we might conclude that the nature of economies of scope has been fundamentally changed and more intimately bound up with the dynamics of combinatory technological innovation with the arrival of a new techno-economic paradigm. Thus corporate technological diversification, which is closely connected to and has been given new impetus from this reinforcement of interrelatedness in innovation and in learning processes, is increasingly becoming a central issue and a key consideration for managers and researchers alike.

References

Cantwell, J.A. and Barrera, M.P. (1998), 'The localisation of corporate technological trajectories in the interwar cartels: cooperative learning versus an exchange of knowledge', *Economics of Innovation and New Technology*, vol. 6, pp. 257–290.

Cantwell, J.A. and Santangelo, G.D. (2000), 'Capitalism, profits and innovation in the new techno-economic paradigm', *Journal of Evolutionary Economics*, vol. 10, pp. 131–157.

Chandler, A.D. (1990), *Scale and Scope: The Dynamics of Industrial Capitalism*, Cambridge, MA: Harvard University Press.

Dosi, G. (1984), *Technical Change and Industrial Transformation*, London: Macmillan.

Fai, F.M. and Cantwell, J.A. (1999), 'The changing nature of corporate technological diversification and the importance of organizational capability', in S.C. Dow and P.E. Eart (eds), *Contingency, Complexity and the Theory of the Firm: Essays in Honour of Brien J. Loasby*, vol. 2, Cheltenham: Edward Elgar.

Freeman, C. and Perez, C. (1988), 'Structural crises of adjustment, business cycles and investment behaviour', in G. Dosi, C. Freeman, R.R. Nelson, G. Silverberg and L.L.G. Soete (eds), *Technical Change and Economic Theory*, London: Frances Pinter.

Granstrand, O., Patel, P. and Pavitt, K.L.R. (1997), 'Multi-technology corporations: why they have "distributed" rather than "distinctive core" competencies', *California Management Review*, vol. 39, pp. 8–25.

Pavitt, K.L.R., Robson, M. and Townsend, J. (1989), 'Technological accumulation, diversification and organisation in UK companies, 1945–1983', *Management Science*, vol. 35, pp. 81–99.

Teece, D.J., Rumelt, R., Dosi, G. and Winter, S.G. (1994), 'Understanding corporate coherence: theory and evidence', *Journal of Economic Behavior and Organization*, vol. 23, pp. 1–30.

Further bibliography

Aaker, D.A. (1991), *Managing Brand Equity: Capitalizing on the Value of a Brand Name*, New York: Free Press.

Abramowitz, M. (1956), Catching Up, Forging Ahead and Falling Behind, *Journal of Economic History*, 46(92), 385–406.

Amihud, Y. and B. Lev (1999), Does Corporate Ownership Structure Affect Its Strategy Towards Diversification? *Strategic Management Journal*, 20, 1063–1069.

Antonelli, C. (2003), *The Economics of Innovation, New Technologies and Structural Change*, London: Routledge.

Argyres, N. (1996), Capabilities, Technological Diversification and Divisionalization, *Strategic Management Journal*, 17, 395–410.

Argyres, N. (1996), Evidence on the Role of Firm Capabilities in Vertical Integration Decisions, *Strategic Management Journal*, 17, 129–150.

Arnould, R.J. (1969), Conglomerate Growth and Public Policy, in Gordon, L. (ed.), *Economics of Conglomerate Growth*, Corvallis, OR: Oregon State University Department of Agricultural Economics, 72–80.

Bachmann, A. (1999), *Technological Capabilities in Large Science-Based British and German Chemical-Pharmaceutical Companies: Changing Patterns of Corporate Technological Specialisation, Leadership and Diversification*, PhD thesis, University of Reading.

Bodnar, G.M., C. Tang and J. Weintrop (1997), *Both Sides of Corporate Diversification: The Value Impacts of Geographic and Industrial Diversification*, Working Paper Series, w6224, National Bureau of Economic Research, Inc.

Bottazzi, G., G. Dosi, M. Lippi, F. Pammolli and M. Riccaboni (2001), Innovation and Corporate Growth in the Evolution of the Drug Industry, *International Journal of Industrial Organization*, 19(7), 1161–1188.

Breschi, S., F. Lissoni and F. Malerba (1998), *Technological Diversification and Knowledge Proximity*, mimeo CESPRI.

Breschi, S., F. Lissoni and F. Malerba (2003), Knowledge-relatedness in Firm Technological Diversification, *Research Policy*, 32(1), 69–88.

Cantwell, J.A. (1995), The Globalisation of Technology: What Remains of the Product Cycle Model? *Cambridge Journal of Economics*, 19, 155–174; reprinted in Archibugi, D. and J. Michie (eds), *Technology, Globalisation and Economic Performance*, Cambridge: Cambridge University Press, 1997, 215–240; in Chandler, A.D., P. Hagström and Ö. Sölvell (eds) (1998) *The Dynamic Firm*, Oxford: Oxford University Press, 263–288; and in Cantwell, J.A. (ed.) (1999), *Foreign Direct Investment and Technological Change, II,* Cheltenham: Edward Elgar, 102–121.

Cantwell, J.A. (2000), Technological Lock-in of Large Firms Since the Interwar Period, *European Review of Economic History*, 4, 147–174.

Cantwell, J.A. and H.B. Andersen (1999), *How Firms Differ in Their Types of Technological Competencies, and Why it Matters*, University of Manchester ESRC Centre for Research on Innovation and Competition Discussion Papers, 25, 39pp.

Cantwell, J.A. and A. Bachmann (1998), Changing Patterns of Technological Leadership: Evidence form the Pharmaceutical Industry, *Journal of Innovation Management*, 2, 45–77.

Cantwell, J.A. and M.P. Barrera (1998), The Localisation of Corporate Technological Trajectories in the Interwar Cartels: Cooperative Learning Versus an Exchange of Knowledge, *Economics of Innovation and New Technology*, 6, 257–290.

Cantwell, J.A. and M.G. Colombo (2000), Technological and Output Complementarities, and Inter-firm Cooperation in Information Technology Ventures, *Journal of Management and Governance*, 4, 117–147.

Cantwell, J.A. and F.M. Fai (1999), Firms as the Source of Innovation and Growth: The Evolution of Technological Competence, *Journal of Evolutionary Economics*, 9, 331–366.

Cantwell, J.A. and F.M. Fai (1999), The Changing Nature of Corporate Technological Diversification and the Importance of Organisational Capability, in Dow, S.C. and P.E Earl (eds), *Contingency, Complexity and the Theory of the Firm: Essays in Honour of Brian J. Loasby*, Cheltenham: Edward Elgar, 113–137.

Cantwell, J.A. and O.E.M. Janne (1999), Technological Globalisation and Innovative Centres: the Role of Corporate Technological Leadership and Locational Hierarchy, *Research Policy*, 28, 119–144.

Cantwell, J.A. and L. Piscitello (1999), The Emergence of Corporate International Networks for the Accumulation of Dispersed Technological Competencies, *Management International Review*, 39, Special Issue, 123–147.

Cantwell, J.A. and L. Piscitello (2000), Accumulating Technological Competence – Its Changing Impact on Corporate Diversification and Internationalisation, *Industrial and Corporate Change*, 9, 21–51.

Cantwell, J.A. and G.D. Santangelo (1999), The Frontier of International Technology Networks: Sourcing Abroad the Most Highly Tacit Capabilities, *Information Economics and Policy*, 11, 101–123.

Cantwell, J.A and G.D. Santangelo (2000), Capitalism, Profits and Innovation in the New Techno-economic Paradigm, *Journal of Evolutionary Economics*, 10, 131–157.

Cantwell, J.A. and G.D. Santangelo (2002), The New Geography of Corporate Research in Information and Communications Technology, *Journal of Evolutionary Economics*, 12(1–2), 163–197.

Cassiman, B. and R. Veugelers (2000), *External Technology Sources: Embodied or Disembodied Technology Acquisition*, mimeo.

Casson, M. and J. Creedy (1993), *Industrial Concentration and Economic Inequality, Essays in Honour of Peter Hart*, Cheltenham: Edward Elgar.

Chang, S.J. (1996), An Evolutionary Perspective on Diversification and Corporate Restructuring: Entry, Exit and Economic Performance During 1981–89, *Strategic Management Journal*, 17, 587–611.

Chang, S.J. and H. Singh (1999), The Impact of Modes of Entry and Resource Fit on Modes of Exit by Multibusiness Firms, *Strategic Management Journal*, 20, 1019–1035.

Chang, Y. and H. Thomas (1989), The Impact of Diversification Strategy on Risk-Return Performance, *Strategic Management Journal*, 10, 271–284.

Chatterjee, S. and J.D. Blocher (1992), Measurement of Firm Diversification: Is It Robust? *Academy of Management Journal*, 35(4), 874–888.

Chatterjee, S. and J. Singh (1999), Are Tradeoffs Inherent in Diversification Moves? A Simultaneous Model for Type of Diversification and Mode of Expansion Decisions, *Management Science*, 45(1), 25–41.

Christensen, J.F. (1998), *The Dynamics of the Diversified Corporation and the Role of Central Management of Technology*, DRUID Working Paper No. 98-4.

Chu, W., *The Changing Pattern of Diversification Strategy of Business Groups in Taiwan*, Working Paper.

Chu, W. and C.M. Chuang (1999), *Coordination Mechanisms and Effectiveness within Diversified Business Groups: Evidence from Taiwan*, presented at the Strategic Management Society 19th Annual International Conference, October 3–6, Berlin.

Cohen, W.M. and F. Malerba (2001), Is the Tendency to Variation a Chief Cause of Progress? *Industrial and Corporate Change*, 10(3), 587–608.

Coombs, R. and A. Richards (1993), Strategic Control of Technology in Diversified Companies with Decentralized R&D, *Technology Analysis and Strategic Management*, 5(4), 385–396.

Daniels, J.D., R.A. Pitts and M.J. Tretter (1985), Organizing for Dual Strategies of Product Diversity and International Expansion, *Strategic Management Journal*, 6, 223–237.

Davis, R. and J.D. Duhaime (1992), Diversification, Vertical Integration and Industry Analysis: New Perspectives and Measurement, *Strategic Management Journal*, 13, 511–524.

Denis, D.J., D.K. Denis and A. Sarin (1999), Agency Theory and the Influence of Equity Ownership Structure on Corporate Diversification Strategies, *Strategic Management Journal*, 20, 1071–1076.

Doyle, P. (1975), Market Planning in the Multiproduct Firm, *Industrial Marketing Management*, 4(4), 183–192.

Errunza, V.R. and L.W. Senbet (1984), International Corporate Diversification, Market Valuation and Size-Adjusted Evidence, *Journal of Finance*, 39(3), 727–745.

Fai, F.M. (1998), *Corporate Technological Competence and the Evolution of Technological Diversification*, Thesis, Department of Economics, The University of Reading.

Fan, J.P.H. and L.H.P. Lang (2000), The Measurement of Relatedness: An Application to Corporate Diversification, *The Journal of Business*, 73(4), 629–660.

Gambardella, A. and S. Torrisi (1998), Does Technological Convergence Imply Convergence in Markets? Evidence from the Electronics Industry, *Research Policy*, 27(5), 447–465.

Gemba, K. and F. Kodama (2001), Diversification Dynamics of the Japanese Industry, *Research Policy*, 30(8), 1165–1184.

Geringer, J.M., P.W. Beamish and R.C. daCosta (1989), Diversification Strategy and Internationalization: Implications for MNE Performance, *Strategic Management Journal*, 10, 109–119.

Giarratana, M. and S. Torrisi (1999), *Competence Accumulation and Collaborative Ventures: Evidence from the Largest European Electronics Firms and Implications for the EU Technological Policies*. Paper prepared for the DYNACOM TSER Project, EC DGXII (contract no. SOE1-CT97-1078), Castellanza, mimeo.

Goold, M. and K. Sommers Luchs (eds) (1996), *Managing the Multibusiness Company; Strategic Issues for Diversified Groups*, London and New York: Routledge.

Gordon, L. (ed.) (1969), *Economics of Conglomerate Growth*, Corvallis OR: Oregon State University Department of Agricultural Economics.

Gort, M. (1962), *Diversification and Integration in American Industry*. Princeton, NJ: Princeton University Press.

Granstrand, O. (1982), *Technology, Management and Markets: An Investigation of R&D and Innovation in Industrial Organizations*, London: Frances Pinter.

Granstrand, O. (ed.) (1994), *Economics of Technology*, Amsterdam: Elsevier North-Holland, Ch. 7.

Granstrand, O. (1998), Towards a Theory of the Technology-Based Firm, *Research Policy*, 27(5), 465–479.

Granstrand, O. and S. Alänge (1995), The Evolution of Corporate Entrepreneurship in Swedish Industry – Was Schumpeter Wrong? *Journal of Evolutionary Economics*, 5, 1–24.

Granstrand, O. and C. Oskarsson (1994), Technology Diversification in Mul-Tech Corporations, *IEEE Transactions on Engineering Management*, 41(4), 355–364.

Granstrand, O. and S. Sjölander (1990a), Managing Innovation in Multi-technology Corporations, *Research Policy*, 19(1), 35–60.

Granstrand, O. and S. Sjölander (1990b), The Acquisition of Technology and Small Firms by Large Firms, *Journal of Economic Behaviour and Organisation*, 13, 367–386.

Granstrand, O. and S. Sjölander (1992), Internationalization and Diversification of Multi-Technology Corporations, in Granstrand, O., L. Håkanson and S. Sjölander (eds), *Technology Management and International Business*, London: John Wiley & Sons.

Granstrand, O., E. Bohlin, C. Oskarsson and N. Sjöberg (1992), External Technology Acquisition in Large Multi-Technology Corporations, *R&D Management*, 22(2), 111–133.

Granstrand, O., C. Oskarsson, N. Sjöberg and S. Sjölander (1990), Business Strategies for New Technologies, in Deiaco, Hörnell and Vickery (eds), *Technology and Investment*, London: Pinter Publishers.

Granstrand, O., P. Patel and K. Pavitt (1997), Multi-Technology Corporations: Why They Have 'Distributed' Rather than 'Distinctive' Core Competence, *California Management Review*, 39(4), 8–25.

Granstrand, O., S. Sjölander and S. Alänge (1989), Strategic Technology Management Issues in Japanese Manufacturing Industry, *Technology Analysis and Strategic Management*, 1(3), 259–272.

Grant, R.M., A.P. Jammine and H. Thomas (1988), Diversity, Diversification, and Profitability Among British Manufacturing Companies, 1972–1984, *Academy of Management Journal*, 31(4), 771–801.

Hagerdoorn, J. (1996), Trend and Patterns in Strategic Technology Partnering Since the Early Seventies, *Review of Industrial Organization*, 11, 601–616.

Hart, P.E, (1961), Notes and Book Reviews, Statistical Measures of Concentration vs Concentration Ratios, *The Review of Economics and Statistics*, XLIII, February, 85–86.

Hart, P.E. (1971), Entropy and Other Measures of Concentration, *Journal of the Royal Statistical Society*, 134(1), 73–85.

Hill, C.W.L. and R.E. Hoskisson (1987), Strategy and Structure in the Multiproduct Firm, *Academy of Management Review*, 12(2), 331–341.

Hitt, M.A., R.E. Hoskisson and R.D. Ireland (1994), A Mid-range Theory of the Interactive Effects of International and Product Diversification on Innovation and Performance, *Journal of Management*, 20(2), 297–326.

Hitt, M.A., R.E. Hoskisson and H. Kim (1997), International Diversification: Effects on Innovation and Firm Performance in Product-diversified Firms, *Academy of Management Journal*, 40, 767–798.

Hoskisson, R.E., M.A. Hitt, R.A. Johnson and D.D. Moesel (1993), Construct Validity of an Objective (Entropy) Categorical Measure of Diversification Strategy, *Strategic Management Journal*, 14(3), 213–235.

Jacobsson, S. and C. Oskarsson (1994), Educational Statistics as an Indication of Technological Activity, *Research Policy*, 23(3), 235–248.

Jacobsson, S., S. Sjölander, O. Granstrand and S. Alänge (1989), Strategic Technology Issues in US Manufacturing Industries – A Critical Analysis, *CIM Working Papers*, WP 03, Department of Industrial Management and Economics, Chalmers University of Technology, Göteborg.

Jacquemin, A.P. and C.H. Berry (1979), Entropy Measure of Diversification and Corporate Growth, *Journal of Industrial Economics*, 27(4), 359–369.

Jose, M.L., L.M. Nichols and J.L. Stevens (1986), Contributions of Diversification, Promotion and R&D to the Value of Multiproduct Firm: A Tobin's q Approach, *Financial Management*, Winter, 33–42.

Keisuke, B. (2000), *An Empirical Analysis on Transition of Technology Structure of Industries – Evidences from Technology Spillover*, mimeo.

Kim, W.C., P. Whang and W.P. Burgers (1989), Global Diversification Strategy and Corporate Profit Performance, *Strategic Management Journal*, 10, 45–57.

Kodama, F. (1986), Technological Diversification of Japanese Industry, *Science*, 233, 291–296.

Kodama, F. (1993), *Emerging Patterns of Innovation*, Boston, MA: Harvard Business School Press.

Lancaster, K. (1990), The Economics of Product Variety: A Survey, *Marketing Science*, 9(3), 189–206.

Lane, P.J., A.A. Cannella Jr and M.H. Lubatkin (1999), Ownership Structure and Corporate Strategy: One Question Viewed from Two Different Worlds, *Strategic Management Journal*, 20, 1077–1086.

Laursen, K. (2000), *Trade Specialization, Technology and Economic Growth: Theory and Evidence from Advanced Countries*, Cheltenham: Edward Elgar.

Link, A.N. and J.E. Long (1981), The Simple Economics of Basic Scientific Research: A Test of Nelson's Diversification Hypothesis, *The Journal of Industrial Economics*, 30(1), 105–109.

MacDonald, J.M. (1985), R&D and the Directions of Diversification, *Review of Economics and Statistics*, 67(3), 583–590.

Mahler, W.R. (1992), *The Diversified Company, An Endangered Species*, Wyckoff, NJ: WRM Inc Publishers.

Mariotti, S. and E. Ricotta (1986), Diversification, Agreements Between Firms and Innovative Behaviour, *Ricerche Econimiche*, XL, 4, 644–674.

Markides, C.C. (1995), *Diversification, Refocusing and Economic Performance*, Cambridge, MA: MIT Press.

Markowitz, H. (1952), Portfolio Selection, *Journal of Finance*, VII, 77–91.

Montgomery, C.A. (1982), The Measurement of Firm Diversification: Some New Empirical Evidence, *Academy of Management Journal*, 25(2), 299–307.

Montgomery, C.A. (1994), Corporate Diversification, *Journal of Economic Perspectives*, 8(3), 163–178.

Montgomery, C.A. and B. Wernerfelt, (1988), Diversification, Ricardian Rents and Tobin's q, *RAND Journal of Economics*, 19(4), 623–632.

Nelson, R.R. and S.G. Winter (1973), Toward an Evolutionary Theory of Economic Capabilities, *American Economic Review*, 63, 440–449.

Omori, T. and G. Yarrow (1982), Product Diversification, Entry Prevention and Limit Pricing, *Bell Journal of Economics*, 13(1), 242–824.

Oskarsson, C. (1993), *Technology Diversification – the Phenomenon, Its Causes and Effects*, PhD dissertation, Chalmers University of Technology, Department of Industrial Management and Economics.

Palepu, K. (1985), Diversification Strategy, Profit Performance and the Entropy Measure, *Strategic Management Journal*, 6, 239–255.

Panzar, J.C. and R.D. Willig (1981), Sustainability Analysis: Economies of Scope, *AEA Papers and Proceedings*, 71(2), 268–272.

Patel, P. (1999), *Measurement and Analysis of Technological Competencies of Large Firms*, Dynacom. Brighton: University of Sussex, SPRU, mimeo.

Patel, P. and K. Pavitt (1994), Uneven (and Divergent) Technological Accumulation among Advanced Countries: Evidence and a Framework of Explanation, *Industrial and Corporate Change*, 3(3), 759–787.

Pavitt, K. (1998), Technologies, Products and Organization in the Innovating Firms: What Adam Smith Tells Us and Joseph Schumpeter Doesn't, *Industrial and Corporate Change*, 7(3), 433–452.

Pavitt, K.L.R., M.J. Robson and J.F. Townsend (1989), Technological Accumulation, Diversification and Organisation in UK Companies, 1945–1983, *Management Science*, 35(1), 81–99.

Piscitello, L. (1998), *Corporate Diversification, Coherence and the Dialectic Relationship Between Technological and Product Competence*, PhD thesis, Politecnico di Milano, Milan.

Piscitello, L. (2000), Relatedness and Coherence in Technological and Product Diversification of the World's Largest Firms, *Structural Change and Economic Dynamics*, 11(3), 295–315.

Raghunathan, S.P. (1995), A Refinement of the Entropy Measure of Firm Diversification: Toward Definitional and Computational Accuracy, *Journal of Management*, 21(5), 989–1002.

Rama, R. (1995), *Growth and Geographical Diversification of Food and Drink Multinationals*, EMOT Workshop on Technology and the Theory of the Firm, University of Reading.

Ramanujam, V. and P. Varadarajan (1989), Research on Corporate Diversification: A Synthesis, *Strategic Management Journal*, 10, 523–551.

Rotemberg, J.J. and S. Garth (1994), Benefits of Narrow Business Strategies, *American Economic Review*, 84(5), 1330–1349.

Rumelt, R.P. (1974), *Strategy, Structure and Economic Performance*, Cambridge, MA: Harvard University Press.

Rumelt, R.P. (1982), Diversification Strategy and Profitability, *Strategic Management Journal*, 3, 359–369.

Rumelt, R.P., D.E. Schendel and D.J. Teece (eds) (1994), *Fundamental Issues in Strategy, A Research Agenda*, Boston, MA: Harvard Business School Press.

Sandvig, J.C. (2000), The Role of Technology in Small Firm Diversification, *Journal of Technology Transfer*, 25(2), 157–168.

Sankaran, P.R. (1995), A Refinement of the Entropy Measure of Firm Diversification: Toward Definitional and Computational Accuracy, *Journal of Management*, 21(5), 989–1002.

Scott, J.T. (1993), *Purpose Diversification and Economic Performance*, Cambridge and New York: Cambridge University Press.

Silverman, B.S. (1998), *Technological Resources and the Direction of Corporate Diversification: Toward an Integration of the Resource-based View and Transaction Cost Economics*, HBS, Working Paper 99–019.

Simmonds, P.G. (1990), The Combined Diversification Breadth and Mode Dimensions and the Performance of Large Diversified Firms, *Strategic Management Journal*, 11, 399–410.

Sjölander, S. and C. Oskarsson (1995), Diversification: Exploiting the flow of Technology. A Swedish Comparison, *International Journal of Technology Management*, 10(1), 21–30.

Stimpert, J.L and I.M. Duhaime (1997), In the Eyes of the Beholder: Conceptualizations of Relatedness Held by the Managers of Large Diversified Firms, *Strategic Management Journal*, 18(2), 111–125.

Tunzelmann, G.N. von (1998), Localized Technological Search and Multi-technology Companies, *Economics of Innovation and New Technology*, 6, 231–255.

Vancil, R.F. and P. Lorange (1975), Strategic Planning in Diversified Companies, *Harvard Business Review*, Jan–Feb, 81–88.

Vonortas, N.S. (1999), How Do Participants in Research Joint Ventures Diversify? *Review of Industrial Organization*, 15, 263–281.

Wang, Q. and T. Tunzelmann (1996), *The Exploitation of Knowledge-based Approaches in Studying Complex Product Systems*, SPRU, University of Sussex.

Wang, Q. and T. Tunzelmann (1997), *A Study of the R&D/Marketing Interface Using SAPPHO Methodology*, SPRU, University of Sussex.

Wang, Q., K.L. Hansen, and T. Tunzelmann (1998), *Evolution of Firms from a Functional Organisation to a Process Organisation*, SPRU, University of Sussex.

Willig, R.D. (1979), Multiproduct Technology and Market Structure, *American Economic Review*, 69(2), 346–351.

Yakov, A. and B. Lev (1999), Does Corporate Ownership Structure Affect Its Strategy Towards Diversification? *Strategic Management Journal*, 20, 1063–1069.

Yip, G.S. (1982), Diversification Entry: Internal Development versus Acquisition, *Strategic Management Journal*, 3, 331–345.

Yoshihara, H. (1988), Dynamic Synergy and Top Management Leadership: Strategic Innovation in Japanese Companies, in Urabe, K. *et al.* (eds), *Innovation and Management*, Berlin: deGroyten.

Zander, I. (first draft 1997-08-05), *Technological Renewal in the Multinational Corporation – an Evolutionary Perspective*, Scancor, Stanford University.

Zander, I. (1997), Technological Diversification in the Multinational Corporation: Historical Evolution and Future Prospects, *Research Policy*, 26, 209–228.

Zander, I. and Ö. Sölvell (1997-08-05), *International Innovation – An Unexplored Aspect of the Multinational Corporation*, Institute of International Business (IIB), Stockholm School of Economics.

Index

This Index refers principally to persons, countries and organisations mentioned in the main body of the text. It supplements the Table of Contents and Lists at pp. ix–xiv. References to individual companies and particular industries are indexed under the heading 'companies (named)' and 'industries (named)'