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CREATING SILICON VALLEY IN EUROPE

PUBLIC POLICY TOWARDS NEW TECHNOLOGY INDUSTRIES

STEVEN CASPER

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Public Policy towards New Technology Industries

Steven Casper

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Great Clarendon Street, Oxford OX2 6DP

Oxford University Press is a department of the University of Oxford.
It furthers the University's objective of excellence in research, scholarship, and education by publishing worldwide in

Oxford New York

Auckland Cape Town Dar es Salaam Hong Kong Karachi
Kuala Lumpur Madrid Melbourne Mexico City Nairobi
New Delhi Shanghai Taipei Toronto

With offices in

Argentina Austria Brazil Chile Czech Republic France Greece
Guatemala Hungary Italy Japan Poland Portugal Singapore
South Korea Switzerland Thailand Turkey Ukraine Vietnam

Published in the United States
by Oxford University Press Inc., New York

First published 2007

British Library Cataloguing in Publication Data
Data available

Library of Congress Cataloging in Publication Data

Casper, Steven.
Creating Silicon Valley in Europe: public policy towards new technology industries Steven Casper.
p. cm.
Include bibliographical references and index.
ISBN 978–0–19–926952–5 (alk. paper)
1. High technology industries–Europe. 2. Industrial districts–Europe.
3. Research, Industrial–Europe. I. Title.
HC240.9.H53C37 2007
338.94–dc22 2007003252

Typeset by SPI Publisher Services, Pondicherry, India
Printed in Great Britain
on acid-free paper by
Biddles Ltd., King's Lynn, Norfolk

ISBN 978–0–19–926952–5

1 3 5 7 9 10 8 6 4 2

To Kornelia

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Acknowledgments

This book grew out of several years research on the development of the "new economy" in Europe. Beginning in the late 1990s I was fortunate to be employed in Germany, the United Kingdom, and the United States, perhaps not surprisingly the three countries studied in this book. I'd like to thank colleagues and staff at the Social Science Center Berlin (WZB), the Judge Business School at the University of Cambridge, and most recently, the Keck Graduate Institute for Applied Life Sciences in Claremont for providing stimulating research environments.

During the 1999–2000 academic year I was invited to participate in a research group focussing on national systems of innovation at the Netherlands Institute for Advanced Studies (NIAS). This experience dramatically expanded my exposure to interdisciplinary research on systems of innovation. I'd like to thank Rogers Hollingsworth for organizing this research group and taking the risk of inviting me to participate within it at a very early stage of my career. I'd also like to thank the other members of this group: Jerry Hage, Ernst Homburg, Marius Meeus, Bart Nooteboom, Birgitte Unger, Frans van Waarden, and Richard Whitley.

The research leading to this book was supported through funding provided by the German Ministry for Education and Research (BMBF), the English Social Research Council (ESRC), and the Cambridge-MIT Initiative. I'd also like to acknowledge funding for summer research interns provided by a National Science Foundation Undergraduate Research Experience grant. I've had five excellent interns funded by this program, each of whom I'd like to thank for outstanding research assistance: Alana Celia, Erin Robertson, Christina Sher, Tiffany Sun, and Christine Tarleton.

Over the years I have benefitted enormously from comments and criticism from colleagues. I'm most in debt to several individuals with whom I've collaborated on research projects. While I am of course responsible for all errors contained in this book, many of the ideas took root from writing collaborative papers. This book is designed to contribute to comparative research on models of capitalism. I've been extremely fortunate to have developed collaborations with two leaders within this field, David Soskice and Richard Whitley, and I thank both of them for their help and encouragement. Other collaborators to whom I owe thanks are Henrik Glimstedt, Bob Hancke, Hannah Kettler, Mark Lehrer, Kate Matraves, Fiona Murray, and Sigurt Vitols. I'd also like to thank the following colleagues for comments and criticism: John Cioffi, Pepper Culpepper, Keith Darden, David Finegold, Orfeo Fioretos, Michel Goyer, Simcha Jong, Anastasios Karamanos, Per Hull Kristensen, Bruce Kogut, Isabela Mares, Jesper Norus (dec.), Woody Powell, Gunnar Trumbull, and Jonathan Zeitlin.

At Oxford University Press David Musson has provided much encouragement and guidance. I am grateful to him and his colleagues for helpful advice and support.

Finally, I'd like to thank my wife Kornelia, to whom this book is dedicated.

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1

Introduction

Through the 1990s and early 2000s, a strength of the US economy has been its ability to foster large numbers of entrepreneurial technology companies, a few of which have grown to dominate new industries, such as Microsoft in software, Genentech in biotechnology, or Google on the Internet. US technology clusters, such as Silicon Valley, have become engines of innovation and wealth creation, and the envy of governments around the world. Indeed, governments have poured resources into policies designed to foster clusters of similar start-up firms in their economies. This book examines trajectories by which new technology industries emerge and become sustainable across different types of advanced industrial economies. It employs empirical studies of the biotechnology and software industries in the United States and three European economies to examine the relative success of policies aimed at cultivating the "Silicon Valley model" of organizing and financing companies in Europe.

While entrepreneurship, at the level of the individual venture, requires ingenuity in pushing new technologies or business models into the marketplace, an assumption behind policies aiming to promote entrepreneurship is that such firms, as a group, have common attributes. The success of Silicon Valley has led to the diffusion of a well-defined model of financing, managing, and organizing new technology firms. This model surrounds the use of venture capital to finance companies, corporate governance arrangements, employing ownership stakes in the company to generate high-powered performance incentives for managers and employees, and flexible patterns of company organization that employ short-term employment to facilitate project-based work environments. The Silicon Valley model has become institutionalized across the advanced industrial economies and is commonly employed to manage new ventures in technologically turbulent or "radically innovative" industries.

While emulated across many countries, have governments succeeded in generating well-performing agglomerations of new technology firms? What are the elements leading to the successful uptake of the Silicon Valley model? How portable is the model? By the mid-1990s most European economies found themselves lagging behind the United States in biotechnology, software, and other "new economy" industries. Moreover, companies in many European economies are generally financed and governed along starkly different models than that employed in Silicon Valley. Most European economies would necessarily be inventing institutions associated with the new economy from scratch.

Nonetheless, most European countries had long-established university research in the biosciences and information technology, leading to a belief that adequate science existed to compete in the new economy, if only it could be adequately commercialized. Many European governments have embarked on ambitious industrial policies to create a support system for new technology sectors. The most elaborate of such policies, seen perhaps most spectacularly in Germany, attempts to orchestrate the creation of large numbers of firms modeled on the Silicon Valley approach. Policies seek to encourage companies to adopt elements of the Silicon Valley model, either directly through channeling resources, such as venture capital, to new technology companies or indirectly through the development of public infrastructures to support such companies, often surrounding the commercialization of university science through financial support or the lending of government funds to create science parks. Governments have also reformed financial and corporate governance regulations, for example, to encourage the use of equity stakes in companies as an incentive structure.

Governments are optimistic about the potency of policy to shape patterns of innovation within the economy. This is in stark contrast to a large body of scholarship linking industrial performance to the orientation of key national institutional frameworks within an economy. Drawing on the work of political scientists, sociologists, and management scholars, much comparative institutional research has argued that patterns of industry specialization within an economy are the result of incentives and constraints created by national financial systems, corporate governance laws, systems of training and skill formation, and labor markets (see Hollingsworth 1997; Hall and Soskice 2001; Amable 2004). A key element of this analysis is that national institutions strongly impact how companies are financed, governed, and organized.

The starting point for much comparative institutional research is that models of capitalism differ sharply. Much discussion of new technology industries surrounds the potential advantages created by a shareholder-dominated, or liberal market economy (LME) model of organizing the economy. Representative of the US economy, this model encourages the diffusion of each of the key practices associated with Silicon Valley firms. The success of Silicon Valley type firms in the United States is the result of the existence of a financial system that encourages venture capital, corporate governance laws facilitating high-powered incentive structures within firms, and largely deregulated labor markets that encourage the generation of flexible labor markets. Of the major European economies only the United Kingdom (UK) is organized around the LME model.

Most of the large Continental European economies have developed elements of a second stakeholder or "coordinaited" model of capitalism. Focussing particular attention on Germany, during the 1980s and early 1990s an important body of research argued that national institutional frameworks within coordinated market economies (CMEs) could encourage strong industrial performance while imposing a system of "beneficial constraints" (Streeck 1996) on companies through encouraging long-term employment and, with it, large company investments in industrial training and willingness of managers to participate within consultative patterns of company organization that came to typify German capitalism. This more collaborative model of company organization was buffeted by a system of financing focussed more on bank credits than capital market financing, linked to stakeholder systems of company law which gave company insiders, including union representatives, seats on most company boards.

An important element of the stakeholder capitalism argument is that the more regulative and organized national institutional model allows companies to pursue successful long-term or incremental innovation strategies within medium-technology industries, such as engineering, machine tools, automobiles, and specialty chemicals, due to its reliance on widespread industrial training and collaborative workplaces that are hard to sustain within the more short-term, shareholder-dominated liberal market model. Liberal market economies, such as the United States and UK, lack appropriate institutions to support long-term success in these industries, leading to poorer performance in such industries.

By the same argument, however, companies located within Germany and other European economies following the stakeholder model faced a series of institutional constraints impeding success in industries characterized by more "radical" innovation. These economies lack financial systems structured to facilitate high-risk venture capital, espouse patterns of company and corporate governance laws that limit the ability of owners to develop high-powered performance incentives and lack flexible labor markets needed to support project-based firms pursuing failure-prone technology strategies. Biotechnology, computers and information technology, and the Internet are leading examples of radically innovative industries. The Silicon Valley model, according to the institutional perspective, should fail across Europe's organized economies.

Can governments within Europe successfully deploy policies to incubate the Silicon Valley model of organizing companies and, with it, encourage industrial success in biotechnology, software, and other new technology industries? Or is the lack of success by most European economies up until the mid-1990s within the new economy industries the result of long-standing national institutional frameworks that encourage some types of commercial innovation patterns within economies, while constraining others? Rarely do the beliefs of governments contrast so sharply with accepted research on the sources of industrial performance. Through exploring a wave of entrepreneurial activity in Europe that began in the mid-1990s, this book aims to examine the interplay between public policy and national institutional frameworks in supporting new technology companies.

Theoretical Perspective: Varieties of Capitalism

While contributing to a large body of research linking national models of organizing economies to differing trajectories of industrial change, the study applies a well-known version of comparative institutional theory known as "varieties of capitalism" as a theoretical lens to explore the development of new technology industries in Europe. This perspective is most closely associated with the work of Peter Hall, David Soskice and collaborators (Hall and Soskice 2001), but draws strongly from the comparative business system tradition (Whitley 1999; Casper and Whitley 2004) as well as a large body of previous research linking national institutional frameworks to the governance of economies (for a review, see Hollingsworth 1997).

An important theme motivating much research on comparative capitalism is the debate surrounding whether the increased financial, economic, and technological globalization of the world economy is driving convergence of national models. As forcefully argued by Castells (1996), the information technology and biotechnology industries are often seen as the forerunners of an increasingly interdependent global economy in which firms adopt functionally similar patterns of organization, financing, and management. Indeed, a finding from the empirical research informing this study is that when entrepreneurs decide to form a new technology company, they increasingly adopt patterns of financing, corporate governance, and general company organization that broadly do follow an accepted Silicon Valley model regardless of geographical location. This is a powerful statement of convergence.

How might institutions impact the diffusion of business models associated with new technology industries or, more broadly, why should we expect that national models of organizing economies remain relevant? One argument, emphasized most forcefully by the historical institutionalism approach commonly used within political science (Steinmo, Thelen, and Longstretch 1992), is that institutions create path dependencies that can be difficult to reverse. In addition to the high transaction costs of developing new institutions, institutions can have distributional effects, privileging and enriching some social actors within the economy, while weakening others. The historical institutional argument suggests that divergence models of capitalism developed through distinct political and economic mechanisms found across countries as they industrialized at different junctures during the nineteenth and early twentieth centuries (see Thelen 2004), a period in which nations were far more loosely coupled through trade, finance, and technology than during the current new millennium era. Path dependency then explains why national differences continue to persist.

The historical institutional approach provides an ultimately unsatisfactory model when explaining why institutional divergence persists across economies. Applying the logic to the new economy, institutional frameworks, particularly within the organized economies, would be primarily seen as constraints on efficiently organizing the new models of industrial organization, perhaps enforced by a political coalition of groups, such as industrial unions, that are opposed to patterns of work organization or governance employed by the new firms. While there are elements of truth to this explanation that will be explored in this book, a difficulty with it is that governments within Germany and other organized economies were strong proponents of the new economy, willing to allocate public resources and, at times, reconfigure some institutions to better advantage the new entrepreneurial companies.

The varieties of capitalism approach contains a positive theory of why divergence in the structure of national economies continues to exist. According to the theory, divergence exists because specific national institutional frameworks create performance advantages for companies in specializing in some industries, while creating obstacles in others. Institutions structuring the organized economy approach continue to exist because they provide competitive advantage for companies employing some innovation strategies, facilitating superior performance for these companies within international markets. According to this logic, countries develop patterns of industry specialization that confirm to their "comparative institutional advantage" (Hall and Soskice 2001). While building on previous studies in the field of industrial sociology (Sorge and Streeck 1988) and the industrial policy tradition within political science (Katzenstein 1978; Zysman 1983), the varieties of capitalism approach has gone farthest in systematizing this more positive theory of why divergent national models should survive in spite of increased globalization. Through the concept of comparative institutional advantage, the perspective creates a theoretical argument explaining why both the liberal market and organized economy models of capitalism are sustainable.

From this perspective, the global appeal of the Silicon Valley model of organizing new technology firms represents a strong test of varieties of capitalism theory. A primary contribution of this book is to use the varieties of capitalism perspective as a starting point to develop and test whether institutional frameworks strongly impact the introduction of new forms of economic organization into the economy.

A second reason for selecting the varieties of capitalism approach as a theoretical lens is the usefulness of the approach in exploring how institutions impact how firms and other actors strategize within the economy. An important contribution of the varieties of capitalism approach is the creation of microfoundations linking patterns of company organization to national institutional frameworks. A tendency of much comparative institutional research is to employ a strongly socialized or isomorphic relationship between institutional structure and agents, in many cases essentially reading off the organizational strategies and behavior of actors from the orientation of institutional frameworks (DiMaggio and Powell 1983). This approach was often justified by the existence of a different research agenda than that employed here. Much previous research on models of capitalism, for example, simply set out to empirically justify the claim that national institutions can shape patterns of industry organization into divergent trajectories that are sustainable within an increasingly globalizing economy (see Hollingsworth 1997). Other research used comparative institutional analysis to explain variation in macroeconomic policy or performance (see Franzese 2001), a research agenda for which broad characterizations of institutional variation again suffices.

To carefully explore institutional effects and help gauge whether public policy has meaningfully impacted entrepreneurial activity within new technology industries in a given country, strong microfoundations are needed. A theory of the more micro-level governance or management challenges facing Silicon Valley firms must be developed. It is then necessary to demonstrate with both theoretical and empirical analysis that the viability of each of the key components of this model is strongly impacted by the orientation of national institutional frameworks and, more broadly, patterns of activity within the economy that they generate.

In developing the theoretical structure of the varieties of capitalism argument, Hall and Soskice (2001) draw on ideas from the economics of organization (Miller 1992; Milgrom and Roberts 1993) to develop a framework linking the success of different innovation strategies to the resolution of organizational dilemmas facing owners, managers, and skilled workers within companies. They argue that the orientation of national institutions strongly impacts the credibility of different types of contracting arrangements employed to resolve these dilemmas. Organized economies encourage credible commitments toward longer-term relational contracting, while LMEs facilitate a variety of often risky but shorter-term incentive contracts.

An important problem or risk of using ideas from the economics of organization is the temptation to assume that governance risks emphasized by the approach, for example surrounding information asymmetries, drive organizational dilemmas within the new technology industries studied here. The version of varieties of capitalism theory developed in this study employs a heavily contextualized approach to using the economics of organization to build theoretical microfoundations. Rather than assuming a given managerial dilemma exists for a given firm due to similarities of a given empirical challenge facing firms with accepted theory, the study draws on both primary research and studies of the organization of innovation processes across sectors (Woodward 1965; Kitschelt 1991; Malerba and Orsenigo 1993) to develop microfoundations of the risks or challenges facing new technology companies.

The Silicon Valley model of organizing new technology firms in important respects represents a set of organizational and financing practices developed to reduce these risks. While new technology ventures have many components, the study will emphasize the connection between national institutional frameworks and the ability of actors to reduce important risks generated by the Silicon Valley model of organizing radically innovative start-ups. When, from the point of view of a venture capitalist (VC), is it sensible to invest potentially millions of dollars in a failure-prone company? From the point of view of managers and employees within such a company, when does it make sense to sign on to intense work efforts, often at low basic salary, in return for stock options in a company that will be lucrative only if a firm succeeds? From the perspective of skilled employees, when does it make sense to leave a "safe" and often interesting job within a university or established company to work within a failure-prone start-up. Institutional frameworks encourage particular types of coordination across these actors within an economy that can dramatically reduce each of these risks, making participation within a new technology firm a sensible course of action.

How does public policy fit into the varieties of capitalism approach? Most research on models of capitalism, including the varieties of capitalism perspective, stress the importance of nongovernmental institutions, such as the orientation of financial or labor market systems. The government is seen primarily as a legislative mechanism to create and at times enforce the provisions of national institutional frameworks (see Wood 2001). The role of government as an active participant in the economy has been ignored in much research on models of capitalism. However, due to the vigorous activities of governments in developing technology policies surrounding the new economy, the role of the state in directly shaping incentives within the economy should be examined.

A strength of developing strong microfoundations surrounding the governance of new technology companies is that it should allow a detailed investigation of how resources and regulations directed at new economy companies through public policy impacts the governance of companies. Under what conditions, for example, should we expect that resources or institutional frameworks created through public policy trump "normal" institutional framework incentives and constraints within an economy? In addition to exploring the interplay between long-standing institutional incentives and constraints and policy, the study will also explore whether, through local policy or the activities of major companies, regional economies can develop alternative patterns of economic coordination used to sustain local patterns of innovation not supported by the country's broader institutional frameworks.

An expectation from varieties of capitalism research is that the content of technology policies aimed at the new economy should differ dramatically across different models of the economy. As generally sufficient institutional frameworks needed to govern new technology firms exist within LMEs, the role of technology policy within these economies should be to complement such frameworks. Examples include frameworks needed to effectively commercialize science or provide adequate resources to universities and other nonmarket actors involved within new technology marketplaces. Within organized economies, on the other hand, public policy, to succeed, may need to develop fundamentally new institutional complexes aimed at new technology firms or, if this is not politically feasible, develop resources and regulations targeted at new technology firms that compensate for inadequate national institutional frameworks within the economy. In either case, an expectation from the varieties of capitalism perspective is that governments within organized economies face a dramatically more challenging public policy agenda.

Research Design and Methodology

The initial research for this study was stimulated by a puzzle. In the late 1990s, during the height of the worldwide boom in new technology companies driven by the commercialization of the Internet, Germany became a European leader in launching new technology companies. While much of this activity could be described as the exploitation of new market opportunities created by the Internet within the German-speaking countries, the boom also spread to the biotechnology sector. By the year 2000 by one measure, the number of firms, the German biotechnology sector had grown from virtually no firms in the early 1990s to Europe's largest agglomeration, with over 400 firms. Much of the new activity in the biotechnology field was the result of government technology policies, leading government officials to proclaim, and take credit for, a "miracle" in Germany (see German BioRegio 1998). Other European economies with CMEs were also developing clusters of new technology companies. One of the most important cases was the development in Stockholm, Sweden, of a large cluster of software and telecommunications start-ups focussed on wireless technologies.

At the same time as the European economies experienced a boom, one of the key technology sectors within the UK, biotechnology, experienced a severe crisis. Several key firms experienced dramatic setbacks in expensive late-stage clinical trials, causing a decline by over 50 percent within UK biotechnology stocks, leading to a decline of UK venture capital funding toward biotechnology by over 300 percent and a general crisis of confidence across the industry. This crisis occurred in 1999, some two years before the bursting of the Internet technology fueled stock market bubble in the United States, which then continued to depress the market for technology companies within the UK.

This puzzle motivated the initial research design for the book. Why was Germany, the leading case of an organized economy that should perform poorly in radically innovative new technology industries, performing so well in biotechnology and software, while the UK, a leading example of an LME, performing poorly? Compounding this dilemma was the legitimization of the idea, within Germany, that public policy could forcefully reconfigure, or at times bypass, national institutions to develop national competitive advantages within the new economy industries.

The book's empirical research focusses primarily on Germany and the UK. These two large European economies serve as ideal typical national models within the broad comparative capitalism literature, and thus represent strong cases for detailed study. Moreover, given their problematic performance during the 1990s, from the point of view of varieties of capitalism theory, they represent good cases with which to focus analysis. The study compares their performance in new economy sectors from the mid-1990s through the mid-2000s. While only a decade in time, this period includes the heady boom in technology stocks during the late 1990s, the powerful crash of technology stocks during 2001–2, and the ensuing recovery. Through examining evidence from this entire period it becomes possible to develop a measured evaluation of whether each country has developed an institutional infrastructure to cultivate and sustain new technology companies.

The primary industry case used to study both countries is biotechnology. This industry was chosen in part due to its attributes as a radically innovative industry in which firms have typically chosen financial and governance strategies that closely conform to the Silicon Valley model. Due to the importance of universities in generating the founding ideas for bioscience companies, public policy is particularly pervasive within this industry. Biotechnology is thus an excellent case to compare policy instruments, and their effectiveness, in stimulating the development of new technology firms.

While Germany and the UK serve as the primary European country examples, the book also includes a detailed study of the biotechnology industry in the United States, focussed on a large cluster of companies located in the San Diego region. San Diego, rather than the San Francisco area, was chosen to demonstrate that the Silicon Valley model of developing new technology companies truly is a model used widely in the United States, rather than a unique regional system of governance. The US case serves an important role in the study through presenting a baseline case used to compare European outcomes in terms of both industrial performance and the financing and governance of companies.

In order to help generalize the findings and develop additional evidence with which to evaluate the usefulness of varieties of capitalism theory, an additional industry, software, and an additional case of an organized economy, Sweden, are used to complement the main findings. Discussing a second industry is important, as it helps demonstrate that the models of industrial organization associated with the Silicon Valley model are likely to be general to the new technology sector, rather than associated only with biotechnology. The study of Sweden focusses on its success in developing a large cluster of Internet software and telecommunications companies. This is used to broaden the analysis, along with a comparison study of Germany's far less successful performance in this sector.

A variety of research methods were used to construct the study. Most of the core insights discussed in the book initially emerged from interviews with founders and managers of dozens of entrepreneurial firms located in each of the four countries discussed in the book, as well as university scientists involved in commercialization, VCs and other members of the financial community, and government officials. While interview respondents are not identified within the text, information gleaned from interviews is noted.

An important critique of interview-based research surrounds the issue of whether insights gleaned from a few firms can be generalized to entire sectors of the economy. To minimize this problem, descriptive statistics are used within the study to generalize key findings whenever possible. These statistics include detailed measures of industrial performance within the biotechnology industry, and more general measures of country-level industry specialization within both the biotechnology and software industries. The goal of the empirical portion of the book is to investigate the extent to which national institutional frameworks impact the viability of the Silicon Valley model of organizing new technology firms. Extensive evidence on the viability of each aspect of this model by biotechnology companies in Germany, the UK, and the United States is presented in the text. This evidence includes both statistics from previous research or industry reports, for example surrounding venture capital investments within each country's biotechnology sector, and also evidence compiled for this study from several dozen companies, including detailed research on the ability of companies in each country to recruit and incentivize skilled managers and scientists. Methods used to develop descriptive statistics are discussed throughout the text.

Roadmap of the Book

The book is organized into two parts followed by a conclusion. Part I of the book, comprising Chapters 2 through 5, contains a structured comparison of the ability of LMEs and CMEs to sustain new technology companies focussed on radically innovative commercialization strategies. Chapter 2 draws on the varieties of capitalism perspective to develop a theoretical framework used to generate expectations linking national institutional structures within LMEs and CMEs to the sustainability of radically innovative companies. The core of this analysis focusses on the development of company competencies associated with the Silicon Valley model of organizing and financing companies, drawing on empirical examples from biotechnology and software. This is followed by a detailed analysis linking institutional frameworks surrounding finance, corporate governance and company law, and labor market organization to the sustainability of each element of this model within CMEs and LMEs. The chapter also discusses mechanisms by which public policy could be expected to impact the governance of radically innovative companies within both types of economies.

Chapters 3–5 contain detailed examinations of the biotechnology industry in three countries, the United States, Germany, and the UK. The chapters are constructed so as to allow a structured comparison of the usefulness of the institutional approach in exploring the emergence and sustainability of radically innovative new technology companies. In addition to providing basic information about the performance of the biotechnology industry and an analysis of the public policy context surrounding the industry, the core of each chapter analyzes the sustainability of economic coordination within and across firms surrounding each element of the Silicon Valley model. This allows for detailed comparisons of how firms in each country are financed, of whether they can develop credible incentive structures to motivate employees, and whether sufficient labor market flexibility exists to allow companies to employ risky, competency destroying staffing strategies. This evidence is used to explore whether institutional frameworks, and in some cases resources provided through public policy, generate an environment facilitating the credible orchestration of innovative capacities within the biotechnology sector.

One of the key findings from Part I of the book is that German technology policies have largely failed to succeed in creating large numbers of viable therapeutics biotechnology companies. This failure is a strong indicator that the pessimistic predictions from varieties of capitalism theory surrounding the viability of the Silicon Valley model in CMEs have merit. Does this mean governments and firms within CMEs should abandon the idea of competing within market segments characterized by radical innovation? Are there alternative strategies available to governments and entrepreneurs within organized economies? Part II of the book investigates alternative pathways by which entrepreneurial technology firms located within organized market economies can become sustainable.

Chapter 6 argues that one viable strategy might be for new technology companies within organized economies to specialize within subsectors of new technology industries with technological and market characteristics demanding the creation of company capabilities in which firms may draw on comparative institutional advantage. To examine this argument, the chapter explores the theoretical argument linking coordinated institutional frameworks to success within industries with incrementally innovative technological characteristics and argues that important subsectors of the biotechnology and software industry share these characteristics. The theoretical expectations from this argument are then tested through examining patterns of subsector specialization of publicly listed biotechnology and software firms across the UK, Germany, and Sweden. The explanation is then further strengthened through a qualitative analysis of the generally strong performance of German firms in the platform biotechnology and enterprise software markets.

A second trajectory by which CMEs could potentially develop agglomerations of successful new technology companies is through regional development. Chapter 7 examines whether regional mechanisms could emerge in organized economies to achieve patterns of economic coordination needed to support radically innovative companies. One potential mechanism is the activities of very large firms that, through their presence within a regional economy, could feasibly alter the "normal" patterns of economic coordination within a locality so as to encourage alternative patterns of industrial organization.

The chapter examines the branch of Internet-related technology known as middleware software development. Within this sector, technological interdependencies linking large and small firms are strong. Focussing on Sweden and Germany, the chapter examines whether technological leadership can act as a stimulus to foster clusters of radically innovative middleware software companies within organized economy. The successful creation of a cluster of radically innovative software firms within Stockholm, Sweden will be linked to the technological leadership and human resource policies of a local telecommunications systems manufacturer, Ericcson. On the other hand, Germany's leading telecommunications provider, Siemens, has failed to achieve leadership needed to develop similar companies in the Munich region of Germany. The chapter concludes by discussing the generalizability of the regional development model, and whether governments can feasibly encourage their large companies to develop strategies needed to encourage models of regional development.

In sum, the study finds that national institutional frameworks do strongly impact the emergence and sustainability of new technology companies. That being said, public policy can have an important role in stimulating industrial performance in new industries, across both LMEs and CMEs. The concluding chapter summarizes these findings and discusses implications of the research for both the study of public policy toward the new economy and comparative institutional research more generally.

2

Varieties of capitalism and innovation: the Silicon Valley model

Joseph Schumpeter (1950) famously defined an entrepreneur as a person willing and able to convert a new idea into a successful innovation. From the 1970s onward entrepreneurship has become institutionalized. The Silicon Valley model refers to a relatively standardized set of financing, governance, and organizational techniques used to package entrepreneurial ideas into new ventures. This chapter investigates this model and explores how concepts from comparative institutional theory help explain why some countries seem better than others in developing competitive advantages within new technology industries characterized by entrepreneurial firms. It begins by defining radically innovative industries and discussing how the Silicon Valley model has developed to govern the commercialization of such technologies. The chapter then introduces the varieties of capitalism framework, discusses a number of empirical expectations surrounding the model for both organized and LMEs, and concludes with a discussion of implications for the design of public policy within different models of capitalism.

Defining Radically Innovative Industries

In order to explore the relationship between national institutional frameworks and the development of company-level innovative competencies, it is important to establish that variance exists across the characteristics of industries associated with entrepreneurial technology firms. To ground our analysis, we will draw on concepts from recent research on "sectoral systems of innovation" (Malerba and Orsenigo 1993; Mowery and Nelson 1999; see also Woodward 1965; Kitschelt 1991). This research stream builds on ideas from institutional economics to provide a starting point for exploring variation in economic and technological dynamics across sectors. Such dynamics are often referred to as a sector's technological regime. By generating unique constellations of organizational risk that the management of companies must govern to successfully compete, technology regimes help create useful microfoundations. Later, when introducing institutional arguments, this leads to predictions linking the orientation of institutional frameworks to advantages in governing risks associated with particular types of entrepreneurial firms.

Radically innovative new technology firms represent stereotypical Silicon Valley type start-up firms attempting to pioneer new fields. Sectors with radically innovative technology regimes share several common features. A defining characteristic of such industries is attractive opportunity conditions, in the sense that firms compete to create important innovations in markets where winners of innovation races can plausibly capture a large share of an emerging market. Moreover, firms within most radically innovative industries can realistically capture the profits from their innovations; what economists call appropriability regimes (Teece 1986) are strong. When risks of expropriation are low, and particularly when standard forms of intellectual property protection are sufficient to guard technical innovations from being copied, then companies can readily embark on research and development (R&D) programs confident that innovation will capture their market value.

Radically innovative industries offer large, defensible markets for companies that successfully develop innovative competencies. However, such industries share two additional characteristics, both of which often create organizational dilemmas for firms. First, levels of technological volatility are high within radically innovative industries, what economists label as low levels of cumulativeness (Breschi and Malerba 1997). Low cumulativeness suggests that a variety of technological approaches may be available to solve a particular innovative challenge, though few or none might eventually succeed. While technological uncertainty is a determinant of high failure rates of particular projects, it is also increased by racing activity across many firms to develop or establish new technologies within "winner take all" markets. Drawing on Schumpeter's idea of creative destruction, radically innovative firms may face high levels of organizational turbulence, as technological changes in the industry necessitate changing technical skill-sets to compete within a given innovation ace.

The second technology regime characteristic shared by radically innovative firms surrounds knowledge properties of inventions (Winter 1987). Most radically innovative industries generate knowledge that can be codified. This is beneficial to the extent that it allows companies to obtain intellectual property surrounding key inventions. Codified intellectual property can often be leveraged as a development milestone used to obtain financing or transferred to other firms through partnerships. Within some organizations, however, there is a risk that key employees responsible for inventions may decide not to codify such knowledge and transfer it to the owners of firms. Such knowledge may be used as leverage to demand more salary or, more commonly, as the founding idea for a new firm. We will examine this issue in more detail in relationship to incentive structures created within common new technology start-ups.

In sum, radically innovative firms are characterized by strong opportunity conditions, low cumulativeness, strong appropriability regimes, and the existence of codified knowledge properties. We will now discuss industry dynamics within biotechnology and software, demonstrating that these industries share the characteristics of radically innovative technology regimes.

Radically Innovative Firms within the Biotechnology and Software Sectors

The biotechnology industry contains numerous therapeutic discovery marketplaces characterized by radically innovative R&D strategies. A defining feature of therapeutics research is its high scientific intensity in the sense of being closely dependent on new scientific knowledge emerging from academic research into the life sciences (Zucker, Darby, and Brewer 1998). Firms engage in racing activity to discover new therapies aimed at curing diseases. Due to strong intellectual property for new drugs, companies introducing a first in class therapy within an underserved disease area can reap huge rewards. Successful biotechnology companies, such as Amgen and Genentech, have secured billion dollar plus annual revenues for successful drugs. However, dozens of companies are typically engaged in discovery activities surrounding large market areas with unmet medical need. A study conducted by Pennan (1996), for example, documented over two dozen distinct groups of firms and laboratories working on distinct new approaches for Alzheimer's disease, a large market disease in which few effective therapies exist. Similar dynamics exist within most cancer markets, with dozens of companies active in some areas.

Industry surveys and ethnographic accounts of biotechnology firms document the widely changing course technological trajectories over time, which often leads to failure or repeated changes in the competence structure of the firm (see Werth 1994; Rabinow 1996; Casper 2000; Robbins-Roth 2000). A tremendous diversity of technologies has been used by therapeutic discovery companies. Examples include gene therapy, large molecule- or biologics-based approaches that have grown out of recombinant DNA research (antibodies, peptides, and proteins), and a variety of "small molecule" approaches drawing on advances in chemistry-based drug discovery drawing on combinatorial chemistry, bioinformatics, and genomics as well as craftsman type approaches focussed on the "rational design" of molecules (see Werth 1994 for an in-depth account of the technological uncertainty facing Vertex, one of the pioneers of rational drug design).

In addition to risks associated with discovery platforms, the vast majority of therapies discovered prove ineffective within clinical trials or must be discarded due to the discovery of high toxicity or other side effects within patient populations. While failure risks for new therapies vary depending on the disease area and discovery technology used, a common industry norm is that only about one in ten thousand targets discovered during discovery projects survives both preclinical trials in tissues or animals and clinical trials in humans (PhRMA 1996). Failure risks are compounded by the enormous expense of clinical trials, which often take several years to complete and the latter stages of which can cost several hundred million dollars (DiMasi, Hansen, and Gabowski 2003). Clinical trials risks are commonly reduced through partnership agreements with pharmaceutical companies—facilitated by strong intellectual property regimes surrounding most therapeutic or diagnostic discoveries. Nevertheless, high failure rates combined with very long lead times of several years compound the risk facing these firms.

Most therapeutics-focussed biotechnology firms are small, research-led ventures employing project-based forms of organization (see Whitley 2005). Firms receive ongoing funding from investors and industrial collaborators based on progress on development milestones. Early milestones vary depending on the technology, and may include collaborating with basic research laboratories to solve an important basic research problem (e.g. solving the structure of a complex protein; see Werth 1994) or demonstrating increased efficiency or precision in discovering new therapeutic target molecules. Later milestones focus on developing a series of validated targets and pushing them through preclinical and then clinical trials. At some point, usually at the beginning of clinical trials, target molecules are passed off to pharmaceutical companies through alliance agreements. Strong appropriability regimes facilitate such alliances, creating what Gans and Stern (2003) call a "marketplace for ideas" within the industry (see also Powell 1996). Partnering activity allows most therapeutic discovery companies to retain a relatively simple or functional organizational structure focussed on R&D. The main organizational challenge facing top managers of biotechnology firms is recruiting and then incentivizing research scientists to participating in high-risk and often grueling innovation races.

Within the software industry, standard (or so-called "packaged") software firms share characteristics of radically innovative project-based organizations (Casper and Whitley 2004). Standard software is created for homogeneous markets where the need for customization is low. Examples include graphic application software (e.g. CAD/CAM), multimedia and computer entertainment software, and a variety of application software used to run computer networks (e.g. e-mail, FTP, groupware, and document management programs). Intellectual property for software has traditionally been relatively weak. While copyright laws can protect a program's source code, the "look and feel" of a product can be mimicked by competitors (see Mowery 1999). Nevertheless, the nature of product market competition and the extremely low marginal cost of manufacturing successful standard software products can create large profits for successful innovators.

Many standard software markets are characterized by a combination of network externalities and end-user lock-in effects that create large markets for successful innovators (see Shapiro and Varian 1999). Switching costs are lower in other segments of the standard software market, such as computer games or multimedia software. Large consumer markets for these products (leading computer games routinely sell several million copies) ensure high profitability for successful firms. Relatively low entry barriers within consumer markets and extremely high long-term profitability for successful firms in network or business impacted segments leads to intensive innovation races across standard software firms. This generates high-technological volatility as rivals race to introduce new features or "functionality" into their products, or to invent new product categories.

While a few dominant application software providers have grown into large complex organizations such as Microsoft (see Cusamano and Selby 1995), most standard software firms are small entrepreneurial firms. Particularly in their early stages of company growth, before a successful product has been launched, standard software firms focus primarily on product development. In mass market areas, such as computer games, packaged software developers often sell their products to publishers, who organize the distribution and marketing of products. In other areas, such as specialized software for finance or statistical analysis, firms sell relatively high-priced software packages directly to customers. Firms race to develop products with the maximum number of features given deadlines imposed by internally announced product launch dates or, more often, innovation races with competitors to launch similar products on the market (for ethnographic studies of project organization at standard software start-ups, see Cusamano and Yoffie's description (1998) of the early days of Netscape, and Ferguson's history (1999) of web-page authoring software start-up Vemeer).

How Radically Innovative Firms Develop Innovative Competencies: The Silicon Valley Model

A widely diffused set of organizational practices associated with Silicon Valley start-up firms have been developed to manage the risks inherent within new technology industries (see, for overviews of Silicon Valley, Saxenian 1994; Kenney 2000). The entrepreneurial business models organized within small innovative firms are characterized by the development of three competencies: the management of high-risk finance, development of human resources within a competency destroying environment, and the creation of sufficiently high-powered motivational incentives for personnel. While there may be other common characteristics of radically innovative start-ups, these three competencies are closely correlated with the technology regime characteristics common to radically innovative firms. Each of these competencies is also associated with widely diffused strategies identified with Silicon Valley start-ups for managing the associated risks with each. Moreover, we will later argue that the viability of each is plausibly impacted by the orientation of national institutional frameworks.

Managing High-Risk Finance

Successful new technology start-ups often create enormous financial returns. However, high-technological volatility, reliance on often unproven business models, and the danger of losing innovation races with competitors produce substantial financial risks. Technology start-ups generally have high "burn rates" generated by large R&D costs coupled with low profitability during the early phases of the firm's development. These risks, coupled with a lack of easily securable assets, make it difficult for most start-ups to obtain credit from traditional lenders such as banks. To obtain investment funds most entrepreneurial technology firms use equity leveraged financing schemes—trading equity within the firm for finance at different periods in the firm's development (Florida and Kenney 1988). During the initial founding of a start-up equity deals are made with venture capitalists (VCs) and then later through the investment banking community and third-party investors through stock offerings. From a competency development perspective, managers of new technology firms must manage complex relationships with VCs, investment bankers, and other financiers to enable funding of high-risk ventures. Within the firm, this necessitates the creation of business strategies and corporate governance arrangements between VCs and company founders that reconcile risk reduction strategies of VCs while ensuring founders have adequate financing and strategic maneuverability.

Particularly during their initial funding, venture capitalists usually demand a strong hand in governance of the firm (see Lerner and Gompers 2001). Most VCs ask for one or more seats on the company's board of directors and preferred stock rights ensuring that, if the company fails, they will have priority in obtaining revenues from the sale of any company assets. VCs also typically retain the right to design vesting schedules for founders and senior managers, which usually mandate that they can only sell stock owned in the company after a predetermined number of years (usually 3–5) or with other predetermined events, such as a sale or stock offering. Finally, VCs often demand the formal right to replace the founding CEO of the company, who is often a scientist or engineer, with a professional manager at any point during the company's growth. In exchange, VCs promise to organize the initial round of financing and often play a strong role in organizing future funding events. Through their membership of the company board, VCs often also play a role in designing the strategic vision of the firm, and in many cases have provided important contacts with experts in the firm's field that can help in recruiting managers, advisers, and contacts with other firms within their industry.

Venture capital funding also impacts the strategic goals of start-ups. VC-funded start-ups must have an orientation toward relatively large downstream markets such that a credible path to liquidate investments via initial public offerings (IPOs) or acquisitions by incumbent firms is viable, usually within a few years of funding. To minimize risk, VCs invest in start-up companies through a series of funding rounds, each of which is typically preceded by the firm reaching a transparent milestone (see Zider 1998). In biotechnology milestones include technological proofs of concept, successful application of the technology to develop a therapeutic or diagnostic compound, and various milestones in the preclinical and clinical development of products. In software milestones include the development of software at different levels of functionality and testing, shipping deadlines, and sales goals. Knowledge that investors can halt funding or demand major changes to the management of firms that underperform puts continual pressure on managers of technology start-ups to demonstrate at key milestones that their projects have met growth or earnings targets that justify ongoing capital investments.

Developing Human Resources within a "Competency Destroying" Environment

Attracting and retaining staff and managers to work in the risky and dynamic new technology fields is a second challenge facing most start-ups. Staff mobility within entrepreneurial start-up firms is generally much higher than at firms within established industries (Saxenian 1996). Extensive hiring and firing is routine at many technology start-ups. To achieve flexibility, managers of technology firms must have the ability to develop quickly new R&D competencies while cutting others. To do this, they must have access to a pool of software developers, technicians, and other specialists with known reputations in particular areas that can quickly be recruited to work on projects. Their success is in part determined by their ability to entice skilled managers and employees to leave lucrative and often "safe" jobs in established companies or university laboratories to join a new venture.

While there are important benefits of working within a start-up, such as financial rewards and exposure to interesting, challenging and fast-paced work environments, there is also a high likelihood that employment tenures within start-ups will be short due to dismissals or failure of the firm. Most start-ups fail to reach a lucrative exit, be it an IPO or acquisition by a larger firm at a favorable valuation. As mentioned earlier, dismissals of top management are often a common response by VC-led boards to firms that have failed to meet development milestones. Managers and employees within start-ups also find themselves at risk of dismissal due to strategic decisions to change the competency structure of the firm. Moreover, as a condition for funding many VCs insist that early technical founders of companies often need to be replaced by "professional" managers as a company develops.

From the point of view of individuals, there is a strong rationale for choosing to work within start-up companies only when viable secondary employment options exist. An important stream of research on labor mobility across technology firms suggests that the geographical proximity of a start-up within a technology cluster, combined with the technology strategy of the firm, determine whether competency destruction risks may be reduced. Many of the core arguments behind this approach were developed by Saxenian (1994) in her comparison of the Silicon Valley and Route 128/Boston regional semiconductor industries. Saxenian argues that Silicon Valley's success is linked to the development of a social structure encouraging the development of numerous informal links across the region's scientists, engineers, and managers. These links raised the innovative capacity of Silicon Valley's firms through diffusing technological and market intelligence. Drawing on Granovetter's research (1973) on referral networks within labor markets, Saxenian argues that social networks within Silicon Valley increased labor mobility across firms and by doing so created an additional mechanism of knowledge diffusion. The declining fortunes of Route 128's computer and semiconductor industry, on the other hand, were influenced by autarkic practices of long-term employment within its companies that hindered the creation of flexible labor markets, coupled with very limited informal sharing across firms through social networks.

A strength of the labor market mobility research stream is its ability to connect career mobility to the heightened innovative capacity of start-up firms by reducing the competency destruction risk, while also establishing a mechanism by which presumably risk-averse skilled employees commit to failure-prone jobs. According to this logic, successful technology clusters develop what Bahrami and Evans (1995) call "recycling mechanisms" to help preserve the value of assets committed to failed enterprises. To quote Saxenian, "Moving from job to job in Silicon Valley was not as disruptive of personal, social, or professional ties as it could be elsewhere (Saxenian 1994: 35)." This helps explain why successful and presumably risk adverse scientists and managers would give up prestigious careers in established companies or university laboratories to work within lucrative but highly risky start-ups: within successful clusters the embeddedness of individuals within social networks makes it "safe", from a career perspective, to do so.

The construction of flexible labor markets within regional technology clusters is a crucial driver of success within new technology industries. According to this argument, regional technology clusters exist primarily as a conduit by which social networks linking agglomerations of firms can develop. These networks are maintained primarily through informal ties linking employees across a region's firms. Interfirm social ties, however, pose an inherent risk to companies as they are a source by which important technical, market, or strategic information can escape. A crucial problem for companies embracing the open employment strategy is thus doing so while adequately protecting key technologies from expropriation. This leads to incentive structures for managers and employees within radically innovative firms.

Organizing High-Powered Motivational Incentives for Personnel

Successful Silicon Valley start-ups are associated with generating huge financial windfalls for their employees. Employees of successful technology start-ups are given financial rewards that far exceed equally skilled personnel working within established firms. High-powered performance incentives associated with start-ups are in part a response to the demanding work conditions in many start-ups created by the need for firms to quickly innovate within highly competitive markets. As first described in Kidder's account (1981) of project-based work within the computer industry, employees engaged in commercial innovation races are often asked to "sign on" to extremely demanding projects involving stressful, high-paced work environments that can come to dominate the lives of employees. The existence of such innovation races, particularly within winner take all markets, is a strong driver of intense work environments within discovery-based organizations in biotech and the standard software industry (see again Werth 1994; Fergusen 1999).

However, high-powered incentives are also a response to risky knowledge characteristics within radically innovative industries. Most key discoveries within radically innovative industries, such as an important software algorithm or the chemical structure of a drug candidate, can be codified. There is a risk within radically innovative firms that key employees may attempt to expropriate knowledge of key discoveries for their own gain. Economists focussed on principal–agent theory use the concept of "holdup" to argue that under situations of asymmetric information employees have the ability to refuse to codify tacit knowledge for owners of a firm until additional compensation is granted (see Miller 1992; Milgrom and Roberts 1993).

While employee holdup in this extreme form seems far-fetched, favorable opportunity conditions and strong appropriability regimes for new technologies, once patented, create strong incentives. In practice, employee holdups most commonly occur when scientists or engineers leave a firm to found their own company on the basis of ideas for technologies developed through research conducted at their prior company. Employee holdup risks are compounded by the career risk issue. If a firm is embedded within a flexible labor market, key employees or scientists become both less dependent on employment within a company and, through social ties with employees of other firms, more able to recruit colleagues to found a new enterprise. The history of Silicon Valley is replete with this phenomenon. Fairchild Computers, for example, was founded in 1995 by senior managers of Schockley Semiconductors. They drew on experience and ideas gleaned from Schockley to develop the integrated circuit. A decade later, some of these same managers left Fairchild to found Intel, this time commercializing ideas for new memory devices (see Jackson 1997).

Radically innovative firms usually employ performance-based incentive schemes and employee ownership plans to reduce holdup risks and induce employees to commit to intense work environments. As most new technology firms have well-defined project development milestones, large bonuses, and in particular stock option grants can be tied to their achievement. The small size of most project-based firms, particularly before initial success is achieved, increases the strength of ownership incentives. The existence of stock option grants within early-stage firms that have achieved success and obtained IPOs on the stock market have created huge sums of wealth for early key employees. Distributing ownership of the firm across key employees and managers can create extremely high-powered incentives to work intensively within a firm. A complementary strategy aimed at reducing the mobility-based holdup risk is to tie stock options to vesting schedules. Under this strategy, stock option grants are only fully owned by an employee after a given time in which the individual must remain employed by the firm (usually 1–3 years).

Institutions and Company Organization: The "Varieties of Capitalism" Perspective

Institutional scholars within the comparative political economy and organizational studies fields argue that variations in economywide national institutional frameworks encourage the construction of different organizational patterns within the economy (Crouch and Streeck 1997; Hollingsworth and Boyer 1997; Whitley 1999; Hall and Soskice 2001). Varieties of capitalism proponents suggest that contrasting patterns of market regulation and forms of business coordination within the economy create incentives that lead to differences in the organization of company-level activities. An appeal of this approach framework is its specificity in linking the orientation of national institutional frameworks to patterns by which actors within the economy coordinate their financing, corporate governance, and labor market and skill formation activities. Hall and Soskice (2001) have made the strongest arguments linking institutions to competitiveness, arguing that contrasting patterns of coordination represent comparative institutional advantages that conduce toward success in how companies can govern some innovation strategies, and disadvantages in others. The following summarizes Hall and Soskice's core argument pertaining to national institutional patterns of business coordination, then applies the framework to discuss how different institutional frameworks impact the governance of innovative competencies within new technology firms.

A first pattern of economic coordination, drawn most directly from empirical studies of Germany, but also attributed to most northern European economies and Japan, is the organized or "coordinated market economy" (Soskice 1997). Nonmarket forms of business coordination are facilitated by the embeddedness of large firms within networks of powerful trade and industry associations, as well as a similar, often legally mandated, organization of labor and other interest organizations within parapublic institutions (Katzenstein 1987, 1989). Businesses and other social actors engage in these associations to create important nonmarket collective goods, such as apprenticeship systems or networks of collaborative technology transfer institutes. Moreover, public policy in these economies relies on the legal system to regulate a wide variety of interfirm and labor contracts (see Casper 2001) as well as sustain neocorporatist bargaining environments through the delegation of issue-area-specific bargaining rights to unions and other stakeholders within firms (Thelen 1991; Turner 1991).

The second mode of economic coordination, associated most closely with the United States, but also the UK, Ireland, Canada, and New Zealand, is the "liberal market economy". Business activity is organized primarily through "markets or hierarchies" (Williamson 1975), with much weaker "nonmarket" or associational coordination across firms (Schmitter and Streeck 1985). Financial and labor markets are largely deregulated, and corporate law is primarily enabling in nature. Because courts refuse to adjudicate incomplete contracts, market participants need to specify control rights in contracts to as full an extent as possible or, when this is not possible, use extremely high-powered performance incentives to align interests within and across organizations (Easterbrook and Fischel 1991; see more generally Milgrom and Roberts 1993).

Differing patterns of market regulation and business coordination have led to substantial differences in how institutional frameworks' structuring activity in different areas of the economy are organized. Table 2.1 presents an ideal typical overview of institutional patterns within CMEs and LMEs that most affect the organization of companies in technology-based industries. This table highlights the conclusion that while most areas of economic activity within LMEs are largely deregulated with

Table 2.1. Institutional framework architectures in CMEs and LMEs

	CMEs	LMEs
Labor law	Regulative (coordinated system of wage bargaining; competition clauses enforced); bias toward long-term employee careers in companies	Liberal (decentralized wage bargaining; competition clauses struck down by courts); few barriers to employee turnover
Company law	Stakeholder system (two-tier board system and codetermination rights for employees)	Shareholder system (minimal legal constraints on company organization)
Skill formation	Organized apprenticeship system with substantial involvement from industry. Close links between industry and technical universities in designing curriculum and research	No systematized apprenticeship system for vocational skills. Links between most universities and firms almost exclusively limited to R&D activities and R&D personnel
Financial system	Primarily bank based with close links to stakeholder system of corporate governance; limited hostile market for corporate control	Primarily capital-market system, closely linked to market for corporate control and financial ownership and control of firms

market-based patterns of business coordination, in CMEs both market regulation and nonmarket patterns of firm-level coordination are pervasive.

Differing national institutional framework architectures allow firms in CMEs to make different types of commitments to employees and other stakeholders than those that are possible in the LMEs. Systematic differences in the organization of careers, in patterns of company organization, and in relationships between firms and owners exist across the two countries which can be linked to the broader patterns of industry specialization and innovation. We will examine both cases in some detail, highlighting the strong role institutions play in shaping the credibility by which the core elements of the Silicon Valley of company organization may be developed in each type of economy.

Developing Radically Innovative Competencies within LMEs

The property rights structure of firms within LMEs is primarily financial in nature (see generally Roe 1994). Owners, or their representatives on company boards, enjoy a high amount of autonomy in governing the firm. In contrast to Germany and other countries with stakeholder systems of corporate governance, no legally stipulated rights of board representation for employees or other stakeholders exist. Company boards typically create a series of high-powered incentive structures for top management (i.e. very high salaries often paid in company shares or share options), who are then given discretion in shaping organizational structures within the firm. These structures include large bonus systems, opportunities for star performers to quickly advance through the firm, and much unilateral decision-control. This system also allows boards to quickly remove top managers that are viewed as underperforming.

Shareholder dominated corporate governance within LMEs is complemented by the existence of large capital markets that companies can draw on for finance. Such financing tends to be short-term in nature, meaning that the value of company shares will rapidly decline if firms fail to meet growth or profitability goals or if products fail to live up to expectations in the marketplace. This system is reinforced by an active marketplace for corporate control, suggesting that controlling shareholdings in failing firms can easily be bought by new ownership groups, who can then engage in radical restructuring of public companies including the hiring and firing of senior management. However, companies that do meet growth or profitability expectations can parlay high market valuations into a mechanism to raise substantial new funds through additional stock offerings or can use their shares as a currency for acquisitions.

Labor markets are deregulated within LMEs. To preserve flexibility, the top management of most firms offers limited employment contracts to managers and skilled personnel. A corporate governance system focussed on short-term incentive contracts reinforces this system. Extensive career mobility also permeates the ranks of middle management and skilled personnel. Laws restricting the mobility of skilled personnel within a given industry are weak. Courts refuse to enforce "competition clauses" inserted into employment contracts to prevent poaching (see Hyde 1998). As a result, poaching of personnel is widespread and within most LMEs a thriving headhunting industry exists to assist firms in recruiting management. While firms can ask employees to sign nondisclosure agreements covering specific technologies, scientists and managers are generally free to move from firm to firm as they see fit, while managers can shed assets through hiring and firing as circumstances within the firm develop.

Short-term employment norms have important implications on how skilled individuals and their employers manage education and skill formation. As corporate governance structures within most public companies make it difficult for firms to credibly offer long-term employment, employees become unwilling to undertake roles within companies that lead to what economists call firm-specific skills, or knowledge that is not easily transferable to another company should their company fail or engage in hire-and-fire practices due to changed strategies. Similarly, ongoing competition for the services skilled personnel and a credible threat that valued employees will be poached by competitors creates incentives against significant company investment in the skills of their employees and, moreover, a reliance on organizational routines drawing on general skills that can be purchased in the marketplace. Cumulatively, this leads to the lack of industry involvement within apprenticeship systems within LMEs and systems of skill development and professional training dominated by general purpose degrees paid for by individuals or governments (see Finegold and Soskice 1988; Culpepper 2003).

In sum, within LMEs these patterns of financing, corporate governance, and labor market and skill formation create a comparative institutional advantage toward the orchestration of radically innovative competencies. An analysis of how liberal market institutions impact the resolution of the key competency dilemmas associated with the Silicon Valley model of company organization supports this claim.

Financial Risks

Large capital markets combined with enabling corporate governance facilitate important risk-reduction strategies used by VCs. The existence of large public markets willing to invest in technology firms is a crucial institutional lynchpin supporting venture capital (see Lerner and Gompers 1999). Companies use early successes, such as promising clinical data for biotechnology companies or successful prototypes for software firms, to build investor enthusiasm needed for successful IPOs at a relatively early stage in a firm's development. The existence of credible exit options within a few years of initial investments allows VCs to more easily diversify risks through creating portfolio investment strategies (see Zider 1998). Portfolio strategies enable VCs to organize investment funds with holdings in multiple companies, with the expectation that very high returns in a small number of companies will more than offset losses created by failures. Large IPO markets also create incentives for the formation of later-stage equity investment pools, composed for example of pension funds, university endowments, and other institutional investors interested in so-called mezzanine investments in entrepreneurial technologies, but at an interim stage of growth in which the completion of early milestones and plausible IPO scenarios reduce investment risks.

Enabling corporate governance institutions characteristic of LMEs also support VC strategies. Flexible corporate governance rules allow VCs to tailor the governance structure of companies (i.e. board composition, existence of preferred shares, and vesting rules), while an open market for senior managers allows VCs to credibly use the board to control the management of the company. While enabling corporate governance rules may sometimes lead to governance arrangements designed to maximize the control and potential return for VCs, these rules may also facilitate substantial investment in very high-risk firms that do not have the assets to secure more traditional credit lines.

Managing Competency Destruction

Deregulated labor markets and the organization of career paths within firms based on the assumption of frequent employee turnover create active labor markets for managers and technical professionals. Active markets for corporate control and the predominance of relatively short-term performance incentives for senior managers within publicly traded firms ensures that large companies will undergo frequent restructurings, either as part of managerial strategies to maintain competitiveness or as the result of board or ownership changes. These activities create an important labor market pool of seasoned managers and technical experts that start-up firms can draw on when building competencies. Moreover, the long-term career risk of a skilled individual of working within a start-up is low, in the sense that high general labor market mobility within the economy creates job openings for individuals at all stages of career development.

As discussed earlier, many successful new technology firms are located within regional technology clusters. Within such clusters open employment policies by companies facilitate particularly high levels of mobility and a market for seasoned managers and technical experts that have worked at successful companies. Flexible labor markets, underpinned by strong networks of social ties, reduce the career risk of working in a start-up, making it easier for companies to engage in R&D in technological fields with low cumulativeness. We will see that the existence of such clusters is rare, even within LMEs, and may be traced to patterns of local economic coordination of open employment policies that are necessary to build social ties helping to sustain regional agglomerations of firms. Nonetheless, cluster formation is encouraged by the existence of active labor markets within the wider economy, reinforced by employment and corporate governance laws favoring deregulated labor markets.

Employee Motivation

Managers of high-technology start-ups within LMEs face few restrictions on the organization of remuneration and performance incentives. Patterns of large company organization focussed on merit-based pay and promotion legitimate the use of high-powered incentive instruments within start-up firms. Moreover, venture capital led financing and corporate governance arrangements conduce toward the creation of high-powered incentives within firms. Most employees within start-ups are given share options as part of their remuneration, coupled with the announced intention of owners and VC to take the firm public within a few years. In the cases of successful firms that have gone public, share options can be worth from tens of thousands of dollars to junior staff to millions to senior scientists and managers. While the widespread dispersion of equity ownership helps create a collective ethos within start-ups, most firms peg future salary increases and equity grants to individual performance reviews. The prospect of large financial rewards, coupled with the credible threat of dismissal or outright failure of the company should it underperform, helps align the private incentives of scientists with those of owners and financiers. This reduces the employee “holdup” problem and more generally encourages employees of start-ups to dedicate themselves to helping the company succeed.

Institutional Constraints Toward Radical Innovation within Coordinated Market Economies

Institutional frameworks within CMEs favor the development of managerial commitments needed for employees to willingly make firm-specific knowledge investments that are not easily salable on open labor markets. Such arrangements tend to lock-in owners, managers, and skilled employees into long-term, organized relationships. Strong norms and legal obstacles to hire-and-fire combined with a long-standing tradition, buffered by codetermination laws, of consultative patterns of work organization, favor competence enhancing human resource policies. As Streeck (1984) has argued with respect to Germany, within CMEs management must treat employees as fixed rather than variable costs, and as a result have a strong interest in developing long-term career structures for all skilled employees.

Within CMEs labor market regulation and a stakeholder system of corporate governance promote long-term employment. Within large firms managers and skilled personnel usually enjoy long-term employment, often after a formal apprenticeship or, in the case of many engineers and scientists, an internship arranged in conjunction with their university degree. While there exist important country variations in industrial relations and corporate governance laws that generate long-term employment equilibriums, within Northern European economies such as Germany, the Netherlands, and Sweden organized labor has used its power on supervisory boards as well as its formal consultative rights under codetermination law over training, work-organization, and hiring to obtain unlimited employment contracts (see Streeck 1984). Once the long-term employment norm for skilled workers was established, it spread to virtually all mid-level managers and technical employees. Within CMEs legal support for noncompete clauses within employment clauses reinforces long-term employment uphold clauses in employment contracts that forbid an employee to take a job at a different firm with the same skill classification for a period of time after leaving the original firm (see Keller 1991 for Germany). Overall, the active labor market for mid-career scientists and technicians is limited.

Long-term employment and the stakeholder model of corporate governance have important repercussions for patterns of company organization (Charkham 1995; Vitols 2001). Managers have an incentive to create a broad consensus across the firm when major decisions will be made. As unilateral decision-making is limited, it is difficult for senior managers to create strong performance incentives for individual employees. Performance rewards are targeted at groups rather than individuals within companies located within CMEs, and individual performance assessments and bonus schemes are limited. Another implication of this system is that career structures become well-defined and are primarily based on broad education and experience within the firm rather than on short-term performance. Promotion tends to be based primarily on seniority within the firm and educational credentials rather than short-term individual performance.

Ownership and financial relationships within CMEs are strongly influenced by corporate governance rules. While there has been a recent expansion of equity markets in Germany and other CMEs, (Vitols and Engelhardt 2005), these economies are characterized by bank or credit-based financial systems (Zysman 1983; Deeg 1999). Banks and other large financial actors (e.g. insurance companies) have a strong oversight role on firms through seats on supervisory boards and through continuing ownership or proxy-voting ties linking large public companies (Edwards and Fischer 1994; Vitols 2001). Companies can obtain bank loans for long-term investments that assets can be easily secured, such as land, capital investments, and merger and acquisition activity. Banks within CMEs can adopt a longer-term focus in part because they know that firms are able to offer long-term commitments to employees and other stakeholders to the firm, and can often closely monitor the status of their investments through seats on the supervisory board or other direct contacts. However, funding for riskier investments, such as human capital intensive R&D is more limited. For such investments companies within CMEs must rely on retained earnings, limiting rapid investment into new technology areas.

Following the comparative institutional advantage theory, varieties of capitalism scholars argue that institutions within CMEs advantage more cumulative technological trajectories in which the orchestration of credible long-term employee commitment and training and so-called patient finance is important. Sustained patterns of vocational training within firms, consensual decision-making, long-term employment, and patient finance are all linked to the systematic exploitation of particular technologies to a wide variety of niche markets in a number of medium technologies characteristic of many engineering and chemical markets, a strategy Streeck (1992) labels "diversified quality production" or "DQP". We will explore this argument in more detail in the context of Germany and argue that some segments of the biotechnology and software industries may in fact have technological regimes favoring incremental innovation; if so, we should expect CMEs like Germany to develop competitive strengths in such subsectors. However, the patterns of economic coordination that allow companies to succeed in such industries also create a series of disincentives toward the successful governance of each of the competencies associated with start-up companies within radically innovative industries.

High-Risk Finance

Capital markets within CMEs are underdeveloped and focus on large, established companies with predictable revenues. This severely limits the viability of IPOs for new technology companies, particularly during their formative years when earnings and profits are limited and most investment is poured into R&D. Short of acquisitions, which are unpredictable, VCs lack a systematic method to liquidate successful investments within a short time. VCs must take a longer-term perspective, liquidating poorly performing companies and then waiting over a potentially long period for shareholdings within successful firms to become liquid through a friendly acquisition or, when the company reaches adequate profitability, eventual public listing. The lack of a short-term refinancing mechanism makes it difficult for VCs to adopt portfolio investments that promise relatively short-term return to investors. Along the same logic, illiquidity of shares also dampens secondary funding rounds by institutional investors.

In addition to limits imposed by credit-based financial institutions, stakeholder systems of company law create obstacles to the normal venture capital-dominated governance of technology start-ups. While in practice VCs and company founders of start-ups within CMEs often mimic the Silicon Valley model of milestone-based funding predicated on VC control of the firm's initial board, as firms grow the shadow of "normal" consensus-based company governance begins to encroach on developing companies. As firms grow successful and eventually begin to anticipate a public share offering, they must adopt company law structures mandated for public companies, such as the German two-tiered board structure or employee representation laws that are common across CMEs. These structures limit the autonomy of owners in governing the firm through granting board seats to employee representatives. Thus, in addition to limits on risk diversification created by lack of an IPO market for technology firms, VCs face eventual limits in their power to impose their will on the firms they fund.

Managing Competency Destruction

Long-term employment strategies used by large firms within CMEs limit the ability of start-ups with substantial failure risks to recruit experienced managers and skilled personnel and also limit the viability of "hire-and-fire" strategies used to manage technological volatility. Due to long-term employment expectations, consensus decision-making, and a lack of investment capital to pour into risky new ventures, most large firms within CMEs invest in cumulative technology strategies that are less likely to fail. From the point of view of new ventures, a crucial by-product of this system is to limit the growth of labor markets for mid-career managers and skilled professionals. If most individuals expect to be employed by one company for most of their career, they will not be actively seeking jobs. Moreover, given the importance of senior systems and internal promotion within established companies in CMEs, moving to an unproven start-up is extremely risky. If a skilled manager or scientist leaves a "safe" career for an invigorating but risky job in a start-up, there is little guarantee that, if the start-up fails, he or she will find employment back in the former firm, while taking jobs at a competing firm could imply starting at a lower position within the company hierarchy. Moreover, as companies within CMEs often develop firm-specific technical routines, upon moving firms these firm-specific skills will be devalued. Thus, compared to typical career management patterns within LMEs that emphasize periodic job hopping and investment in primarily general skills, the risk of moving to a start-up is substantial within CMEs.

In sum, long-term employment patterns by large companies severely limit the size of labor markets for skilled personnel and, by doing so, inflate the career risk of leaving a "safe" job to move to a new venture. Entrepreneurial ventures facing high-technological volatility may experience particularly severe recruiting problems due to both the inflated failure risk for these companies and the necessity of such firms to periodically shift their R&D trajectories to cope with changing technologies. Given the risk of moving from a safe job to a risky start-up, it is likely that assurances of continued employment to key personnel will be given to any mid-career personnel that are recruited, in an effort to lower the perceived risk of leaving a safe job in a large firm or university. This limits the flexibility of start-ups, implying that new technology start-ups within CMEs will have less flexibility in reacting to technological volatility than competitors located within LMEs. Alternatively, new technology firms within CMEs might need to react to changes in technology differently, by, for example, attempting to retrain skilled employees rather than engaging in hire-and-fire. Or, given limited labor markets for mid-career professionals, start-ups within CMEs might attempt to recruit primarily junior level technical personnel and managers, who presumably face lower career risks of failure than more senior hires.

While national institutional frameworks within CMEs clearly create labor market obstacles to start-ups, it is possible that regional technology clusters could develop that sustain patterns of flexible labor market coordination more conducive to flexible personnel policies within technology start-ups. This issue is explored in Chapter 7. However, a different institutional logic connecting national with local patterns of economic coordination exists across the CMEs and LMEs. While within LMEs patterns of deregulated labor market coordination and frequent job hopping by employees of large companies are consistent with the development of high interfirm mobility and open employment strategies within clusters, within CMEs labor market coordination within clusters must circumvent dominant patterns of career management and labor market development within the broader economy. National institutional frameworks within CMEs create strong constraints against the Silicon Valley model of labor market coordination within clusters.

Employee Incentives

While small start-up companies within CMEs have considerable autonomy in designing incentive schemes for employees, they must do so in the shadow of practices and norms created by larger firms within the economy. Large firms within CMEs avoid creating high-powered incentives for managers, unilateral decision-making structures, and opportunities for rapid career advancement because these organizational structures go against the logic of the established institutional framework and would risk alienating important long-term stakeholders to the firm. Entrepreneurial companies thus must countervail norms of primarily long-term, collective performance reviews.

The tactic associated with the Silicon Valley model of organizing is the widespread use of ownership share options. Options may be viable within CMEs, in that they create a collective incentive across all employees of the firm; if the firm becomes publicly listed and thereafter sees its share price increase, then all owners in the firm profit. An interesting issue is whether the senior management of companies can credibly disperse share options as a tool to reward individual performance. If so, they might credibly create high-powered incentives as seen within LMEs. Very small companies in their initial start-up phase seem more likely to do this, as they are farthest removed from the shadow of employee representation laws that tend to conduce toward lower powered, collective employee incentives. More importantly, the strength of share ownership incentives is dramatically muted for companies operating within institutional environments precluding credible IPO for technology companies. Lacking liquidity cannot easily value or capture their stock holdings in the short term. Moreover, within many CMEs, including Germany, tax laws and restraints on company activities in buying and selling shares existed throughout the 1990s that created technical barriers to adopting patterns of company governance based on share ownership.

Public Policy

The varieties of capitalism approach generates strongly divergent predictions surrounding the predicted success of new technology industries across CMEs and LMEs. Given a willing government, how might public policy impact these outcomes? Varieties of capitalism research has been relatively silent on the issue of public policy, in particular toward innovation. Given the strong interest of governments across the world in importing elements of the Silicon Valley model, it is important to conceptualize how public policies might interact with institutional configurations across different types of economies to impact the governance of new technology firms.

To help generate public policy predictions, Figure 2.1 illustrates the main explanatory mechanisms behind the approach, suggesting that innovative competencies being developed by companies within a

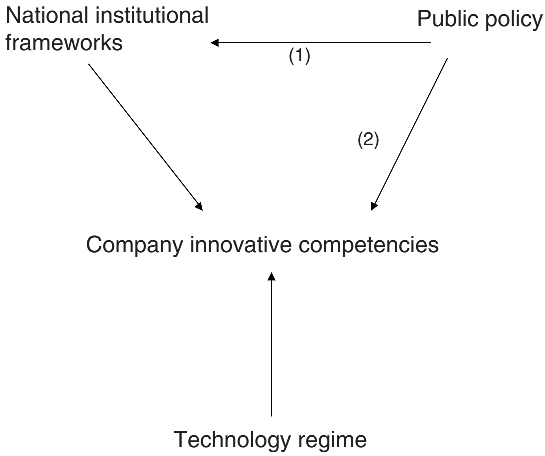

Figure 2.1. National institutional frameworks and public policy trajectories

particular sector are defined by that sector's technology regime. Within the varieties of capitalism framework the primary explanatory work is performed by societal institutions that are not explicitly tied to the state. Public policy is viewed as autonomous from the content of national institutional frameworks. Within this framework, there are two mechanisms by which policy can impact the governance of company level innovative competencies. First, as indicated by the arrow labeled "1", public policy can aim to reconfigure national institutional frameworks to better accommodate the needs of a given sector. Second, indicated by the arrow labeled "2", public policy can be designed to complement or, at times, circumvent "normal" incentives and constraints within an economy toward particular firms.

Policies Aimed at Institutional Change

Most policy implications of the varieties of capitalism view stem from the perspective's assertion that national patterns of industry specialization are created by a country's comparative institutional advantage. Countries whose patterns of business coordination are organized around the LME model should excel at generating successful entrepreneurial technology firms focussed on rational innovation, as each of the innovative competencies of the "Silicon Valley model" can be effectively governed within LMEs. Countries whose institutions conduce toward the CME pattern will face difficulties in generating successful radical innovative companies, as institutions in these countries hinder the effective governance of innovative competencies within such sectors.

A policy implication of the comparative institutional advantage argument is that all countries face trade-offs in designing institutional frameworks. A country can develop institutions to support radically innovative or incrementally innovative technological trajectories, but not both. If true, CMEs should not be able to successfully introduce policies aimed at reforming national institutional frameworks to better support radically innovative firms. Instead, an entirely new structure of institutional supports would need to be developed to support these firms. An important assumption surrounding the comparative institutional advantage argument is that financial systems, patterns of labor market regulation, and other crucial frameworks needed to support new economy firms are economywide in scope. This suggests that policies would need to recast the country's basic model of capitalism. However, an alternative approach, which we will see has been attempted to some degree in Germany, is to create alternative institutional arrangements for newly favored sectors.

There are both economic and political arguments to suggest that policies aimed at changing some or all of a country's institutions from one logic of coordination to another should prove difficult to implement. There is an important political implication of the comparative institutional advantage argument. Over time, companies with innovation strategies positioned to enjoy a country's comparative institutional advantage will outperform companies situated within disadvantaged sectors. The existence of a favorable institutional environment should ensure that a majority of companies within a country are specialized in sectors falling under that country's comparative institutional advantage. As a politically dominant coalition, such firms should be able to resist demands made by disadvantaged companies for institutional reform.

Recent work by political scientists has demonstrated that the political preferences of companies vary dramatically across LMEs and CMEs. Mares (2003), for example, has argued that companies within Germany and other CMEs have a strong stake in protecting investments in highly skilled workers, and have thus supported encompassing social policies aimed at protecting workers that are often resisted by companies within LMEs. In a similar study of Germany, Wood (2001) has shown that companies have successfully resisted proposed policies to weaken the country's codetermination laws suggested by the free-market leaning Free Democratic Party (FDP) during their years as coalition partner in the Kohl government.

Drawing on arguments made by institutional economists (Milgrom and Roberts 1995), Hall and Soskice (2001: 17–21) have developed an economic argument, arguing that institutional complexes coalesce around what they call institutional complementarities. They emphasize the importance of interdependencies across institutions governing different domains of the economy. They argue that companies benefit from increasing returns in performance from the correct alignment of institutions and, conversely, face obstacles to effective performance when institutions support contradictory patterns of business coordination within an economy.

While the idea of institutional complementarities has not been rigorously tested empirically at the micro-organizational level (see Hall and Gingerich 2004 for a macroeconomic analysis), the idea appears plausible. Referring once more to the Silicon Valley model of organizing competencies, the existence of a primarily capital market-based financial system capable of supporting high-risk venture capital and IPO markets seems strongly contingent on the existence of corporate governance and company law rules privileging owners in designing incentive systems within the company. Such incentive systems seem contingent on the existence of deregulated labor markets supporting hire-and-fire strategies needed to reinforce company performance incentives and facilitate flexible human resource strategies needed to compete within technologically volatile industries.

If institutional complementarities are indeed strong, then it is unlikely that a policy of creating a mixed set of institutions aimed at accommodating diverse sets of innovative competencies within a country could succeed. For example, in Germany from the late 1990s onward there has been ongoing discussion about moving the country's financial system from a primarily bank-based system with concentrated ownership toward a capital market system focussed more on dispersed corporate ownership and shareholder value norms of governance (see Vitols 2001). These changes would, however, be enacted with little or no change to the German institutions structuring company law, industry-led skill formation, or industrial relations. As German new technology start-ups are strongly impacted by the structure of financial markets, but at least in the start-up phase do not participate in the apprenticeship system and are not unionized, they might benefit from the development of a mixed set of institutions.

From the varieties of capitalism perspective, however, it seems unlikely that this shift would succeed in dramatically changing the performance of most companies, so long as company law continues to promote the stakeholder system of company governance and industrial relations patterns continue to conduce toward long-term employment of most skilled employees and managers. According to the logic of institutional complementarities such a change could disrupt the performance of normal German companies embedded within sectors focussed on incremental innovation, for example, through impacting the ability of firms to obtain long-term "patient" finance. If the logic of institutional complementarities is indeed strong, one would also expect the performance of more radically innovative firms to continue to suffer, for example, in terms of the ability of companies to employ flexible human resource policies.

In sum, within CMEs, sort of systematically rewiring the nation's pattern of business coordination toward the LME model, policies oriented toward shifting national institutional frameworks toward the liberal market model preferred by radically innovative new technology firms should fail. Moreover, public policies designed to change the logic of coordination within overarching frameworks impacting most firms within an economy will be politically difficult to achieve.

Policies Aimed at Circumventing Existing Institutions: Sectoral Support Systems

A second approach is to devise policies designed to circumvent or compensate for inappropriate national institutional frameworks. While policies aimed at national institutional reform are primarily legal or regulatory in nature, this second approach to policy is aimed more directly at companies, and thus encompasses a much wider set of potential policy instruments. Most traditional industrial policies aimed at steering resources to particular firms or industries belong in this category. Examples of such policies include programs to steer financial resources toward companies, policies aimed at trade promotion, the government support or creation of organizations aimed at helping companies within a particular sector, and a variety of supply-side policies, such as public science funding and the support for the commercialization of science within most new technology fields.

Recent research on public policy toward specific industries has emphasized the importance of government policy in creating "sectoral support systems" (Mowery and Nelson 1999) needed to promote the success of firms within particular sectors. Support systems may include institutional elements. However, within Mowery and Nelson's conception, such institutions tend to be sector specific. As much government policy toward biotechnology and the software industry in Europe has the aim of creating a sustainable industry, the sectoral support system framework is particularly relevant for this analysis. Much policy toward new technology policy contains a mix of resource provision and the creation of sector-specific rules and regulation, but within institutional frameworks aimed squarely at a particular sector. Most European countries have developed strong sectoral systems toward "new economy" sectors, and particularly biotechnology. In analyzing these policies, it is important to develop expectations as to how sectoral support systems interplay with more overarching national institutional frameworks emphasized by varieties of capitalism theory.

LMEs enjoy a comparative institutional advantage toward radically innovative firms. Sectoral support systems may be necessary for well-performing industries to emerge in such countries, but the aim of such policies should be to build on or complement broad institutional incentives that are conducive toward success in these sectors. While sectoral support system policies alone should not be sufficient for a country to succeed in a radically innovative sector, they may be necessary. For example, within the biotechnology and pharmaceutical industry levels of science funding, rules structuring the commercialization of science, the degree and regulation of market competition for medicines within society, and rules surrounding the types of biological discoveries that can be patented all have a strong impact on the performance of a given country's industry. Absent a well-designed sectoral support system, a given industry might fail, even if embedded within a "correct" pattern of more overarching business coordination as stressed in the varieties of capitalism theory. This may help explain, for example, why the pharmaceutical industry of the United States and UK has outperformed the Australian pharmaceutical industry. Each of these countries is an LME, but the United States and UK may have better sectoral support systems than Australia (see Casper and Matraves 2004 for the United States and UK; West 2001 for Australia).

Within CMEs policies aimed at creating a sectoral support system should, according to the varieties of capitalism perspective, be much more difficult to successfully develop. Policy must both create the necessary sector-specific supports that are general to an industry, but also create programs to circumvent the "normal" patterns of economic coordination that companies within the targeted sector face. With regard to the Silicon Valley model, this suggests that policy must devise a system of high-risk financing, high-powered performance incentives within companies, and sufficiently mitigate career concerns of scientists and managers to stimulate flexible labor market coordination within the local sector. Drawing once more on the logic of institutional complementarities, the varieties of capitalism perspective suggests that such policies will only work if they are comprehensive, covering each of the three main competencies associated with entrepreneurial new technology firms. This leads to the expectation that sectoral support systems supporting radically innovative firms should generally fail within CMEs.

Conclusion

This chapter has extended the varieties of capitalism approach to institutional theorizing to develop expectations surrounding the sustainability of the Silicon Valley model of commercializing radically innovative technologies. Chapters 3, 4, and 5 test these expectations through detailed examinations of the biotechnology industry within the United States, Germany, and the UK. The chapters are constructed so as to allow a structured comparison of the usefulness of the institutional approach in exploring the sustainability of radically innovative new technology companies. In addition to providing basic information about the performance of the biotechnology industry and an analysis of the public policy context surrounding the industry, each chapter analyzes the sustainability of economic coordination within and across firms surrounding each element of the Silicon Valley model. This approach allows for detailed comparisons of how firms in each country are financed, of whether they can develop credible incentive structures to motivate employees, and whether sufficient labor market flexibility exists to allow companies to employ risky, competency destroying staffing strategies. This evidence is used to explore whether institutional frameworks, and in some cases resources provided through public policy, generate an environment facilitating the credible orchestration of innovative capacities within the biotechnology sector.

3

How an American technology cluster emerged and became sustainable: San Diego biotechnology

The ability of the US economy to generate new technology industries, such as semiconductors, personal computers, and the Internet provides strong support to the contention that LMEs have a comparative institutional advantage in generating radically innovative firms. However, the link between varieties of capitalism and innovation within LMEs has not been systematically explored. Rather, a correlation exists between national institutional frameworks strongly oriented toward the LME model and the existence of many industries populated by displaying characteristics of radically innovative firms. This chapter examine whether radically innovative firms in the United States benefit from a comparative institutional advantage of being located within an LME. To do so, it explores whether national institutional frameworks within the United States help generate patterns of economic coordination in the areas of finance, incentive structures within companies, and labor market organization that are consistent with varieties of capitalism theory and are actively embraced by a cluster of successful radically innovative companies. The chapter also discusses the policy context surrounding the US biotechnology industry, examining the extent to which policy toward biotech companies comprises a sectoral support system toward the industry that complements appropriate institutional frameworks.

The chapter focusses on a successful cluster of biotechnology companies located in San Diego, California. Along with Silicon Valley and the Boston region, San Diego is one of three large clusters of biotechnology companies in the United States. One rationale for selecting San Diego as a region to study is that it is not Silicon Valley. The

San Diego case will be used to verify that the Silicon Valley model of organizing competencies has diffused to another region in the United States and that this model can be more plausibly associated with radically innovative firms within LMEs rather than just one region. The case will also be used to study patterns of economic coordination surrounding firms in the region, allowing benchmarks to be developed for use in comparing biotechnology clusters in Germany and the UK.

Research Setting and Methodology

San Diego is an excellent laboratory to study patterns of economic coordination surrounding radically innovative firms within an LME. The region went from having virtually no presence in commercial biotechnology at the start of the 1980s to developing one of the world's most vibrant biotechnology clusters that by 2004 was employing over 39,000 people (DeVol et al. 2005). While San Diego has recently developed a cluster of wireless telecom companies to complement its biotechnology presence (see Simard 2004), the region did not have a presence in high-technology industry during the late 1970s, and was primarily known for its large naval base and defense contractors. Biotechnology was the first high-technology industry to grow in San Diego. The Silicon Valley biotechnology industry, by contrast, was able to draw on the high-technology infrastructure developed around the semiconductor industry, including VCs and a pool of experienced general managers (see Robbins-Roth 2000). This should allow a careful examination of the mechanisms by which the cluster emerged, in which we can assess the relative importance of market versus nonmarket, or public policy influences.

To investigate patterns of economic coordination over the history of San Diego's biotechnology cluster, a methodology of tracing career histories of senior managers and scientists working within San Diego biotechnology companies was adopted. Using a regional directory of biotechnology companies in existence during 2004 (AlexanderX 2004), company web-pages, and US Securities and Exchange Commission filings, career histories were located for 604 senior managers of San Diego biotechnology firms employed in at least one firm listed in our database between 1982 and 2004 (see Casper 2007 for a complete description of the research methodology including a discussion of possible biases). This includes all types of senior management positions, both those in scientific and general management positions. Of the 602 managers, about half (302) had a graduate science degree (Ph.D.) and half (300) had no graduate science training and were presumably general managers.

The career history method creates a useful window to examine the entry and exit of biotechnology companies within the region. Most senior managers working within San Diego companies during the 2004 period had worked at several other companies within the region, many of which had failed or been acquired. Thus an advantage of the career history approach is its ability to identify failed companies within the cluster, particularly during the 1980s and early 1990s when published directories or Internet profiles are not available.

The career history methodology also facilitates an analysis of patterns of labor market coordination within the San Diego clusters. It allows the tracing of the founding and growth of dozens of San Diego biotechnology firms and investigates both agglomeration patterns (people moving to San Diego) and mobility across firms. Career histories also allow the construction and study of a relatively complete set of social ties formed between managers through joint employment in the same biotechnology firms. Social network data will be used to explore patterns of labor market coordination within a successful LME biotech cluster, as well as the process by which the social networks underpinning mobility emerge. Thus the strongest empirical evidence developed in this chapter surrounds the development and organization of labor coordination for senior managers and scientists. However, during the process of investigation supplemental data was also collected on patterns of financing surrounding regional biotechnology companies and, using SEC documents, employee incentives.

San Diego Biotechnology Company Demographics

Table 3.1 displays descriptive statistics on the entry and exit of San Diego biotechnology companies between 1982 and 2004. During this period 142 independent biotechnology companies were founded, with 58 subsequently failing or being acquired. The pattern of growth within the cluster is relatively consistent over the cluster's history. The growth rate for the cluster in terms of companies was relatively steady, at about 15 percent a year. Starting with a handful of firms, by the early 2000s the size of the cluster peaked at approximately ninety firms.

Table 3.1. San Diego company demographics, 1982–2004

Year	Number of firms	Entrants	Exits
1982	5	5	0
1983	8	3	0
1984	12	4	0
1985	11	0	1
1986	14	3	0
1987	20	6	0
1988	28	9	1
1989	35	7	1
1990	35	2	2
1991	40	4	0
1992	48	9	1
1993	54	8	2
1994	55	5	4
1995	57	4	0
1996	65	10	2
1997	74	12	5
1998	79	11	5
1999	82	6	3
2000	92	20	8
2001	91	9	9
2002	93	4	1
2003	89	1	7
2004	86	0	6
Total		142	58

Only research intensive companies with characteristics of radically innovative firms were included in the database. As a first screen to include only research intensive firms, the database included only companies that are listed as the affiliation on at least one scientific article, as allowing scientists to publish a good indicator that firms are conducting intensive research (see Casper and Murray 2004). All companies within the database are also independent firms dependent on financing from VCs or, for more advanced companies, public stock markets. Most carefully explain on web-pages and SEC filings that they are "development stage" companies, pouring large sums of venture funding into basic research needed to capture large market, particularly the therapeutics market in which unmet medical needs exist.

A majority of the companies, 86 or 63 percent, are focussed on drug discovery. These firms are particularly high risk as they combine the risk of technological failure with funding problems inherent in multiyear clinical testing schedules. The remaining companies focus on platform technologies, diagnostics, and a variety of niche-markets. Twenty or 15 percent have platform technology specializations. As will be discussed in more detail with reference to the German biotech industry, platform technology companies develop service models typically used to enhance the drug discovery operations of clients. Service-based business models reduce financial risks through helping to accrue ongoing revenues. Of the remaining companies, eleven (8%) are focussed on medical diagnostics and the remaining nineteen focussed on a variety of niche markets, including agricultural biotechnology and plant genetics (4%), tissue engineering (2%), drug delivery (2%), biopolymers (2%), and blood substitutes (2%).

An important indicator that these firms are engaged in radically innovative activities is a high failure rate. Over 40 percent of the companies founded between 1982 and 2004 have lost their independence. While a small number of exits were acquisitions priced at substantial profits for investors, the vast majority can be classified as failures, either through outright bankruptcy or through fire-sale acquisitions at extremely low sale prices. This failure estimate should be considered conservative for two reasons. First, many of the newly formed companies have not had enough time to fail. Of the 108 companies established prior to 2000, a higher percentage, 44 percent, have lost their independence. Only 24 percent of the companies founded in year 2000 or after have failed. Second, the career history approach creates a bias toward the inclusion of companies that received substantial VC investments needed to hire senior management teams. Such firms have usually succeeded in reaching early development milestones, and may be less likely to fail. There is evidence that a substantial number of early-stage biotechnology companies were formed and failed before receiving sizable capital investments. A 2000 report on ties between San Diego research institutes and local biotech firms lists forty-six San Diego-based biotechnology companies with ties to regional research institutes that are not included in the career history set of companies (Lee and Walshok 2002). As these firms are not included in the 2004 databases of San Diego companies or the list of failed firms derived from career histories of senior managers, most presumably failed at an early stage. If these companies are added to the pre-2000 set of failed companies in the database, this produces 93 failures out of a total of 153 firms in existence prior to 2000, or a 60 percent failure rate.

Patterns of Economic Coordination within San Diego Biotech

San Diego is located within an LME and is home to a large number of radically innovative biotechnology companies. This evidence is supportive of the theory of comparative institutional advantage, but only as a correlation. Have San Diego biotechnology firms been able to successfully implement patterns of company governance associated with the Silicon Valley model? If so, firms should be able to raise high-risk finance, implement high-powered incentive structures across managers and scientists of firms, and easily sustain flexible human resource strategies needed to compete within competency destroying technological fields. The following investigates each issue.

Raising High-Risk Finance

Venture capital financing and associated patterns of corporate governance were imprinted onto San Diego biotechnology start-ups from the cluster's inception. Many early San Diego companies were initially funded by Silicon Valley venture capital firms. The most important of these firms was Hybritech, a molecular diagnostics company funded in 1978 by the same team as from Silicon Valley's premier venture capital firm, Kleiner, Perkins, and Byers, that successfully founded Genentech in San Francisco two years earlier. While their initial capital investment in Hybritech was only $300,000, the Kliner Perkins VC team took an active role in the initial governance of the firm, recruiting a successful general manager from the medical device leader Baxter, Howard Greene, to become CEO and cofounder of the firm along with two scientists from UC San Diego, Ignor Royston and Howard Birndorf. Hybritech quickly became the region's first major success story, and was acquired in 1986 by Eli Lilly for about $400 million (Crabtree 2003). Royston and Greene became important VCs capitalists within the region, with Birndorf often partnering with these and other area VCs to become interim CEO of several early-stage start-ups.

Due to the link between Hybritech and Kleiner Perkins, San Francisco Bay area VCs often refer to San Diego as a "colony" due to its early reliance on Silicon Valley venture capital. If so, the region soon gained independence, as a number of home-grown venture capital funds appeared. By the early 1990s, a dozen VCs had offices in San Diego, growing to twenty-seven by 2005 (San Diego SourceBook 2006).

The Silicon Valley model of managing financial risks became well-entrenched within the San Diego biotechnology. Dozens of firms have been able to secure high-risk venture capital to fund their initial operations. Detailed records on VC investments are only available for the post-1995 period. Table 3.2 displays data on venture capital activity

Table 3.2. Venture capital investments and IPOs in San Diego biotechnology, 1995–2004

Year	VC investment (million $)	Total VC deals	Avg. deal size (million $)	IPOs
1995	72	19	3.8	2
1996	142	30	4.7	4
1997	162	24	6.8	6
1998	166	26	6.4	5
1999	257	36	7.1	2
2000	621	48	12.9	9
2001	565	43	13.1	2
2002	401	31	12.9	1
2003	353	38	9.3	1
2004	567	38	14.9	6
Total	3306	333	9.9	58*

* An additional 19 IPOs took place between 1983 and 1994, 16 of which occurred in the 1990–4 period.

Source: PriceWaterhouseCoopers MoneyTree Venture Capital Survey. IPO data from company records and Internet searches.

and IPOs for San Diego biotechnology for this period. San Diego biotech enjoyed a vibrant VC scene in most years. Over $3 billion of venture capital was ploughed into San Diego biotechnology firms during a ten-year period (1995–2004). Note that while the number of deals per year remains relatively stable at between twenty and fifty deals per year, the size of total investment increases substantially. This suggests that the monetary value of deals increased, possibly as therapeutics oriented companies were able to draw on relatively large VC investments to fund clinical research prior to expected IPOs.

The Silicon Valley model of venture capital funding is predicated on the availability of plausible exits for investors. San Diego VCs have been able to rely on a willing pool of investors to support IPOs of area biotechnology firms. Between 1982 and 2004 fifty-eight companies, or 40 percent of the firms in the database, were able to achieve IPOs. Most San Diego IPOs were on NASDAQ, the New York-based stock exchange well-known for supporting new technology start-ups. While there is evidence that the so-called IPO window has opened and closed at various points over the years, a handful of companies have gone public most years from 1990 onward.

Investors were also willing to invest large sums in San Diego biotechnology stock offerings despite a high risk that many would fail. San Diego companies were able to go public during their early development, long before profitability could reasonably be expected. Most companies were experiencing losses at the time of IPO and, particularly for the therapeutics companies, fully expected to continue to make loses for many more years. Firms are required to disclose balance sheets on IPO prospectus documents, which are available through the Securities and Exchange Commission Edgar database from 1995 onward. Of the forty-four San Diego companies which took IPOs during this period, thirty-nine were loss-making at the time of IPO. Most companies explicitly classified themselves as "development stage"; a term commonly used within SEC filings to denote high-risk research-oriented companies with only operating losses to show on balance sheets. IPOs by no means insured that firms would succeed; indeed, eleven of San Diego's public companies have declared bankruptcy or been acquired by other public companies.

In addition to raising additional investment capital, IPO activity allows early investors to sell shares on the stock market, often at high multiples of initial investments. The steady progression of companies reaching successful exits for initial investors creates a credible investment environment for VCs by ensuring that companies successfully meeting early development milestones can go public. The availability of IPO exits suggests that VCs were able to generate lucrative returns, presumably at many multiples of initial investments, for many companies in their portfolio. The mean time from inception to IPO for these firms is five years, though with substantial variation. A few companies achieved IPOs at within two-to-three years of inception, while other companies were in existence for more than a decade before their IPO. The relatively short time to IPO suggests that VCs could plausibly support portfolio strategies within San Diego biotech, using funds developed by IPOs to support ongoing investments with other portfolio companies.

In addition to providing liquidity for private equity investors, by supporting IPOs of early-stage companies, investors within public markets undertook much of the risk involved in financing the long-term R&D and clinical development of their products. The early success of Hybritech added credibility to San Diego biotech investors. The vast sum paid for the company at an early stage in the development of the biotechnology industry demonstrated to San Diego entrepreneurs and VCs that lucrative returns could be made on technology investments. Moreover, by the early 1990s three early biotechnology pioneers operating elsewhere in the United States, Genentech, Amgen, and Biogen had successfully launched products, earning each firm hundreds of millions in annual revenue, and multibillion dollar market valuations. Many San Diego therapeutic companies promised to mimic their formula for success, using funds generated by stock offerings to retaining ownership of promising therapeutic compounds through clinical trials, ensuring handsome profits should a new drug eventually go to market.

IPOs provided modest capital injections into San Diego companies, typically between $30 and $70 million. However, once public companies could leverage further milestone successes, particularly in clinical trials for lead products, as the basis for secondary offerings, many San Diego biotechnology companies were able to raise hundreds of millions of dollars through IPOs and follow-on offerings. Examples of companies using public markets to finance late-stage clinical trials as of 2004 include Alliance Pharmaceuticals ($440 million) and Arena Pharmaceuticals ($300 million).

The most dramatic example of a San Diego company successfully raising vast sums on public markets is Amylin Pharmaceuticals, a therapeutics company founded in 1987 by former Hybritech CEO Howard Greene. The firm faced bankruptcy in 1999 when one of its lead products failed clinical trials and Johnson & Johnson, a prominent development partner, ended its relationship with the company. The company was able to raise additional investments after key senior managers and board members, including Greene, left their positions (Weintraub 2006). In 2005, the firm successfully launched two products aimed at the diabetes market, Symlin and Byetta, and has seen its stock market capitalization exceed $4 billion. While documented evidence on Amylin's total investments prior to the launch of their two products are unavailable, San Diego biotech observers estimate that Amylin spent over $2 billion, raised through venture capital, stock offerings, and partnerships prior to establishing revenues from Symlin in early 2005. While Amylin is the most extreme example of a San Diego biotechnology firm able to raise sizable funding to pay for the development of drug candidates, the firm's experience is indicative of high-risk financing within successful technology clusters within LMEs.

The Viability of High-Powered Performance Incentives

The general flexibility of company boards within the United States to develop contracts for founders and top managers of companies legitimates the practice of using share ownership schemes as a tool to create high-powered incentives for managers. Initial founders of companies often own a small percentage of the company, which often translates into ownership of hundreds of thousands of shares of stock. Public offerings for companies that eventually achieve large market capitalizations can generate tens to hundreds of millions of dollars for founders, and smaller yet still sizable windfalls for other senior managers and scientists within venture-financed firms. The potential size of such windfalls can serve as a powerful inducement for managers and scientists to dedicate themselves to the success of the company. The development of vesting schedules, which transfers ownership of stocks or stock options to employees incrementally over multiple years, is commonly used to generate longer-term commitment of key employees to firms. This is particularly important for firms situated within regions in which labor mobility is generally high and, due to the availability of venture capital, opportunities to start new ventures are abundant.

The dispersal of share ownership across founders, senior managers, and most skilled employees within San Diego biotechnology companies can be assumed to be universal. SEC data again can be used to verify the use share ownership and option plans within the publicly traded firms. For the thirty-nine publicly listed companies for which SEC records are available on the Internet, all provide details of share ownership and option plans for senior managers and founders. However, without the liquidity provided through IPOs ownership-based incentive plans can lose credibility. In San Diego 40 percent of the companies in our database failed, but another 45 percent reached successful IPOs that presumably generated stock-option windfalls for most early employees in these firms. Despite the high probability of failure, the history of successful IPOs for several dozen firms and, for a few firms like Hybritech, highly priced acquisitions, brings life to these plans, as managers and scientists can credibly foresee these options as becoming valuable, and salable should the company go public or be acquired at a high valuation.

The demonstration effect of the early Hybritech acquisition had a crucial role in legitimating share-based incentive schemes within the region. Not only did this $400 million acquisition of a privately held company occur relatively early in the history of the cluster, most of the founders and senior managers of the firm were soon employed elsewhere in the region, becoming walking scions to Hybritech, demonstrating the wealth and prestige associated with working in a successful start-up. Several other companies, such as Invitrogen, IDEC, and Amylin, have developed successful commercial paths after IPO, allowing market capitalizations to reach the billion dollar plus level and presumably generating sizable wealth generating effects for employees of these firms. In sum, high-powered incentive plans focussed around share ownership are credible within San Diego biotechnology.

Labor Market Coordination

To examine whether labor market coordination in San Diego is capable of supporting radically innovative companies, two aspects of labor mobility are discussed. First, using the career history database, the general growth of the labor market within San Diego biotechnology is investigated, both in terms of the general level of mobility across companies on a yearly basis and on the composition of this labor market. Composition refers to the ability of companies to recruit individuals from a variety of previous career experiences that seem relevant to biotechnology firms, such as individuals with experience in large pharmaceutical companies, other biotechnology firms, or academic science. Second, again using the career history database, the degree to which labor mobility within San Diego has created social networks linking managers within the region's companies is investigated. This will help examine Saxenian's claim (1994) that decentralized social networks within a regional economy can potentially raise the innovative capacity of a region while, from the point of view of individuals, lower the career risk of joining a high-risk start-up.

THE SIZE AND COMPOSITION OF SAN DIEGO'S LABOR MARKET FOR SENIOR MANAGERS

To help gauge the growth and composition of labor markets for senior managers, Table 3.3 provides data on new senior management hires by San Diego biotechnology firms on a year-by-year basis, along with the type of previous job held prior to each career move. Most generally, the career history database shows that San Diego biotechnology firms were able to recruit managers on a regular basis throughout the history of the cluster. The number of new hires steadily increases on a yearly basis as the cluster, presumably driven by both the existence of new entrants and the growth of many established firms.

A first interesting finding is that San Diego biotechnology benefitted from interfirm mobility, but also from extensive inward migration to the area. Very few senior managers were employed in the San Diego area prior to their first biotechnology job in the region; the percentage of senior managers who moved to the region at some point during their career is over 90 percent. The existence of strong inward migration to San Diego biotechnology firms speaks to the existence of a strong national labor market for experienced managers within the United States. Most

Table 3.3. Previous jobs of San Diego senior managers (1982–2004)

Year	San Diego biotech.	San Diego academic	Other biotech.	Large pharma. & med. devices	Industry	Other academic	Total yearly moves
1982	0	1	0	3	0	3	7
1983	3	2	2	0	0	2	9
1984	0	0	0	0	3	0	3
1985	0	2	0	2	1	4	9
1986	2	2	0	1	0	2	7
1987	3	3	0	2	4	3	15
1988	14	0	1	2	5	4	26
1989	9	2	0	6	6	1	24
1990	4	1	3	7	5	1	21
1991	1	1	5	7	3	1	18
1992	7	5	6	12	4	3	37
1993	3	3	6	9	7	1	29
1994	7	3	12	15	6	3	46
1995	13	4	6	7	2	3	35
1996	14	3	10	12	10	2	51
1997	25	1	14	5	15	9	69
1998	31	1	10	12	10	6	70
1999	25	3	19	9	3	2	61
2000	32	3	19	8	10	6	78
2001	21	1	22	11	16	6	77
2002	27	2	26	12	24	3	94
2003	26	1	13	7	13	2	62
2004*	12	0	8	3	5	1	29
sum	279	44	182	152	152	68	877

* Data for 2004 incomplete (January–June only).

subsequent career moves were to other San Diego biotechnology firms, averaging about twenty-five moves per year from the mid-1990s onward. Over the 1982–2004 period there were 279 lateral moves across San Diego biotechnology firms. This is strong evidence that a flexible labor market exists within the region.

Firms were also able to recruit senior executives from a variety of previous career backgrounds. Relatively few senior managers with science backgrounds came directly from academic laboratories. Out of 877 total career moves, less than 10% were scientists moving from academia to industry. In many instances these individuals were part of the scientific founding team of the company. While often lacking managerial expertise, the placement of scientists from the founding laboratory into spin-off biotechnology companies aids the transfer of often tacit knowledge, such as laboratory protocols, from the laboratory to the firm (see Zucker, Darby, and Brewer 1997). Moreover, the placement of founding scientists within spin-off companies helps consolidate long-term relationships between the founding laboratory and the company, relationships that are often crucial in building the early reputation of the company with investors and potential employees.

Over 80 percent of the scientists working as senior managers in 2004 had previous industry experience. Obtaining personnel with previous industry experience can be crucial to companies, as a criticism of many biotechnology companies has been their inability to turn great science into commercial products. Prior experience in commercial biotechnology is a strong indicator that a senior scientist will be able to effectively orient the firm's R&D endeavors. San Diego firms were able to draw from a labor market for experienced general managers from pharmaceutical companies and large medical device firms (such as Baxter and Abott) had, by the early 1980s, developed in the United States. San Diego biotechnology firms were able to recruit 152 senior managers with experience in such firms.

Of particular importance to drug discovery companies is recruiting scientists with experience in moving therapeutic compounds through the clinic. This is a highly complex task combining science and regulatory expertise. Because pharmaceutical development occurs almost exclusively in companies, skills in the area are most likely to be mastered through direct experience, typically within large pharmaceutical or, to a lesser extent, medical device firms. The ability of San Diego therapeutics firms to consistently recruit scientists with industry experience signifies an important competitive advantage for the region's companies. Later in the book, when analyzing similar data for German firms, we will observe important differences on this point.

Industry experience, particularly with a large, product-oriented firm, is also important in generating individuals capable of providing general management skills to biotech start-ups. In a recent book, Higgins (2005) has explored the development of labor markets in the United States for mid-career managers moving from large pharmaceutical and medical device companies to biotechnology start-ups. Higgins focusses on the medical device firm Baxter in generating a wave of biotech senior managers. During the 1970s Baxter developed a system of hiring young managers from elite business schools and then providing broad general management training through a system of rotation across the company's various product divisions and international divisions. During this time the firm had a relatively flat managerial hierarchy, creating an "up or out" system in which many talented managers, after failing to be promoted to senior management positions at Baxter, left the company to join biotechnology start-ups during the 1980s. Due to the quicker regulatory cycles in the medical devices sector, compared to pharmaceutical development, Higgins argues that the medical device industry is well-suited to training biotech managers. While recruits from large pharmaceutical companies might never see a product actually launched, most managers trained in this sector had actual experience bringing a product to market. San Diego biotechnology firms were able to consistently recruit managers from large medical device companies. Twenty-three had worked at Baxter, including the founding CEO of Hybritech, Howard Greene. Nineteen San Diego biotech managers had experience at Abbott Laboratories.

Social Networks as a Source of Labor Mobility

As discussed earlier, Saxenian, Grannovetter, and others argue that successful regional technology clusters are characterized by dense social networks linking area managers and scientists. Social ties linking personnel across firms are the "oil" needed for well-functioning flexible labor markets to form, reducing career risks and allowing companies to more easily support volatile R&D strategies. Evidence showing the existence of such networks would further support the claim that, as a cluster within an LME, San Diego senior managers and scientists were able to substantially reduce the career risk of employment within failure prone companies.

Social network analysis methods (see Wassermann and Faust 1994) were used to examine the emergence of career affiliation networks formed between senior managers working within San Diego biotechnology between 1982 and 2004 (see Casper 2006 for more details on the methods used). Social network analysis attempts to map the structure of social relationships within a given community, in this case ties between senior managers formed through employment at the same organization. Career affiliation ties are formed between individuals through shared employment in the same organization, and are retained, at least for a period, when one or more of these individuals change affiliations. A focus on career affiliation ties is warranted due to the study's emphasis on mobility patterns. Moreover, it is plausible to assume that through working together on senior management teams, individuals form durable social ties with one another and have obtained relatively full information about one another. These ties should be particularly useful when used for job referrals.

An important issue surrounding the construction of networks is how long social relationships should be assumed to last once an individual leaves an organization. Once an individual moves jobs there is a likelihood that ties will decay, or weaken over time, as individuals lose touch with one another. Moreover, from a theoretical perspective, if social ties are assumed to last indefinitely, dense social networks become much easier to produce and the problem of sustaining the network drops away. By creating a model where ties decay over time, new ties must be continuously generated in order for a network to become sustainable. As ties linking organizations are only produced through mobility, this assumption generates a system in which relatively high levels of labor market mobility will be needed to maintain useful networks. Following an approach implemented in similar social network studies by Uzzi and Spiro (2004) and Fleming, King, and Juda (2006), it is assumed that ties linking an individual to others within an organization cease to exist five years after an individual changes jobs, unless renewed by subsequent joint employment at the same organization.

Table 3.4 displays descriptive statistics for San Diego career affiliation networks during the 1982–2004 period. In addition to the number of people in the network and the number of San Diego biotechnology companies they represent, Table 3.4 contains data on the connectivity of social networks in the region for each year. Most networks initially consist of several fragmented clusters of individuals with ties to one another, called network components. As ties continue to form, these clusters begin to coalesce, eventually forming one giant or main component. A good indicator of a network's connectivity is the percentage of people linked in the main component.

Within San Diego three distinct periods of social network development occurred. During the early 1980s the network was fragmented, with no more than roughly half of a relatively small network of senior managers linked into the main component. During the late 1980s and early 1990s the network begins to gain coherence, as over two-thirds of the members of a larger network consisting of more than 100 people are members of the main component. From the post-1995 period onward the network continues to grow but has gained coherence; over 90 percent of its members are connected to the main component. The very high level of connectivity points to the existence of a potentially vibrant network, at least in terms of the availability of most senior managers in San Diego to contact peers through career affiliation ties.

Table 3.4. Descriptive statistics, San Diego career affiliation networks

Year	Number of individuals in network	Number of firms represented	Size of main component (individuals)	Percent of individuals in main component
1982	15	5	8	53
1983	29	8	16	55
1984	33	12	13	39
1985	41	11	19	46
1986	46	14	22	48
1987	57	20	44	77
1988	72	28	48	67
1989	84	35	60	71
1990	104	35	78	75
1991	120	40	90	75
1992	152	48	96	63
1993	185	54	133	72
1994	216	55	176	81
1995	223	57	203	91
1996	275	65	234	85
1997	308	73	282	92
1998	344	78	306	89
1999	356	83	318	89
2000	379	92	355	94
2001	422	92	380	90
2002	485	93	457	94
2003	534	89	491	92
2004	573	86	523	91

Source: Casper (2006).

Large social networks connect most San Diego biotechnology senior managers. But how useful are these networks of contacts in aiding job mobility? Job referrals are often developed by asking acquaintances for contacts that they may know at target companies. A common statistic to measure indirect ties is called the path length, which measures the number of ties linking individuals within the network. For example, in 2003 the average path length between any two individuals in the main component of the career affiliation network was 4.5 ties. While useful, this measure only measures tie structures linking individuals, not between individuals and firms.

A more insightful measure of the usefulness of the network in generating referrals is to examine the number of companies individuals have access to within the network, particularly companies that can be accessed through relatively few intermediaries. To make this estimate, path length information for each individual was recalculated on a yearly basis to examine the average number of contacts each senior manager had at other companies at each degree of separation, that is, how many direct contacts, how many contacts linked through one individual, two individuals, and so forth. All senior managers that were members of the network main component for each year starting in 1985 (the first year the main component was of significant size) were included.

Table 3.5 displays the results of this analysis. As the network grows, progressively more companies become accessible to San Diego senior managers, as does the number of companies reachable with relatively few intermediaries. During the early years virtually all firms, and individuals, were in close contact due to the small size of the network main component. As the network gained size, however, companies entered the main component at a relatively steady rate, and as they did so about 40 percent of companies are within close contact of the average manager. The usefulness of the network then becomes strongly dependent on its size. By the 2000s, over seventy companies are accessible to senior managers, many through a small number of intermediaries.

It is open to debate as to how many people a given manager can easily use as intermediaries when "working the network" to gain access to a given firm. It seems reasonable, however, that companies requiring two or less intermediaries to contact are readily accessible to most senior managers. The final two columns of Table 3.5 calculate the number of firms in such close contact to the average manager and the percentage this represents of all firms in the main component. Note that from the late 1980s onward at least ten companies are within close contact, on average, to San Diego biotechnology managers, increasing to over twenty to thirty contacts from the mid-1990s onward, or between 40 and 50 percent for most years.

These estimates of the usefulness of San Diego referral networks are strongly impacted by the modeling assumption that ties decay five years after an individual changes jobs. If ties were allowed to persist, then the percentage of companies within close contact would accumulate over time. However, the demonstration that relatively high numbers of companies are at close reach to managers during much of its history under conservative modeling assumptions supports the argument that social ties are supportive of career mobility under risky employment conditions that typify the biotechnology industry.

The Policy Context

National institutional frameworks within the United States provide a supportive context for radically innovative San Diego biotechnology firms.

Table 3.5. Average number of companies reachable to a manager at each "degree of freedom", 1985–2003

Year	Direct contact	1 person	2 people	3 or more people	Sum (all firms in) main component	Sum (close contacts)*	Percent firms with close contact
1985	2	0	0	0	2	2	100
1986	4	1	0	0	5	5	100
1987	4	4	3	1	11	10	93
1988	4	5	3	2	14	12	85
1989	5	6	6	5	22	17	77
1990	4	4	3	11	22	11	50
1991	3	4	2	15	24	9	36
1992	3	4	3	14	24	10	41
1993	3	5	5	24	37	13	35
1994	2	5	5	22	34	12	35
1995	3	7	9	20	38	19	49
1996	3	9	12	22	46	24	53
1997	3	8	11	30	52	22	42
1998	3	9	14	26	52	26	50
1999	4	11	19	34	68	34	50
2000	3	7	12	56	78	22	28
2001	4	9	14	41	68	27	39
2002	3	10	17	45	75	30	40
2003	3	9	15	44	71	27	38

* Close contacts are defined as the sum of companies with which the average manager has direct contact or can be reached through one or two intermediaries.

We now examine how US government policy impacted the formation and growth of the cluster. The expectation here is that, given that an appropriate institutional context exists to support radically innovative industries within the United States, policies aimed at the construction of new national institutional frameworks required to support biotechnology should not be needed. Rather, policies should build on a generally sufficient complex of institutions to create a sectoral support system (Mowery and Nelson 1999) focussed on the biotechnology sector. The following analysis supports this expectation. US public policy toward biotechnology primarily consists of supply-side policies driven by funding for biomedical research within universities complemented by a regulatory framework strongly supportive of the commercialization of science.

US Science Policy Toward Biotechnology

Drawing on the Mowery and Nelson framework, Henderson, Orsenigo, and Pisano (1999) have argued that the United States has developed a sectoral support system promoting industrial success in the pharmaceutical and biotech industries. This system has at least three components: support for open patterns of market competition and pricing toward patented pharmaceutical products that produce large markets for new drugs meeting unmet medical needs, regulatory frameworks overseeing the clinical testing and approval of new drugs, and science policy supportive of the development and commercialization of biomedical research. While the first two elements are extremely important in producing lucrative opportunity conditions for US pharmaceutical and biotechnology firms, the area of national policy most strongly impacting formation of early-stage biotechnology firms is science policy. Moreover, we will observe important differences cross-nationally in how science is commercialized, particularly in comparison with the UK. A brief overview of US science policy toward the biomedical sciences is thus warranted.

As documented by Kenney (1986), Murray (2004) and others, the boundary between pure and applied research in the biosciences became increasingly blurred from the 1980s onward, creating a reservoir of research technologies that could easily be applied to both basic research and commercial biotechnology problems. The quality of the science generating such new technologies has an important impact on the ultimate success of biotechnology firms. Zucker, Darby, and Brewer (1997) have the performance of biotechnology companies directly impacted links to "star scientists" defined through bibliometric measures. The United States is home to over 80 percent of such star scientists, in large part due to large federal government investments in basic biomedical research during the 1980s and 1990s.

During the late 1990s and early 2000s funding for biomedical research funneled through the National Science Foundation and National Institutes of Health climbed to over $20 billion annually, reaching close to $30 billion in 2005. This level of funding sustained large research complexes in hundreds of universities and research institutes within the United States. The generous funding of biomedical science within the United States has had important spillover effects toward the country's biotechnology industry. While this book has emphasized the importance of institutional frameworks impacting the financing, staffing, and organization of new technology firms, without the tidal wave of basic research in biomedical sciences created by US federal funding policies the size of the country's biotechnology industry would be much smaller.

In addition, federal research funding helped fund large numbers of graduate students and postdoctoral fellowships in the biomedical sciences.

The supply of Ph.D.-level scientists trained through federal funding programs appears to have far outstripped the availability of university research positions. This created an able labor supply for the US biotechnology industry. A study of career histories of several hundred graduates from cell biology laboratories within American universities found that 23 percent of alumni eventually took positions in industry. This figure raises to 30 percent of alumni of elite Howard Hughes Medical Institute laboratories (Casper 2003*a*).

In addition to financial support for research and training, the United States has developed a regulatory framework, through the 1978 Bayh–Dole Act, that has been widely praised as being conducive to the efficient commercialization of university science (Mowery et al. 2004). The Bayh–Dole Act transfers ownership of intellectual property for federally funded research to universities, who then have an obligation to steward and license intellectual property. The Bayh–Dole Act created a strong motivation for universities to develop technology licensing offices (TLOs). Offices are typically given responsibility to assess the commercial value of university research, develop patents to protect intellectual property on valuable research, and license these patents to either existing companies or to new companies founded to exploit them. The Bayh–Dole Act has spurred universities to patent license thousands of technologies. According to a review in *The Economist* (2005), in 2004 alone universities applied for over 10,000 patents and earned $1.4 billion in licensing fees. Moreover, in the first 25 years since the laws enactment over 4,500 firms have been spun out on the basis of patents generated as a consequence of the Bayh–Dole regulatory framework.

The existence of large endowments within many American universities encourages widespread licensing activities. In 2005, fifty-six American universities had endowments of $1 billion or more (Pope 2006). While endowment drawdowns are used to fund a wide variety of activities, many universities have used endowments to seed investment funds within technology transfer offices. In addition to covering the cost of hiring skilled licensing officers, long-term funding allows technology transfer offices to more easily sponsor spin-off companies from university laboratories. Sponsoring spin-offs is a higher risk but potentially more lucrative tactic compared to licensing technologies to established firms. The spinout option entails the universities take longer-term equity stakes in firms rather than immediate royalties for licenses. By taking equity stakes in such start-ups universities can adopt portfolio strategies similar to those adopted by VCs: some companies will fail, but companies that eventually reach IPOs can generate lucrative returns for universities.

A final federal policy of importance to the development of biotechnology companies is the availability of federal grants aimed at commercializing research offered through the Small Business Innovation Research (SBIR) program. The SBIR program mandates that federal agencies active in supporting research dedicate 1.5 percent of funding to grants aimed at commercialization projects. SBIR grants are often used to fund the development of early-stage companies based on university patents before venture capital funding is secured. Most grants have two components, an early "proof of principle" stage funded at less than $100,000 and a commercialization stage, with funding up to $500,000. While funding must be channeled to a commercial enterprise, such companies can be owned by universities and function as shells into which university laboratory technology aims to be spun off. SBIR grants are competitive and are screened by US governmental agencies to complement basic research funding; review panels at the NIH are responsible for selecting most biotechnology-related grants. While proposals must outline both scientific and commercial aims of the project, the use of NIH science review panels tends to bias reviews toward an evaluation of the scientific merits of a project. In 2003, the federal government funded $1.6 billion into over 6,000 SBIR grants, at an average of $270,000 per grant. About one-third of this funding, $525 million, was administered by the NIH for the commercialization of biomedical technologies (NIH 2006).

While most SBIR investments are small in size, there are several advantages of the program. Perhaps most importantly, it creates a mechanism by which hundreds of founding scientific ideas for firms can be explored, the best of which can then move on to venture capital funding. Funding often pays for one or more postdoctoral students within a university laboratory to work on commercial applications of a basic research project that is being commercialized. SBIR funding is a mechanism by which scientific founders of new companies, particularly laboratory personnel contemplating the move from basic to commercial science, can gain experience working on a commercial project, but typically within the confines of their current academic laboratories. This lessens the short-term career risk of experimenting with a commercial spin-off. If the project fails or is unable to receive further VC funding, it becomes easier to remain within the academic laboratory, returning to basic research projects.

SBIR funding can also positively impact the financial development of start-ups. In most cases the founding team of a potential new company use SBIR funding to secure early research milestones surrounding the technology, such as a preliminary technical proof of principle, without having to immediately turn to VCs. When the founders of new companies do seek venture capital funding, their projects are at a more mature and often less risky stage of development. In addition to reducing the risk exposure to VCs, companies that have had the chance to reach early research milestones may be assigned higher "pre-money" valuations by VCs. Start-up ventures will then need to relinquish less equity to receive a viable VC stake, which benefits the founders and provides more leverage to the company in seeking secondary investments.

US Science Policy and San Diego Biotechnology

Can the existence of an effective national support system surrounding biotechnology explain the existence of the San Diego biotechnology cluster? At the national level the United States has developed policies toward the funding and commercialization of science that is conducive toward the creation of science-based industry. San Diego is ideally suited to become a biotech hot spot due to existence within the region of a leading research university and two world-class biomedical research institutes.

The San Diego region has benefitted from federal policies toward the funding and commercialization of biomedical science. San Diego has long been home to several world-class biomedical research institutes, such as the Scripps Research Institute and the Salk Institute for Biological Studies, while the University of California, San Diego (UCSD) was founded in 1962 with the explicit aim of becoming the "MIT of the West" and has developed a medical school and strong departments in chemistry, biology, and other fields with links to biotechnology. The colocation in San Diego of this sprawling biomedical research establishment places the region in an ideal position to benefit from national science funding. In 2002, for example, San Diego science laboratories received $500 million in basic biomedical research grants, equal to about half of the $945 million in total science funding to the region. UCSD, Salk, and Scripps have also developed large technology transfer offices active in founding new biotechnology firms. Scripps has launched over forty companies since forming its office in the late 1980s. The Salk Institute has launched over 20 companies, and UCSD has generated over 120 start-ups, most focussed on biotechnology. Many of these start-ups have benefitted from the SBIR program. In 2002, 183 companies in San Diego received SBIR funding, totally $28.9 million (all figures from UCSD Connect 2004).

Is the existence of strong national policy toward the funding and commercialization of science, combined with appropriate national institutional frameworks, sufficient to explain the emergence of the San Diego biotechnology cluster? Returning back to Table 3.1, the San Diego cluster emerged relatively slowly over time; well over fifteen years occurred between the founding of the region's early entrants in 1978 and the existence of a cluster with more than fifty firms in 1983. This evidence supports the idea that a critical mass emerged slowly, perhaps as a result of the development of an effective process of commercializing science within the region. Referring back to Tables 3.2 and 3.3, venture capital and labor markets also grew incrementally over time, also supporting a gradual emergence theory. While not addressed systematically in this chapter, interviews with managers and scientists working within the San Diego cluster suggest that no local- or state-level policies aimed at the formation of a biotechnology cluster in the region existed during the 1980s. The only clear program aimed at supporting biotechnology within the region is a networking initiative developed by UCSD in the early 1990s called Connect that aimed at linking university scientists with entrepreneurs. In sum, there is strong evidence that San Diego biotechnology grew organically.

While attractive from the point of view of comparative institutional theory, the explanation that within LMEs technology clusters emerge from a confluence of appropriate national institutional frameworks and sector science policies with local research endowments cannot be viewed as a sufficient explanation. Within the United States there exist many more regions with world-class universities than biotechnology successful clusters. San Diego is one of three large biotechnology clusters in the United States, joining the San Francisco and Boston regions. While each of these areas do have large biomedical research endowments, so do many other regions of the United States which have failed to produce successful biotechnology clusters. The Chicago area, for example, is home to Northwestern University and the University of Chicago, both of which have leading biomedical research departments and teaching hospitals, but the region has not developed a sizable biotechnology cluster. The same can be said about the New York City region, which has failed to develop a presence in the biotechnology industry despite being home to Columbia University, New York University and, of particular importance for biomedical research, Rockefeller University. Finally, the Los Angeles region has several universities with large biomedical research departments and medical schools, and the California Institute of Technology, but has failed to develop a sizable biotechnology cluster.

National institutional explanations have difficulty explaining why there is so much spatial variation in the performance of technology clusters within the United States, particularly across regions with promising starting conditions for high-technology industry. Why have many regions failed to develop successful biotechnology clusters? The existence of regional heterogeneity in the success of US technology clusters, particularly across regions with seemingly appropriate endowments in university research, is an important problem facing varieties of capitalism theory.

The Problem of Regional Heterogeneity: Why so Few Successful Biotechnology Clusters in the United States?

Comparative institutional research has not systematically explored the issue of regional heterogeneity within national models. Potential explanations include differences in the ability of universities to develop effective technology transfer organizations, or the colocation of appropriate venture capital resources within a region (see Florida and Kenney 1988). A third explanation for the divergence in performance across US technology clusters begins again with Saxenian's emphasis on regional social structures facilitating mobility. While the technology transfer explanation has been generally unexplored, both the venture capital and labor market mobility explanations are consistent with varieties of capitalism theory. According to the logic of this argument, within LMEs there is a regional component to economic coordination that must develop surrounding high-risk finance, flexible labor markets, or perhaps an unidentified form of coordination, in order for a cluster of radically innovative firms to emerge. The rarity of successful biotechnology clusters within the United States suggests that such mechanisms of emergence might occur rarely.

While competing explanations exist surrounding the regional heterogeneity problem, we will focus our analysis of San Diego on the development of flexible labor markets. Within the field of economic sociology ongoing research has demonstrated the strength of this explanation in explaining the success of Silicon Valley's semiconductor industry compared to other US clusters. Saxenian's findings (1994) on Silicon Valley are strengthened by a comparative study of a similar cluster of semiconductor and computer companies centered around Route 128 in Boston.

Saxenian argues that the declining fortunes of Route 128's computer and semiconductor industry during the 1980s was influenced by autarkic practices of long-term employment within its companies that hindered the creation of flexible labor markets, coupled with very limited informal sharing across firms through social networks.

In recent years, economic sociologists have strengthened Saxenian's account through further comparative studies. A study by Fleming, King, and Juda (2006) used patent data to examine the formation of social networks across inventors within Silicon Valley and the Route 128/Boston area. This study demonstrates that large and well-connected social networks linked Silicon Valley inventors from the early 1980s onward, but were small and less-connected in the Boston area until the recent emergence of its biotechnology cluster. Almeida and Kogut (1999) developed a quantitative study using patent data from twelve US semiconductor clusters. In their study, patent data was used to gather information on levels of interfirm mobility of inventors within each cluster and as an indicator of aggregate innovativeness. Their study again supported the mobility argument, showing that only Silicon Valley had both high levels of job mobility and markedly higher levels of patenting. Due to their ability to provide data comparing a dozen clusters, Almeida and Kogut provide persuasive evidence that achieving high mobility within a cluster might be rare and, moreover, strongly linked to the innovative performance of companies within a cluster.

From a theoretical perspective, an attractive aspect of the career mobility and social network explanation is that it can explain both success and failure cases. The explanation is similar to a game theoretic equilibrium model. It links the rational behavior of talented individuals to different labor market equilibriums which are then linked to the generation of different innovative capacities for companies. High levels of interfirm mobility help diffuse technology across companies and, from the point of view of skilled personnel, generate the formation of social networks that can be used to offset the career risk of leaving a "safe" job to work in a high-risk start-up. However, most localities have neither the agglomeration of firms and people nor the social ties needed to sustain high-risk firms. In such regions, key personnel are unable to reduce the risk of participating in a high-risk firm. This leads to a second, much more common equilibrium—that of failed cluster development. Within most regions social networks promoting extensive career mobility do not exist. From the career perspective, leaving a safe job in an established company or university to join a start-up truly is a high-risk proposition that most will choose not to do. It becomes easier to understand why most localities fail to develop successful technology clusters: talented individuals might populate a region, but they face a collective action problem. They lack the appropriate social ties needed to reduce the risk of working within a high-risk venture.

Studies linking clusters of highly innovative companies to social networks encouraging mobility have been conceived primarily at the regional level of analysis. However, national institutional framework conditions seem likely to impact the ability of local actors to generate the patterns of labor market mobility needed to sustain radically innovative firms. Within LMEs deregulated labor markets and shareholder dominated corporate governance conduce toward extensive labor market mobility. Most regions within the United States could lack the supportive regional social network needed to sustain clusters of radically innovative firms. Skilled personnel working within these regions then face the decision of locating a relatively "safe" job if living in a region lacking social structures promoting mobility or of relocating to a region that does. The pronounced agglomeration effects seen in the career mobility data from San Diego support this view: many of the San Diego senior managers had industrial experience at large firms located elsewhere in the United States and eventually made career transitions into San Diego biotechnology. Less understood, however, are the mechanisms that can "tip" a region into a social network equilibrium supporting radically innovative firms.

Mechanisms of Emergence: The Role of Founder Networks in Seeding San Diego Biotech

The rarity of well-performing clusters, even within nations with supportive national institutional frameworks, suggests that the emergence of appropriate social infrastructures is a difficult problem, perhaps one rarely solved. A key issue then becomes one of emergence. How do individuals within a region develop the social infrastructure needed to sustain agglomeration of high-risk firms? This issue, of moving essentially from "nothing" to the generation of a decentralized social infrastructure capable of diffusing innovation and facilitating career management, has been largely ignored in studies of high-technology clusters. Yet the issue is crucial in terms of identifying potential policy instruments that may be used as a mechanism to stimulate cluster development. While we can only examine the San Diego case closely, mechanisms identified through this case can be useful for comparative studies.

The San Diego biotechnology cluster, and the social ties between managers and scientists supporting it, developed organically over a twenty-year period. This growth dynamic supports explanations positing that social networks develop slowly or incrementally. Early entrants to a cluster might be particularly risk acceptant individuals. Over time, they could seed a nucleus of companies and establish social ties between them. It is possible that, after reaching a certain size and rate of mobility, a tipping point could be reached whereby the cluster becomes sustainable and regional innovation effects begin to accrue. Once sustainable, agglomeration effects might become established as jobs within the cluster become attractive to more risk adverse individuals.

A difficulty with this explanation is that social network effects may only be pronounced once a large number of individuals participate in the network; benefits may only develop as social networks become relatively large and efficiently organized. If so, early pioneers within a cluster may be particularly failure prone. Early failures are likely to be much more costly, in terms of their effects on network growth, than later failures. If so, nascent technology clusters might never reach the critical mass to become sustainable. This could lead to the outright collapse of a cluster or the decision by individuals and companies to abandon radically innovative strategies in order to pursue safer and more incremental innovation strategies.

Given the organic pattern of growth in San Diego, a key issue to investigate is whether a mechanism developed to overcome such early collective action problems. Through coupling network analysis with a closer analysis of the history of the cluster's key firms it is possible to examine the mechanisms by which the network emerged. One frequent catalyst of a network's development is the emergence of what network theorists call a "backbone" or group of initial ties that later entrants to a network can latch on to, stimulating the growth of a cohesive network. An interesting finding in San Diego is that a network backbone did develop, and can be attributed almost entirely to the career strategies of a set of senior managers with ties to Hybritech, the prominent early San Diego biotech company acquired by Lilly in 1986.

The Lilly acquisition of Hybritech is now routinely called a failure, but a tremendously beneficial one in terms of the emergence of San Diego biotechnology. The acquisition had the immediate effect of transforming Hybritech's top management team, all of whom owned shares in the company, into extremely wealthy individuals. As part of the acquisition, the top management team was encouraged to remain, but Hybritech became a subsidiary of a large Indiana-based pharmaceutical company with a relatively conservative managerial ethos. Hybritech had developed a free-flowing, informal corporate culture typical of technology start-ups. This created immediate clashes with the Lilly managers. Tina Nova, one of the senior scientists at Hybritech, reflects that "It was like "Animal House"' meets "The Waltons" (Fikes 1999). Lilly also began a practice of rotating established managers into and out of the Hybritech facility at frequent intervals, making it difficult for the original Hybritech managerial crew to develop working relationships with the Lilly managers. Lilly was ultimately unable to integrate Hybritech's management and scientific team into its corporate culture, and in the years immediately following the acquisition most of the former Hybritech senior managers, including all managers located within the San Diego career history database, left.

The cadre of former Hybritech managers are now widely credited within San Diego for "seeding" the San Diego biotechnology industry. These managers had the financial resources, managerial experience, and a reputation for developing one of the biotechnology industry's early and rare success stories. Numerous important San Diego companies were founded by former Hybritech managers, including Amylin, IDEC, Gensia, Gen-probe, Ligand, Nanogen, Immune Response, and Biosite. Taking into account a wider set of venture capital and advisory board ties, a report by the UCSD Connect Organization (2003) identified fifty San Diego biotechnology companies with links to Hybritech personnel.

Hybritech managers also played a pivotal role in the development of well-connected social networks linking senior managers and companies in San Diego. This group of managers could serve as a reliable and trusted referral network to one another. Their credibility as successful biotech entrepreneurs was also important in recruiting highly skilled individuals to join San Diego start-ups to which the Hybritech managers were linked. Figure 3.1 illustrates the importance of Hybritech managers in the development of cohesive social networks within San Diego. It compares the average number of ties held by each manager, a statistic known as degree centrality, of managers who had worked at Hybritech at some point during their career versus the average degree centrality of all other managers for the years 1980–2004. Figure 3.1 shows that during the period between 1986, when Hybritech was acquired, and 1995 the Hybritech alums had a dramatically higher number of ties within the network than other managers, evidence that these managers formed the crucial "backbone" of the network which facilitated the longer-term growth of social ties within the San Diego biotechnology cluster.

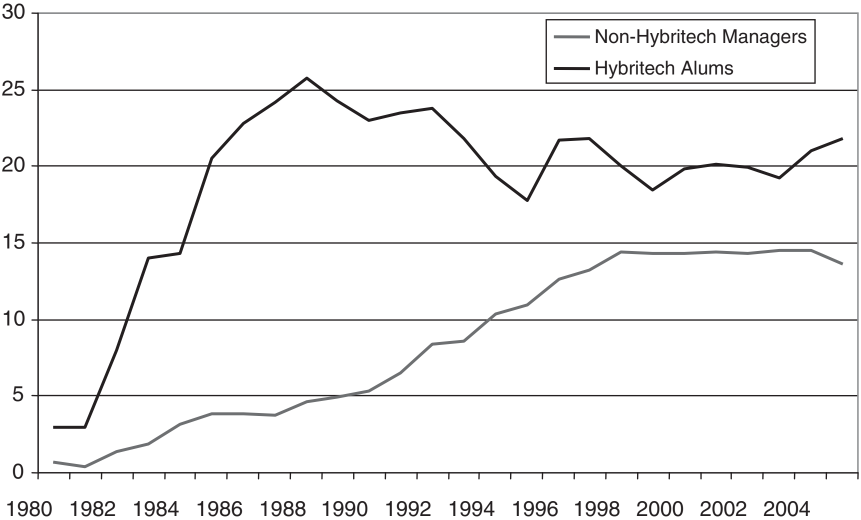

Figure 3.1. Degree centrality of Hybritech alumni and all other managers within San Diego biotechnology, 1980–2005

In sum, the activities of the former Hybritech managers in seeding the region's biotechnology industry help explain how the collective action problem surrounding cluster generation was resolved. Through both seeding a generation of follow-on companies to Hybritech and, through mobility to and from these firms, creating a web of social ties across the new firms, a credible network backbone emerged. Referring back to the earlier game theoretic analogy, career expectations across senior managers within San Diego "lipped" from out of the low commitment equilibrium into one where it made sense for highly skilled individuals to take jobs within regional biotech start-ups.

Summary and Implications for Comparative Analysis

This chapter has examined how the San Diego biotechnology industry emerged and became sustainable. The sustainability issue allows a direct examination of whether institutional frameworks emphasized by proponents of the varieties of capitalism approach can be linked to a comparative institutional advantage for radically innovative biotechnology firms in the San Diego area. There is strong evidence that institutional frameworks within the United States facilitate patterns of financial and labor market coordination linked to the Silicon Valley template of organizing radically innovative firms. San Diego biotech firms are able to use venture capital and IPO markets as mechanisms for high-risk financing, develop high-powered incentive structures based on share ownership to motivate employees, and draw on large socially cohesive labor markets of mid-career professionals to employ skilled workforces in failure prone environments.

The policy context surrounding the development of San Diego biotechnology is relatively benign. While benefiting enormously from federal science policies and a supportive regulatory environment favoring the commercialization of science, no direct governmental policies were directed at cluster creation in San Diego. Instead, the cluster appears to have developed organically, seeded through the activities of a network of founders and senior managers emerging from the failed acquisition of Hybritech. Comparative studies of cluster performance in the United States suggest that radically innovative clusters only succeed when social structures supporting mobility develop. Network analysis suggests that the Hybritech founder network created a sustainable and credible social network backbone, which other firms and their managers could use to support high-risk firms.

If cluster development depends on the formation of social networks that have primary origins through shared career experiences, what is the role for governments? Governments across the world are spending large sums of money in attempts to orchestrate the development of technology clusters. In the field of biotechnology, these policies usually link subsidized venture capital with policies to encourage and hasten the commercialization of university science. What is worrying about these plans is that there is little empirical research suggesting that the social networks underpinning the development of clusters of high-risk entrepreneurial firms can quickly be orchestrated by nonmarket activities. Can governmental policies provide alternative mechanisms for social network creation within clusters? We now turn to Germany, a country experimenting with some of the world's most expansive technology policies toward biotechnology.

4

The German biotechnology industry: the limits of orchestrated innovation

Germany has long been categorized as an "'organized" or "coordinated" economy (Shonfeld 1965). German institutions facilitate the creation of organizational competencies necessary for firms active in sectors characterized by incremental innovation processes within established industries, such as many segments within the metalworking, engineering, and chemicals sectors (Streeck 1992). Deep patterns of vocational training within firms, consensual decision-making, long-term employment, and patient finance are all linked to the systematic exploitation of established technologies to a wide variety of niche markets, a strategy Streeck (1992) labels 'diversified quality production'. Due to this institutional figuration, a consistent prediction made by scholars interested in cross-national comparisons of capitalist economies is that the German economy should perform poorly in generating radically innovative companies (see Hollingsworth 1997; Hall and Soskice 2001; Casper and Whitley 2004). Whether it is finance, labor markets and industrial relations, or corporate governance, Germany appears to lack institutions to systematically nurture the development of entrepreneurial competencies.

Evidence from studies examining the performance of German high-technology industry during the 1980s and 1990s is consistent with this prediction, arguing that German performance in biotechnology and software was poor (see Streeck 1996; Casper and Vitols 1997; Soskice 1997; Casper, Lehrer, and Soskice 1999). To support their concept of institutional comparative advantage, Hall and Soskice (2001) present patent evidence from 1984 and 1994 showing that, compared to other OECD nations, Germany patented more in machine tools and other industries characterized by incremental innovation patterns and much less than the average OECD country in the more radically innovative sectors. Moreover, the Hall and Soskice data suggest that the German pattern of specialization toward incremental innovation and away from radically innovative industries increased from 1984 to 1994. In sum, the theory of comparative institutional advantage appeared to be well supported by both industry case studies and broader economywide statistics.

In the mid-1990s, however, the German government introduced a series of new technology policies designed to orchestrate the development of small entrepreneurial firms. By the end of the 1990s these policies had fostered several hundred high-technology start-up firms in Germany, many of which are pursuing strategies that differ dramatically from those commonly associated with small- and medium-sized German firms. One of the more impressive sectors experiencing rapid growth was biotechnology, in which a tiny industry of less than two dozen firms grew, within a few years, to a size of between 300 and 400 firms, mostly located in regional technology clusters that at least superficially resemble Silicon Valley and other US clusters.

The rapid growth of German high-technology industry poses an important challenge to theories arguing that the innovative capabilities of organizations are strongly impacted by the orientation of national institutional frameworks. If relatively large clusters of radically innovative firms are found to be located and performing well in Germany, this would be strongly contradictory to the expectations of institutional theory. The link between national institutions and the governance of innovative competencies might be much less directly envisioned by the broad varieties of capitalism research school. Institutions may be epiphenomenal or, at best, one of many mechanisms companies can draw on to support innovative competencies. Moreover, governmental policy has had an influential role in both providing resources and attempting to develop new institutions to better support the needs of high-technology industry. If found to be successful, such evidence would falsify the expectation that within CMEs government policies aimed at reconfiguring institutions to better support radically innovative industries should fail. While of course only one country case among many, Germany has long served as the ideal-typical model for an organized economy within the broad comparative capitalism tradition. If key assertions linking the structure of this economy to the innovative activities of its companies were shown false, this evidence would be damaging, particularly to the varieties of capitalism perspective.

Focussing on biotechnology, this chapter examines the development of the German biotechnology industry between 1995 and 2005. As the growth of this industry within Germany is clearly a result of governmental policies, the chapter begins with a discussion of these initiatives, particularly as they relate to the crafting of new institutions and support systems surrounding biotechnology, and their success, at least in terms of generating large numbers of companies that are pursuing radically innovative trajectories. The remainder of the chapter then investigates the sustainability of the German industry in terms of the availability of high-risk finance to companies, the existence of credibility of high-powered performance incentives within firms, and the existence, within Germany, of labor markets capable of supporting competency destroying innovation strategies.

Germany's "Innovation Crisis" and Response

By the mid-1990s the success of Silicon Valley and other US technology clusters promoted calls that Germany faced an innovation crisis. Politicians from both the left and the right bemoaned Germany's inability to develop entrepreneurial new technology firms. A 1995 statement, from Joshka Fischer, leader of the Green Party and future foreign minister, that "A company like Microsoft would never have a chance in Germany" (cited in Audretsch 2000) characterizes the general mood. Success in new technology industries became associated with innovation, economic growth, and, above all, the creation of new high-wage jobs within a country reeling from high unemployment and the related challenge of unification. Promoting innovation became a rare unifying goal of both the left and right parties in Germany. Over the ensuing years first the right-leaning Christian Democratic Union (CDU) and eventually the left-oriented Social Democratic Party (SDP) would direct government resources, and with it, political fortune, toward the development of new technology industries.

While new technology policies would be extended toward a variety of high-tech sectors, biotechnology became the most heavily promoted sector. There was a solid rationale to focus on biotechnology. The country had an established record of investment in basic biomedical research through both teaching universities and the funding of several Max Planck Society institutes focussed on the life sciences. During the late 1990s a study by the Wellcome Trust ranked Germany third, behind the United States and UK, in biomedical research productivity (Wellcome Trust 1998). As most biotechnology firms have founding links to university science, which was linked to public funding and control, the government could plausibly aim to develop relatively focussed policy instruments to encourage the commercialization of science.

Germany also had a world-class pharmaceutical industry. Germany's big three pharmaceutical companies, Hoechst (now Aventis), Bayer, and BASF employed over a hundred thousand people, led Europe in the export of medicines, and had produced several so-called blockbuster drugs capable of capturing over a billion dollars in world revenues (see Casper and Matraves 2004). Hoechst and Bayer both had established records of forging partnerships with biotechnology firms, though primarily with biotech firms located in the United States (Casper and Matraves 2004). Sophisticated demand for biotechnology products and research methods thus existed in Germany and would presumably support the creation of a local biotechnology industry.

In the summer of 1995 Jurgen Ruttgers, a high-ranking CDU politician and minister responsible for leading the German governmental bureaucracy overseeing research and education (the BMBF), traveled to the international biotechnology industry conference (BIO) and, in a keynote address, announced that Germany would become Europe's 'leader' in biotechnology by the turn of the new millennium, in five years. This was a remarkably bold statement, given the embryonic state of German biotechnology at the time and the existence of a relatively mature biotechnology industry in the UK. Only a handful of German companies existed at the time, most tiny firms performing contract research and reagent supply for the pharmaceutical industry. In addition to the various national institutional obstacles, prior to 1993 the German government enforced stringent regulations governing recombinant DNA research, regulations which were widely characterized as designed to halt commercial genetic engineering firms from being launched in Germany (Müller and Rump 2002). While in 1993 Germany adopted a voluntary system of company self-governance modeled on the US system, the regulations were widely perceived as leaving German competencies in recombinant DNA methods significantly behind the United States and UK.

Following Ruttgers' speech, German policymakers developed a relatively coherent framework to organize technology policies toward the new economy, which can be summarized as the resource orchestration view (Casper 2000). The rationale behind this perspective is found in an influential report by the Munich-based IFO-Institute, a respected voice on German competitiveness issues: 'If there is an "innovation crisis" in Germany, then this "crisis" is due . . . to a high degree of inertia in shifting capital investments, human resources, and existing ingenuity talents from traditional to new high-tech areas promising higher growth rates in the future.' (Büechtemann and Ludwig 1997: 36; see also Audretsch 1995). The implication of the resource orchestration view is that the government should search for obstacles blocking innovation processes within particular sectors and introduce new policies to transfer resources to and orchestrate the coordination of the necessary linkages within the innovation chain (see Lehrer 2000). Debate centered on the development of policy instruments capable of shifting resources (people, finance, and infrastructure) away from declining industries and toward those represented by new technology industries, particularly biotechnology and software.

A focal point of the new policies was generating spinout companies from universities. In Germany, the relationship between universities and the private sector is strong, but the primary technology link has been the licensing of technology to large firms (Abramson et al. 1997). Until the early 2000s, under German law professors owned most intellectual property and generally commercialized research through long-term relationships with established firms. The system was geared toward applied technology fields, such as engineering. Firms would sponsor a professor's research, which often included the provision of stipends for graduate students, in return for the opportunity to license any intellectual property that resulted. Lacking ownership of IP, German universities have had little incentive to establish technology transfer offices. This framework creates poor incentives for the commercialization of more basic research, such as much biomedical science, in which start-ups typically spend several years commercializing new research findings, often in close contact with founding university laboratories, before technology can easily be applied to product markets. As a result, research within the biomedical sciences and other basic research fields has recently been conducted with minimal attention to possible commercial spin-offs (see Asakawa and Lehrer 2004 for a broader discussion).

Taking careful note of these and other perceived obstacles to the establishment of small entrepreneurial start-up firms, German public officials crafted a dense network of support policies for university-centered spin-offs. As part of a federally funded 'BioRegio' competition that began in 1995, numerous German regions created government biotechnology promotion offices. Three programs, in Munich, Heidelberg, and Cologne, won \$35 million grants to support technology programs. Fourteen additional regions submitted proposals and, to varying degrees, secured regional government support for biotechnology promotion policies. A follow-up program called "BioProfile" was launched in 1999. Funded at about $150 million, it allows regions to apply for federal funds aimed at developed regional research strengths, for example, in genomics or plant biotechnology. By the early 2000s there were at least twenty-five organized biotechnology cluster promotion efforts in Germany (Asakawa and Lehrer 2004).

The new biotechnology promotion offices generally aim to help scientists and local entrepreneurs organize every phase of start-up formation within the biotechnology sector. This includes the hiring of consultants to persuade university professors or their students to commercialize their research findings and help them design viable business plans, subsidies to help defray the costs of patenting their intellectual property, and the provision of management consulting and partnering activities once new firms are founded. Most of the BioRegio programs have used public funds to create new technology parks and "incubator laboratories" to house fledging start-ups in and around universities or public research laboratories.

The technology transfer offices created through the BioRegio programs are also responsible for the disbursement of an array of grants, loans, and subsidy programs created in recent years for high-tech start-ups. Programs typically include support for patent applications, free or subsidized rental space in technology incubators and science parks, and access to a variety of short courses and networking events aimed at convincing university scientists to participate in new ventures. Both the federal and regional governments also provide grants that are similar to those provided through the US SBIR program, primarily research grants aimed at creating resources for academic laboratories to create necessary "proof of principle" needed to secure private venture capital. Funding initiatives have been launched on revolving two- to-three year periods by the BMBF. For example, one of the core programs launched in 1995 in connection with the push toward biotechnology was a $200 million research initiative in genome analysis. A more recent cycle of programs, launched in 2003, targeted about $400 million in grant aid for commercial research in tissue engineering, nano-biotechnology, bioinformatics, systems biology, genomics, and biomanufacturing (BMBF 2004).

While noteworthy for their comprehensive nature, regional governments around the world have long been active in funding technology transfer activities surrounding universities. A second, striking feature of the new German policies, however, is the government's willingness to become strongly involved in financing German start-ups. In 1996 the federal government, wary of criticisms of the lack of venture capital

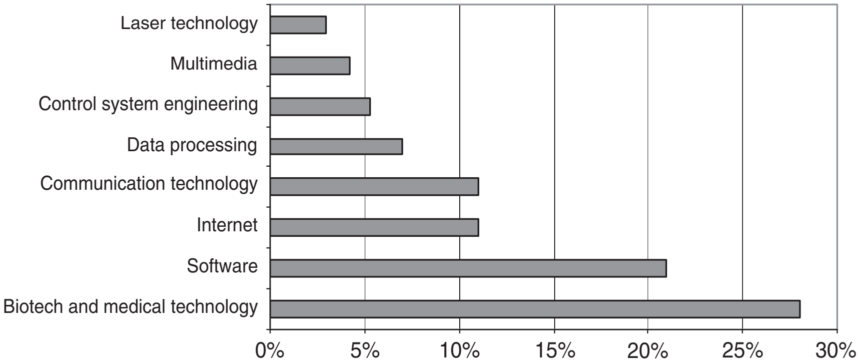

Figure 4.1. German public venture capital by sector, 1998
Source: *tbg* (2001).

in Germany, decided to provide "public venture capital" in the form of silent equity partnerships from federal sources (see Adelberger 2000). The agency set up to administer the program, the *Technologie Beteiligung Geselleschaft* (*tbg*), was responsible for distributing about a $1 billion in public venture capital investments over the 1996–2000 period, distributed to several hundred start-up companies. In line with the resource allocation perspective, the aim of the policy was explicitly to encourage start-ups in new technology sectors.

Figure 4.1 shows the sectoral distribution of investments for the year 1998, in which biotechnology, software, and Internet start-ups received the majority of funding. Biotechnology was the most supported sector within the program; $527 million was invested in several hundred biotechnology firms between 1996 and 2000 (Boehm and Schuehsler 2003; see also BMBF 2001*a*, 2001*b*). Much less funding went to more 'medium technology' industries, such as control systems engineering or lasers, in which German firms had a preexisting competitive advantage. This is in line with the resource orchestration view: the aim of the policy was to forge competitive advantage for German firms in new technologies.

The *tbg* program also aimed to encourage the development of venture capital firms in Germany. Federal funds were only provided to start-ups capable of securing matching private investments. Private sector venture capital firms were asked to serve as lead investors, performing due diligence on proposed start-ups, and taking the lead in assigning the so-called "pre-money" valuation which determined the division of equity ownership between founders and investors once capital was infused into the company. The federal government took the role of silent partner, obtaining an equity stake and the right to invest in future offerings, but not becoming directly involved with the governance of the firm.

The program had obvious appeal to potential VCs. Public funding could dramatically reduce investment risks, both through increasing the leverage of individual investments (i.e. firms would need to invest less to ensure that new ventures were adequately capitalized) and, through doing so, allowing firms to diversify risks through expanding the number of firms they could invest in with a given fund. In the biotechnology sector these effects were further magnified by the formation of quasi-public venture capital arms within regional biotechnology development initiatives. Both the Heidelberg and Munich offices, for example, used funds secured through winning the BioRegio competition in part to invest in area start-ups. This meant that many biotechnology firms received $2 in public investments for every $1 of private venture capital secured.

Following the success of the American NASDAQ exchange, the German venture capital subsidy programs were coupled with initiatives to develop a technology-oriented stock market. If successful, this market would allow firms to raise further funds and, importantly, create viable exit options for VCs and other investors that are widely perceived as necessary to sustain long-term investing in new technology sectors. The German government worked with the financial community to introduce measures designed to stimulate the provision of higher-risk investment capital and allow technology firms to undertake rapid growth trajectories commonly seen within American technology clusters. The most important initiative was the creation in 1997 of a new stock exchange, the *Neuer Markt*, with substantially less burdensome listing requirements than those that exist for the blue-chip Frankfurt stock exchange. Moreover, in March 1998 the government succeeded in passing legislation allowing firms to more easily buy and share shares in their stock, a reform passed with the intent of facilitating the widespread use of stock options as incentive devices within German firms (Cioffi 2002).

Definitive government statistics on public spending toward biotechnology have not been published. An estimate frequently given during interviews, however, is that German federal and state governments have steered over $3 billion during the 1995–2001 period toward a variety of initiatives designed to spur the growth of biotechnology start-ups. This includes funding for the twenty-five regional biotechnology promotion programs, most of which have also received funding for publicly owned technology parks and incubators, and funds provided to firms through the public venture capital programs and through research grants.

Table 4.1. German biotechnology industry dynamics, 1994–2004

	Number of companies	Entrants	Exits	Employment
1994	52	n/a	n/a	n/a
1995	75	23	0	n/a
1996	104	29	0	n/a
1997	173	69	0	4,013
1998	222	49	0	5,650
1999	279	57	0	8,124
2000	332	59	6	10,673
2001	365	44	11	14,408
2002	360	25	30	13,400
2003	350	23	34	11,535
2004	346	n/a	n/a	10,089

Source: Ernst & Young (2000b, 2004).

Germany's Emerging Biotechnology Industry: Is It Sustainable?

By all accounts Germany's new programs were successful in stimulating the widespread entry of new technology firms. Hundreds of start-ups were launched in Germany (Ernst & Young 2002), with biotechnology among the most vibrant sectors. Table 4.1 displays industry survey statistics on the size of the German biotechnology sector in terms of number of firms and employment between 1994 and 2004. The figures show a sharp rise in the number of firms during the late 1990s, leading to a peak of 365 firms employing about 14,000 people at the height of the boom in 2001. The German biotechnology sector was strongly impacted by the bursting of the Internet bubble in late 2001, leading to a slight decline in firms during the 2001–4 period, and a dramatic scale back of employment down to about 10,000 people. Nevertheless, there can be no doubt that German policymakers met their goal of creating a substantial biotechnology industry.

The new biotechnology start-ups also appear to have specialized, at least during the 1997–2001 boom period, on radically innovative therapeutic discovery markets. In 2002, for example, 65 percent of German firms, or about 240 total, were focussed on developing new drugs. These firms have succeeded in generating a plausible pipeline of drugs. Table 4.2 displays data on German clinical trials pipelines for the 1999–2004 period, along with comparison figures from San Diego. While the majority of German clinical compounds are still in the early, and less costly, preclinical stages, again there can be no doubt that a large number of German firms are attempting to innovate in therapeutics.

Table 4.2. Pipeline data for German and San Diego therapeutic biotech

	Preclinical	Stage 1	Stage 2	Stage 3	Approved
1999	69	11	15	0	0
2001	122	27	27	4	0
2002	117	34	22	4	0
2003	133	38	26	5	1
2004	160	33	38	9	1
San Diego 2005	n/a	26	73	27	27

Sources: German data from Ernst & Young (2000*a*, 2000*b*, 2002, 2004, 2005*a*, 2005*b*); San Diego data compiled from company websites.

Is the German industry sustainable? A key issue is whether the government aim of developing an environment capable of supporting radically innovative technology companies has been created. To help answer this question, the varieties of capitalism framework will be used to explore whether patterns of financial coordination, employee incentive creation, and labor market coordination can readily sustain therapeutic biotechnology companies. The German biotechnology industry has experienced both a boom and bust cycle associated in part with the rise and decline of the Internet sector during 1997 through 2002, creating a good baseline for analysis of the sustainability of the country's newly expanded biotechnology industry.

To investigate whether the Silicon Valley model of developing companies has taken hold within the German biotechnology industry, publicly available information from surveys of the German industry will be combined with descriptive statistics and insights from interviews designed specifically to evaluate the sustainability of the German biotech sector. Beginning in 1995 the German subsidiary of the management consultancy Ernst & Young has published periodic surveys of the German biotechnology industry. These reports used standard definitions of biotechnology firms and industry dynamics drawn from long-standing reports prepared by Ernst & Young on the United States and European industries and are thus reliable and generally used within the business press to discuss the health of the industry.

To gather additional information on employment patterns within German firms, data were gathered on all companies found to have published at least one scientific article that was located within the four largest German biotechnology sectors, Munich, Berlin, Cologne, and Heidelberg, during the 1998–2000 period. Publishing was used as a screen in order to focus on companies with a clear orientation toward science-based industry and also allows identification of scientists working within firms. Forty-two companies were identified using this method, which includes most of the larger companies, defined within Ernst & Young statistics as firms with more than thirty employees, across these regional clusters. Career histories were obtained for all publishing scientists as well as senior scientists employed with the firm and listed on company web-pages. These histories were obtained through subsequent bibliometric searches on individuals using the *Web of Science* and, in some cases, Google searches. In sum, career history information was obtained for 299 individuals, 82 of which were senior scientists listed on company websites and 217 of which were presumably more junior scientists located through bibliometric searches.

Finally, during the 1998–2000 period background interviews were conducted with managers, financiers, and government officials working within German biotechnology. This included interviews with managers employed by a dozen biotechnology firms located within the Munich, Heidelberg, Cologne, and Berlin clusters, public officials working within biotechnology promotion offices in each of these clusters, partners with two Munich-based venture capital firms, and an official working on the federal public venture program at the *tbg*.

Financial Coordination

Through focussing on the expansion of venture capital and the creation of a NASDAQ-style market for high-risk technology offerings, the German government attempted to create a system of high-risk financing closely attuned to the LME model. It is important to emphasize the starting point: Germany in the mid-1990s had a decidedly credit-based system of financing oriented toward providing "patient finance" to firms in traditional sectors with relatively low long-term risk. Data from 1996, for example, reveals that market capitalization as a percentage of GDP in Germany was only 21 percent compared to 121 percent in the United States (*Deutsche Bundesbank* 1997). Within credit-based financial systems most R&D investments not easily secured against capital assets are funded through retained earnings. This strategy of funding R&D is difficult, of course, for development stage technology start-ups lacking such earnings. Moreover, although Germany's Frankfurt Exchange was a well-established stock market for large, blue-chip companies, the nation had no tradition of funding small- and medium-sized companies through stock offerings.

The *Neuer Markt* would, within the German context, be a bold experiment in equity financing.

German financial markets underwent a boom period, lasting from 1996 until 2001, in which the comprehensive financial incentives offered by German technology policy programs were reinforced by a global wave of enthusiasm for technology start-ups associated with the explosive growth of the Internet. This was followed by a period of retrenchment, precipitated by the decline in the US Internet stock boom in early 2002. To examine the sustainability of entrepreneurial financing patterns in Germany, we examine biotechnology-related venture capital and IPO activity through both the boom and bust, and then examine ongoing financing prospects for companies in both the growth and early start-up phase during the mid-2000s, a period when venture capital and IPO markets had generally recovered within the United States and other LMEs.

Fueled in part by the global Internet-related boom of the mid-to-late 1990s, the federal public venture capital quickly precipitated a dramatic expansion in German venture capital. Figures obtained from the German Venture Capital Association document these trends (the following draws from Casper 2003*a*, 2003*b*). While only a handful of VCs existed in Germany in the early 1990s, by 2000 there were 320 registered members of the association. While this figure includes numerous private and state-owned banks involved with venture capital and investment banking, several dozen venture capital firms were formed in the late 1990s. The size of reported funds held by VCs for future investments rapidly escalated, from less than $4 billion in 1995 to close to $8 billion in 1998 and over $16 billion by the year 2000. Much funding was steered toward higher-risk early-stage investments. In 1995, for example, less than 15 percent of total German VC investments were for start-ups; this figure had increased to close to 40 percent by 2000. Finally, there was a dramatic increase of funding for new technology firms. While in 1994 less than 10 percent of VC investments were allocated to companies in biotechnology, information technology, and communications, funds allocated to these sectors increased to over 50 percent by 2000.

Table 4.3 reports on biotechnology-related venture capital in Germany for the 1990–2005 period. During the early years of the program the major emphasis was on starting new companies, and the federal public venture capital investments were generally only available to new start-ups. The data for 1998 and 1999 from Table 4.3 illustrate this trend. In 1998, $232 million followed into 105 companies, while in 1999, $366 million flowed into 148 companies, creating average deal sizes of $2.2 million and $2.5

Table 4.3. Venture capital investments to German biotechnology companies, 1990–2005

	Private VC ($ million)	German 'public' VC/*tbg* ($ million)	Total German VC ($ million)	Number of deals	Avg. deal size ($ million)
1990	7	0	7	n/a	n/a
1991	19	0	19	n/a	n/a
1992	15	0	15	n/a	n/a
1993	12	0	12	n/a	n/a
1994	29	3	32	25	1.3
1995	16	7	23	n/a	n/a
1996	59	6	65	n/a	n/a
1997	61	27	88	n/a	n/a
1998	148	84	232	105	2.2
1999	247	119	366	148	2.5
2000	505	193	698	93	7.5
2001	497	93	590	70	8.4
2002	180	15	205	45	4.5
2003	233	0	233	42	5.5
2004	295	0	295	33	8.9
2005	308	n/a	308	n/a	n/a

Sources: Boehm & Schuehsler (2003); data on number of deals from 1998 and 1999 from Ernst & Young (2000*a*, 2000*b*).

million for these two years. Most investments during these years were for early-stage start-ups, which typically received about $1 million in private venture capital, up to $1 million in federal funds, and for some firms, additional investments from state government promotion programs.

The data for the years 2000 and 2001 present the most optimistic scenario that the technology promotion plans were on their way toward creating a viable venture financing mechanism for German biotech. The state financing program reached its peak of activity, making close to $200 million in investments in 2000 before tapering off to $100 million in 2001. However, private venture capital investments increased to about $500 million for both years, and the average deal size increased to $7.5 million in 2000 and $8.5 million in 2001. This suggests that numerous companies were able to receive sizable rounds of secondary funding. A few relatively high-profile firms, such as the Munich-based antibody therapy firm Micromet, and Cellzome, a functional genomics firm located in Heidelberg, were able to raise $30 million each in secondary funding during these years. At this stage both firms were years away from potentially launching drugs. As these secondary funding rounds generally included no public venture capital subsidy funds, they could be interpreted as evidence that a sustainable VC industry capable of making long-term investments in radically innovative firms was emerging in Germany.

Table 4.4. Initial public offerings and related stock market activity of German biotechnology firms, 1997–2005

	IPOs	Total listed companies	Funds raised through IPOs ($ million)
1997	0	0	0
1998	0	0	0
1999	5	5	93
2000	10	15	655
2001	1	16	21
2002	0	16	0
2003	0	8	0
2004	1	9	50
2005	2	10	116
Total	18		935

Sources: Ernst & Young (2000*a*, 2000*b*) and company web-pages.

An important reason for the growth of venture capital, and in particular the availability of relatively large secondary offerings, was the rapid success of the *Neuer Markt* stock exchange during the 1998–2001 period. The German *Neuer Markt* was one of several new stock exchanges launched in Europe during the late 1990s, and the most successful, sponsoring 279 IPOs by its peak in 2001 (Vitols and Engelhardt 2005). The *Neuer Markt* was particularly strong in software, with over sixty firms listed, many of which, as we'll see later in Chapter 6, were established and profitable enterprise software companies using IPOs to fund expansion activities. Due to their relatively young age, fewer biotechnology firms successfully took *Neuer Markt* during the 1997–2001 period. As reported in Table 4.4, 16 German biotechnology firms completed IPOs during the boom period, raising $769 million in total capital. Many of the early German biotechnology IPOs were for firms focussed on a variety of platform biotechnologies (see Chapter 6), some with the potential of eventually generating therapeutic compounds. While only three of these IPOs were for development stage therapeutics companies, the early biotech IPOs created a general confidence that venture financing and IPOs could be used to fund the long-term, risky development cycles of drug discovery start-ups. In Ernst & Young's 2000 survey of German biotechnology 40 percent said they considered an IPO "likely" within the next 2 years, and most firms considered an eventual IPO to be the most desirable funding strategy (Ernst & Young 2000*b*: 15).

Unfortunately, the viability of high-risk venture financing for drug discovery firms within Germany may prove to be short lived. The rapid downturn in the US technology market that began in late 2001 had a dramatic impact on Germany's new technology marketplace during the 2002–3 period. Confidence within the *Neuer Markt* quickly evaporated and the market lost an incredible 96 percent of its value and a majority of firms were delisted. The 16 biotechnology firms cumulatively lost 90 percent of their value and 8 firms were delisted. There were no new biotech IPOs in Germany for a three and a half year period starting in mid-2001, and in 2003 the *Neuer Markt* was closed. Venture capital investments into biotechnology declined by about 60 percent, from about a half billion dollars during both 2000 and 2001 to $180 million during 2002. The number of deals also declined, from a peak of 148 in 1999 to 42 in 2003.

There has also been a shakeout within the German venture capital industry. Discussing the German venture capital market, an equity market consultant notes that "It was very easy for new players to come in and take advantage of government guarantees. They felt they could not lose money (Meek 2005: 6)." This assessment was clearly wrong, as German Venture Capital Association figures from 2005 report seventy firms exiting the industry in 2003 and 2004, mostly VCs focussed on early-stage funding (Meek 2005). The German federal public venture capital program also suffered losses in most investments, with the important implication that the agency's expectation that profitable exits would allow a gradual reduction in the use of public funds proving false. The *tbg* thus wound down its activities during 2003.

During the 2004–5 period some German commentators suggested that investor confidence had returned (Ernst & Young 2005*a*, 2000*b*; Meek 2005). As part of the process of closing down the *Neuer Markt*, a few dozen of the more viable *Neuer Markt* listed firms were transferred to a technology-oriented segment of the main Frankfurt Stock Exchange. Turning first to the larger firms, as of 2005 there were ten publicly traded firms, five of which are in therapeutics areas. While firms were required to meet tougher auditing and transparency requirements than those previously required for the *Neuer Markt*, the new technology segment did create a potentially viable market for continued technology company IPOs. Three biotechnology firms were eventually able to take public listings during the 2004–5 period, averaging $50 million in new funds for the listing companies.

The relatively small size of the renewed IPO market for German biotechnology firms implies that most of the 300 or so German biotechnology firms must rely on continued venture funding for most, if not all, of their finance. German venture capital firms have demonstrated a funding

Table 4.5. German venture capital deal size, 2002–4

Deal size ($ million)	Number of investments	Percent	Sum invested ($ million)	Percent
30+	6	11	201	36
15–29.9	8	15	150	27
5–14.9	18	33	165	30
2–4.9	10	16	36	6
0–1.9	12	22	5	1

Source: Meek (2005). Statistics compiled from a list of German venture capital investments from January 2002 to October 2004. Excluded from this table are sixteen presumably small biotechnology deals in which funds invested are not available.

commitment to a few of the larger biotechnology firms. Most German biotechnology investments during the 2002–5 period were larger, secondary placements in existing companies. Referring once more to Table 4.3, in 2004 thirty-three deals were completed for a total of $295 million or $8.9 million per deal. Table 4.5 contains more information on biotech deal size during the 2002–4 period. The top ten deals reported for this period totaled $330 million, or about 45 percent of all money invested in German biotechnology venture capital, while the top 15 deals accounted for 55 percent of funds invested.

Several German therapeutic firms are continuing to receive sizable investments in the $30 million plus range. A problem facing these firms is that they are competing with better funded firms in the United States and, we will see, the UK. Will the German firms have the funds to take lead products through enormously expensive second and third stage clinical trials? It seems unlikely that any German biotechnology firms will be able to raise funds into the hundreds of millions of dollars, as commonly occurs with US therapeutics start-ups. Rather, many of the firms have had trouble meeting fund-raising goals. Funding shortfalls were responsible for the dramatic downsizing of the German biotechnology industry, which lost 30 percent of its employees between 2002 and 2005. For many therapeutics firms, the choice when downsizing is whether to keep scientists involved in discovery or development personnel charged with moving compounds into the clinic. For example, the Munich therapeutics firm Micromet, having successfully raised over $50 million in venture capital in 2001, was forced to lay off 35 of its 120 employees due to failed fund-raising activities in 2003. The firm decided to concentrate its layoffs in discovery, in part to ensure "continuity" in its clinical programs (Micromet 2004). To give another prominent example, the Heidelberg firm Cellzome was forced to lay off 25 of its 100 person staff in 2004–5, despite having successfully raised over $30 million in new funding in 2003 (Cellzome 2003, 2005).

In the case of Micromet workforce cutbacks were presumably made to allow firms to focus on expensive clinical trials. But if few if any German therapeutics firms are able to raise more than $100 million over several rounds of financing and IPO funding, and most raise far less, how will these trials be funded? One common strategy is to license compounds to large pharmaceutical companies. Firms with several compounds can license most to pharmaceutical companies and use earnings to push forward one or two particularly promising products. Many firms are using this strategy (Ernst & Young 2002). However, companies may find themselves in a difficult bargaining position with larger partners. The most lucrative deals are typically found for compounds which have received some data on clinical efficacy from stage 2 clinical trials, an expensive process that can take several years. If firms cannot afford to finance these trials, they must license compounds at an earlier stage of development, in which upfront payments, milestone payments, and future royalties are lower.

Some firms have adopted more creative strategies. Perhaps the most interesting example comes from Medigene, a firm launched in 1994 as a spinout from the Munich Gene Center and cofounded by Ernst-Ludwig Winnacker, a prominent German scientist who eventually became president of the German Research Council, the country's equivalent to the US NSF. Medigene focusses on developing cancer therapies, but turned to in-licensing strategies often employed by specialty pharmaceutical firms to obtain funds for its clinical trials. In March 2000 the company raised approximately $125 million on the *Neuer Markt* and is currently listed on the reformed Frankfurt Stock Exchange technology segment. After determining that it lacked funds to push its cancer compounds through clinical trials, Medigene used funds from its IPO and undisclosed funds from several licensing deals to in-licensing a sustained release hormone treatment drug from a US company. During the 2002–4 period the company effectively put its cancer drug development program on hold, and was able to successfully bring the hormone treatment through late-stage clinical trials and to market. While only producing revenues in the $20–$30 million range in 2004 and 2005, Medigene claims that the drug will eventually generate $100 million in yearly revenue, funds the company is now investing in its original cancer therapies.

Referring back to Table 4.5, an alarming finding is the relatively small number of total VC deals during the 2002–4 period. Of the 350 biotechnology companies in existence during this period, only 54 received venture capital investments, with over a third being small placements of less than $5 million. This suggests that the vast majority of companies not receiving funding were left to persist on any remaining start-up funding, which for most of the smaller firms was primarily from the government, ongoing revenues (which generally do not exist for therapeutic research companies), or funds generated by other sources, such as milestone payments generated by alliances with pharmaceutical companies. While a few of the larger companies have completed alliance deals (Ernst & Young 2005*a*, 2005*b*), very few of the smaller companies had. In sum, it appears that the majority of German biotechnology companies faced severe financial hardship during the 2002–4 period. One result, discussed below, is that most German biotechnology firms were unable to grow; in 2004, for example, over half the firms employed less than ten individuals.

One possible strategy is for the smaller companies to create critical mass through mergers and acquisitions. This was a widespread expectation within the German industry during the late 1990s, heard repeatedly during interviews with VCs and government officials working within the BioRegio offices. According to this logic, the government programs overemphasized starting companies, in part due to a political goal of being able to pronounce that Germany would soon have Europe's largest biotechnology industry, at least in terms of companies. While many of these small companies were unsustainable, their problems could be solved through acquisitions by larger, more successful firms, or by horizontal mergers of two or more small firms to create larger firms with critical mass. Presumably, these combinations would be accompanied by ongoing venture capital investments to fuel continued growth.

The expected merger wave, however, never occurred. This is tied to the dramatic downfall of the *Neuer Markt* and the chill created during the 2002–3 period across Germany's new technology market. Funds for early-stage companies dried up, and many early-stage VCs failed, meaning that companies that had failed to raise the funds needed to gain critical mass during the pre-2002 period were unlikely to do so afterward. This closed off the horizontal acquisition strategy: firms could merge, but if these mergers were not accompanied by fresh investment capital, they were meaningless. A wave of larger firm acquisitions also failed to materialize, as, particularly in the post-2003 period, very few large firms were in the position to take on new employment commitments; instead most firms were engaged in corporate downsizing activities. Referring back to

Table 4.1, the decline in aggregate biotech employment from over 14,000 to 10,000 between 2001 and 2004 exemplifies this trend.

In sum, during the 2003–5 period the German biotechnology industry was generally unable to access sustained private venture capital investment to sustain either new start-ups or the 200 or so embryonic companies launched during the pre-2001 boom period. Short of allowing widespread failures, the only obvious government policy instrument available to support young firms was public funding, and during this period new public support programs were indeed launched. The German government has announced that it will commit about $1.5 billion in additional funds toward "German biotech innovation" between 2005 and 2010 (BMBF 2004).

A core area of renewed funding is the provision of capital for German biotech firms. The new programs differed from the earlier public venture capital initiative in that money was provided in the form of grants, meaning that the government would not take equity stakes in companies nor require that public funds be matched by private venture capital. One new program, called "BioFuture", is similar to the SBIR program, in that it aims to provide individual grants of up to $500,000 to 50 scientists to conduct basic research with an aim toward commercialization. A second program called "BioChancePlus" aims to invest about $100 million annually in expansion activities of existing companies. During 2004 the program made 87 investments within existing companies, most for about $1 million (Lampel 2005). The "BioChancePlus" program is clearly aimed at bridging the funding gap created by the withdrawal of early-stage venture capital in Germany. According to the BMBF, the program "contributes to the establishment of German biotech companies in the international market (BMBF 2005)."

How should we assess the new public investments? Most optimistically, the new programs signal the German government's continued commitment toward the industry. Particularly when combined with other regional subsidies for new firms, the new initiatives may create a pathway where firms could raise several million dollars in public funding to support the riskier stage of their development, upon which private venture capital could take over. During 2004 and 2005 the market for expansion phase venture funding and IPOs did revive in Germany, suggesting that promising firms funding through early stages by the government could be handed over to the private sector.

A more pessimistic interpretation, however, is that continued subsidy programs, and the "BioChancePlus" program, in particular, could represent an effort by the government to avoid widespread failures by the group of 200 or so tiny companies currently populating the German industry, and as such, may be politically expedient investments with little chance of long-term success.

More pragmatically, will the government funded start-ups be able to benefit from the corporate governance advantages commonly associated with VC involvement? Most strong VC firms employ partners with extensive industry experience in their focus industry, who then serve on boards and provide ongoing help for firms developing a strategy, recruiting executives, developing contacts with other firms, and so forth. An advantage of the earlier *tbg* program is that public funding was tied to the ability of each firm to secure private venture capital funding and with it active venture capital governance. Through dropping this requirement, the new programs create the risk that dozens of companies may be funded without strong venture investors. While most companies will be located within incubators managed by the BioRegio offices, and may secure some consultancy and managerial services through these programs, can essentially public governance of start-ups match that of experienced VCs, particularly within fast moving new technology segments such as therapeutics?

To summarize, while the drive to create a system of high-risk equity finance in Germany has been strong, there is little evidence that a sustainable system of entrepreneurial finance based on the LME model currently exists within Germany. As of the mid-2000s, the German government appears to have taken over the role of funding the early development of start-ups. While perhaps a needed life-support system for the German industry, the corporate governance of these firms remains open to doubt, and there currently is little evidence that many of these firms will be "passed on" to private market VCs willing to make expansion phase investments. There is a market for continued VC investment into established companies. But this market has at most a few dozen companies, while hundreds of German companies are in need of funding. The situation could improve with more successful venture capital exits, such as IPOs or high value acquisitions, or the successful launching of large market drugs by German therapeutics firms. Industry reports like to point to the three successful German biotech IPOs held during 2004 and 2005 as an important sign of vibrancy (see Ernst & Young 2005*a*, 2005*b*). While these IPOs, along with a reemergence of expansion phase venture funding for more established firms, certainly show that entrepreneurial finance is not dead in Germany, it is difficult not to conclude that the overall situation for radically innovative German biotech start-ups remains precarious.

High-Powered Employee Incentives

While the German pattern of corporate governance has historically generated strong incentives against the use of employee stock options and other high-powered performance incentives, in recent years practices by large companies and legislative reforms have legitimized their use. While the power of stock ownership as an incentive instrument may be systematically weakened in Germany by the limited viability of stock offerings, there can be no doubt that, as an organizational practice, stock offerings can now be easily implemented by German new technology firms.

Germany's stakeholder system of corporate governance has historically generated a strong bias within most firms against individualized performance incentives. Long-term employment by most skilled employees and managers, combined with consensual decision-making routines, creates a bias against strongly individualized rewards and has dampened the use of large salary or stock bonuses as an incentive system for top management. For example, as of 2000 the average German CEO's income was only 11 times that of average hourly paid employees, while the equivalent ratio for CEOs in the United States had grown to 531 (Buck, Shahrim, and Winter 2004). Moreover, many German firms works councils strongly resist efforts by management to institute performance-related pay, especially on an individual basis. Finally, as part of laws designed to stabilize shareholdings, prior to 1999 German firms faced legal restrictions on firms buying and selling their own shares which complicated matters further by creating technical difficulties on the organization of stock option plans (Cioffi 2002).

However, the situation has improved dramatically. While large German firms continue to be governed through a stakeholder model of company law, in recent years, the management of many large companies have developed an interest in tapping international financial markets and broadening their shareholder base in order to generate shareholder value pressures, stock option schemes, and other mechanisms to increase short-term performance pressures within the firm. German business generally supported the liberalization of German shareholding laws in March 1998 to allow firms to buy and sell their own shares and, through doing so, simplify the issuance of employee stock options. Within two years 43 of the 100 largest German companies which traded on the Frankfurt Stock Exchange had implemented employee stock options (Buck, Shahrim, and Winter 2004). Interestingly, however, the organization of plans differs from common practice in the United States. According to early evidence provided by Buck, Shahrim, and Winter (2004), German firms distribute employee stock options more widely across managers and employees within their companies than typical US firms. Moreover, the relative weight of stock options-based remuneration, as a percentage of salary, is less in German firms than within US firms. This may signify that, within German firms, stock options represent a collective rather than an individual instrument, and, as performance incentives, may be milder than found within US firms. As such, stock options may provide an incentive for employees of German firms to focus more on short-term competitiveness, but within the context of broadly long-term employment and consensual decision-making typical of the country's stakeholder model.

While there is unfortunately little survey evidence of the use of employee stock options within German biotechnology start-ups, interviews with the management of a dozen biotechnology firms visited during the 1999–2000 period found that each firm used stock ownership-based incentive schemes, with wide dispersals across most employees of the company. It should be assumed that most German new technology start-ups have adopted stock option plans. While this evidence is idiosyncratic, during interviews managers repeatedly asserted that employees in their firms were very hardworking and generally strongly incentivized by working in a fast-paced start-up. It is likely that stock options are being used to create strong incentive structures, but within a generally collective group effort that may more broadly draw on "normal" norms of relatively strong group commitment within these firms. This is likely to be especially true during the early start-up period of a technology firm's development, in which a relatively small team can more or less mimic the US model of creating very strong performance incentives through collective ownership stakes across founders and early employees.

In practice, however, the utility of employee stock options within German biotechnology has been limited by the limited success of German firms in achieving stock market liquidity for their shares. There have been at least 430 biotech start-ups launched in Germany since the mid-1990s, but only 19 IPOs and very few successful exits through acquisition, most during the boom period in the late 1990s. This means that employees in less than 5 percent of biotechnology ventures were potentially able to secure earnings from their stock options.

Given the adoption of stock options by many larger German companies, the use of high-powered performance incentives by German new technology firms appears to be a component of the Silicon Valley model that has had the most success in being adopted in Germany. However, the long-term viability of the model will depend on the success of firms in systematically achieving IPOs or numerous high visibility acquisitions. The slowdown in German IPO activity from 2001 onward can only have diminished the expected value of stock options.

Labor Market Coordination

Research on human resource systems within Germany stress long-term employment. Most employees spend most of their careers within one firm, often after a formal apprenticeship or, in the case of many engineers and scientists, an internship arranged in conjunction with their university degree. While there exist no formal laws stipulating long-term employment, German labor has used its power on supervisory boards as well as its formal consultative rights under codetermination law over training, work-organization, and hiring to obtain unlimited employment contracts (Streeck 1984). Once the long-term employment norm for skilled workers was established, it spread to virtually all mid-level managers and technical employees. Long-term employment norms also conduce toward systems of internal promotion, meaning that the top management of most large German firms have traditionally been long-term employees. Moreover, within many technology intensive companies, top managers are often scientists or engineers that moved into management and eventually were promoted to leadership positions (see Lehrer 1997).

Can German biotechnology firms develop scientific and managerial expertise to compete in high-risk therapeutic research fields? If most technical personnel and managers do indeed develop primarily long-term careers with single firms, this implies that the labor market for mid-career personnel will be limited. From the point of view of an experienced scientist or manager at an established firm, the career risk of moving from a “safe” job in an established company to a start-up might be much higher than within an LME, in that similar mid to late career opportunities at other established firms might be limited. Finally, if it is true that established firms have a bias toward promoting managers with technical skills into top management, then any well-performing mid-career personnel of this type that do leave might be jeopardizing a legitimate opportunity to move into top management. If the career management within large companies is as entrenched as proponents of the CME perspective argue, then new technology start-ups face severe obstacles.

To investigate patterns of labor market coordination across German biotechnology firms, three types of evidence are examined: broad data on company demographics derived from Ernst & Young surveys of German biotechnology, career history data on German scientists working within larger German biotechnology firms, and network data used to examine the connectivity and composition of social ties linking scientists working in German biotechnology firms.

COMPANY EMPLOYMENT DEMOGRAPHICS

Beginning in 2001 Ernst & Young began publishing data on the size distribution, in terms of employment, of German biotechnology companies. Table 4.6 summarizes this data for the 2001 to 2004 period. This data demonstrates that the vast majority of German biotechnology firms are very small. In 2004, for example, there were sixty-four German biotechnology companies employing more than thirty people. These firms can be considered viable in that they have reached critical mass in terms of employment, and, possibly, financing. There is however also a much larger group of very small firms. In 2004 over 80 percent of German biotechnology firms, or 281 firms, employed less than 30 people, and just over half of all firms, or 176, were tiny companies with 10 or fewer employees. Most of these tiny firms are located within incubation centers and technology parks created through the BioRegio centers. Many have been able to draw on initial seed funding for multiple years due to the availability of free or subsidized rent within university-centered incubation centers and technology parks and use laboratory equipment within academic founder laboratories. Moreover, over the 2001–4 period German biotechnology firms on the whole became smaller in size, not larger.

Why are most German biotechnology firms so small? Given the earlier survey of financing in Germany, it is likely that many of these companies

Table 4.6. German biotechnology company demographics by employment

Employees	2001 Number (%)	2002 Number (%)	2003 Number (%)	2004 Number (%)
300+	4 (1)	4 (1)	4 (1)	3 (1)
101–300	7 (2)	11 (3)	7 (2)	10 (3)
51–100	44 (12)	32 (9)	28 (8)	17 (5)
31–50	40 (11)	36 (10)	32 (9)	35 (10)
11–30	124 (34)	119 (33)	119 (34)	104 (30)
1–10	146 (40)	158 (44)	161 (46)	176 (51)
Total	365	360	351	345

Source: Ernst & Young (2005*a*).

were financially constrained, particularly from 2002 onward. It is also likely, however, that these firms have faced obstacles in recruiting qualified personnel. The data for 2001 may be most revealing, as during this year the German biotechnology boom was still underway and most firms had received financing through government programs and VCs. During the end of the boom, however, 146 (or 40 percent) of companies had less than 10 employees and 74 percent of all companies employed less than 30 individuals. This is suggestive evidence that labor market structures in Germany create obstacles to recruiting personnel.

According to the Ernst & Young surveys at least 65 percent of German firms claim to be developing therapeutics. This implies that, in addition to the larger German therapeutics companies that have received sizable financing, many of the tiny companies populating the German industry are also specializing in therapeutics. Can they create credible capabilities to innovate? A norm obtained from an interview with a drug discovery expert working within the US biotechnology industry is that a drug discovery project, defined as an effort to use a given discovery method to locate and perform preliminary lead verification on a target, commonly engages about twenty-five individuals. If true, then most German biotechnology firms are understaffed. In this respect, it is interesting to note the high number of compounds in the preclinical trial stage among German therapeutics firms, 160 as of 2004. Among the thirty-six larger German therapeutics firms examined as part of the four cluster study discussed earlier, there were thirty-one preclinical compounds. This suggests that most of the 160 preclinical compounds within the German drug pipeline are owned by tiny companies. In addition to the severe financial obstacles facing small German companies discussed earlier, it is unlikely that most German companies have sufficient technical expertise to push their drug targets into the advanced stages of preclinical discovery or stage 1 clinical trials, stages of development in which companies could possibly form development alliances with larger companies.

CAREER HISTORY PROFILES OF GERMAN BIOTECH SCIENTISTS

Turning to the larger German therapeutic discovery companies, have they been able to recruit sufficient scientific and managerial talent needed to plausibly innovate in therapeutic discovery fields? As mentioned earlier career histories were gathered for 299 scientists working within 42 of the larger companies located in Munich, Heidelberg, Cologne, and Berlin. Table 4.7 presents career history information, in the form of previous job

Table 4.7. Previous jobs of biotechnology scientists, Germany 2002 and San Diego 2004

	All Germany: number (%)	Germany junior scientist: number (%)	Germany senior manager: number (%)	San Diego senior managers 2004: number (%)
Founder lab	101 (34)	61 (28)	40 (48)	n/a
Local academic	23 (8)	21 (10)	2 (2)	17 (7)
Nonlocal academic	143 (47)	119 (54)	24 (20)	27 (10)
Biotech	12 (4)	6 (3)	6 (7)	168 (65)
Pharma/industry	20 (7)	8 (4)	12 (14)	47 (18)
Total sample	299	215	84	259

Sources: ISI *Web of Science* and company web-pages.

counts, for German scientists in 2002 and comparative data from San Diego senior scientists from 2004. German biotechnology firms employ significantly fewer scientists with prior experience in commercial therapeutic research than the San Diego biotechnology spin-off firms. Of the 299 German scientists in this sample, only 11 percent were directly recruited from either a biotechnology firm (4%) or a pharmaceutical firm (7%). Breaking the figures down into individuals involved with senior manager jobs versus individuals in presumably more junior scientist positions, the results improve somewhat, as 18 of 84 managers, or 21 percent, have industry experience.

The comparison with San Diego managers is striking. Of the 259 San Diego senior managers who have a Ph.D. and are presumably in a science-oriented position, 215, or 83 percent, had previous work experience in a biotechnology or pharmaceutical firm before starting their current job. Of course, the San Diego comparative data represents a cluster that had undergone twenty years of development. A fairer comparison might to compare the German data from 2002 with data from an earlier phase of San Diego's development. Turning back to 1989, a few years into San Diego's development, 75 percent of scientists had previous industry experience. San Diego companies were easily able to recruit scientists with industry experience, primarily from larger pharmaceutical companies, throughout the history of the region's development. German firms have not.

The inability of most firms to secure scientists with industry experience is consistent with expectation that, due to long-term employment patterns within the German industry, there would be a limited labor market for mid-career scientists to draw on. Interestingly, of the thirty-two scientists with industry experience, half were recruited from abroad. Of the remaining sixteen individuals, half were from German biotechnology firms, primarily interfirm moves within the Munich cluster. Due to the infancy of Germany's biotechnology industry, it should be expected that few individuals would have domestic biotechnology experience. However, the lack of mobility from Germany's large pharmaceutical industry is noteworthy given its large size. Of particular importance to therapeutics firms is attracting scientists with experience in developing compounds through preclinical and eventually clinical trials. The German pharmaceutical industry employs tens of thousands of scientists, many with pharmaceutical development expertise that is of crucial relevance to Germany's biotechnology industry. The finding that, among forty-two of Germany's more prominent biotechnology firms, only eight scientists with pharmaceutical industry backgrounds could be recruited is startling evidence of the impact Germany's traditional system of long-term employment has on the labor market facing start-ups.

On the other hand, German biotechnology firms have been able to easily recruit from the ranks of academic scientists. Is the strong reliance on academic scientists, and particularly scientists from the founder laboratory, a positive development? There can be no doubt that German professors responded enthusiastically at the opportunity to form biotech companies. As Asakawa and Lehrer (2004: 66) note: "German scientists jumped at the business opportunities because the potential returns were substantial while the combination of various local and federal support programs meant they could do so without much risk to themselves."

Due to the need to transfer what are often tacit research methods and retain an ongoing relationship, most biotechnology firms with academic origins hire one or more academic scientists. However, within these 42 German firms 101 individuals previously worked, in most cases as graduate students or postdoctoral fellows, in the academic laboratory that spun-off the biotechnology firm in which they were employed. Sixteen additional scientists were employed within their firm's founder laboratory at an earlier point in their career, bringing the total percentage of scientists with founder laboratory connections to 40 percent. While direct comparative data on this point with San Diego or other US clusters is unavailable, this is almost certainly a much higher percentage than commonly found within the US industry.

An optimistic interpretation of the reliance of German firms on academic scientists is that the trend demonstrates a capability of many German firms to potentially innovative in areas of the industry strongly impacted by university science. Personnel from the firm's founder will be in the best position to exploit a firm's scientific founding ideas, leading to a potential conclusion that the strong reliance on such scientists might be an advantage to German firms. A few German firms, such as Cellzome or Micromet, have demonstrated a strong scientific capability through generating high-quality publications in leading academic journals, such as *Nature*. Similar strategies of signaling scientific prowess through academic publishing are common within the US industry, and as milestones can be used to generate additional resources for the firm (see Murray 2004).

However, there is also the possibility that the heavy reliance on founder laboratory employees within German biotech start-ups signals an inability to recruit stronger scientific staff from industry and, at worse, might signal an attempt by academic founders to push scientists from their laboratories that are having difficulty in finding subsequent academic employment into spin-offs. Comparative organizational and employment dynamics within academic research systems is a relatively unexplored issue. Whitley (2003), however, has argued that the German research system is more centralized or less pluralistic than found in the United States or the UK. German academic departments have a small number of senior (chaired) professors responsible for organizing all research and teaching within a given field. These professors have generous long-term funding and organize large laboratories that are likely to be active in international science agendas. An interesting issue is whether employment tenures of graduate and postdoctoral students are longer within German laboratories than those in the United States or UK and, as a result, whether German senior professors have an implicit obligation to take a strong role in orchestrating the career moves of junior scientists within their laboratories. If so, the temptation to locate such scientists within laboratories academic spin-offs might be strong.

SOCIAL NETWORK DEVELOPMENT WITHIN GERMAN BIOTECHNOLOGY

Do dense social networks link scientists within German biotechnology firms? If so, this could signify the development of interorganizational ties that could eventually form the backbone of a flexible labor market linking biotechnology scientists. By drawing on data from the career histories gathered from scientists working within German biotechnology firms, affiliation networks can be developed and analyzed. Due to the much younger history of the German biotechnology industry, a simpler method of social network modeling was used for the German scientists than

Table 4.8. Career affiliation networks within German biotechnology clusters

	People	Firms	Percent in MC (connectivity)	Previous business ties	Previous science ties
Munich	87	10	100	20 (11%)	156 (89%)
Heidelberg	94	7	100	13 (8%)	170 (92%)
Cologne	71	13	82	14 (10%)	140 (90%)
Berlin	53	12	88	10 (10%)	86 (90%)
Combined ('all Germany')	305	42	96	57 (10%)	552 (90%)

used earlier for the San Diego study. Social networks were generated for scientists employed within the Berlin, Cologne, Heidelberg, and Munich regional cluster and for an aggregate "all Germany" network containing all scientists in the database. Knowing that most scientists had entered industry from academia within the previous five years, it was decided not to use the five year decay rule for ties that was implemented with the San Diego database. This creates a bias toward connectivity in the network. The results of the analysis are presented in Table 4.8.

Joint career affiliations within Germany's biotechnology clusters are strong. Network connectivity is high across each cluster, with 6 percent of all scientists in the aggregate all Germany network linked together and 100 percent in Germany's two largest biotechnology clusters, Munich and Heidelberg. However, most of this connectivity is generated through prior affiliations with academic laboratories. To illustrate this trend, Table 4.8 provides count data on the composition of all previous ties prior to joining each scientist's current firm; each job is counted once within the data. Within each of the four regions about 90 percent of the organizations represented within the network are academic. Munich has the strongest industry representation, with 20 commercial organizations represented, but this is counterbalanced by 156 prior jobs held by its scientists in academia.

An implication of these findings is that German firms have strong referral links with academic scientists. Social networks can be used to find both job referrals and to share technical information. In the case of German biotechnology, the dominance of academic ties suggests that German scientists should have a strong capability in locating information relating to scientific programs and job positions relating to science (both in academia and in biotechnology). In this regard, German social networks linking German scientists reinforce the overwhelming tendency of these companies to recruit primarily from academic institutions. Network penetration into communities of industry scientists, whether within the pharmaceutical or biotechnology industry, is low.

Conclusion: Has German Governmental Policy toward Biotechnology Failed?

Back in 1995 the German government promised to create Europe's largest biotechnology industry. Some ten years later, the government is pleased to report that they have made good on this promise. According to "Germany: A Favorable Location for Biotech Companies", a German federal government publication aimed at potential foreign investors, Germany has "the largest number of biotech companies in Europe". The 346 firms reported in the 2004 Ernst & Young report do in fact surpass the UK's 275 firms. The German government's own statistics paint an even rosier picture; employing a more expansive definition of biotechnology, the German Bureau of Statistics claims that Germany claims that as of 2004 the country had 572 "core" biotechnology firms (Statistische Bundesamt 2005).

To an important degree, German biotechnology is a case of institutional entrepreneurship (DiMaggio 1988; Fligstein 1997). Policy explicitly aimed to create new institutions needed to support entrepreneurial technology firms. Government promotion programs created a substantial technology transfer infrastructure aimed at fostering science-based start-ups. Dozens of senior scientists have embraced this program to nurture their university research into start-ups. The government has also worked creatively with the country's financial community to support an investment banking system capable of supporting both high-risk venture capital and stock market offerings. While creating this system, changes to finance laws were created to more readily accommodate the use of stock options as an incentive scheme within firms, an instrument now widely employed throughout German industry. A number of legitimate biotechnology firms have emerged from this system. Given that in the mid-1990s *Science* magazine commented that "Germany provided perhaps the most inhospitable climate for biotechnology in the Western world" (Dickman 1996), that is quite an accomplishment.

Nonetheless, there is little evidence that German institutions can systematically support radically innovative companies, such as those typically found within the therapeutics segment of biotechnology. Most of the new German biotech firms are tiny enterprises housed within incubators and technology parks surrounding the country's two dozen regional biotechnology promotion centers. The primary funding source for most smaller firms has been the government, and the primary source of talent for these companies has been inexperienced scientists from nearby university founder laboratories. While over 65 percent of German firms report a therapeutics focus, it seems hard to see how most firms will develop adequate capability to discover and fund clinical development of compounds, even within the more inexpensive early stages. Most firms appear unable to recruit scientists with industry experience, and as a result seem unlikely to acquire skills in pharmaceutical development. Government funding may be adequate to keep large numbers of firms operating, but it is unlikely to provide the larger tranches of investment capital from VCs or IPOs on stock markets that, in the mid-2000s, only a few established companies have secured.

There are a small number of larger companies whose prospects, at least in the short term, are more promising. But these companies are competing in intense innovation races against other companies, typically located within one of the successful US technology companies, that have access to dramatically higher venture capital and stock market funding and more easily recruit needed technical and management talent from large, flexible labor markets. Therapeutic discovery companies within the United States have brought dozens of products to market, whereas as of mid-2006 no compound discovered by a German biotechnology company had been successfully commercialized. While a small number of German companies may eventually succeed in commercializing an in-house compound, it seems unlikely that such successes can develop adequate refinancing mechanisms needed to reinvigorate the country's larger industry or, turning to labor markets, convince large numbers of talented scientists or managers to leave safe jobs in larger companies to move to what can only be considered in Germany as high-risk biotechnology firms.

It is hard to avoid the conclusion that government policy toward biotechnology has failed. While institutional reforms and sector-specific technology policies have lessened some restraints, key problems, particularly in the area of venture finance and related governance and arranging human resource competencies within high-risk technology start-ups, continue to undermine the viability of most therapeutics projects in Germany. An institutional framework capable of sustaining radically innovative biotechnology companies does not exist in Germany.

5

Biotechnology in the UK: good but not great

National institutional frameworks within the UK strongly conform to the LME model. As such, institutional frameworks governing finance, labor market organization, and corporate governance should conduce toward patterns of coordination within the economy supportive of radically innovative new technology enterprises. Combined with strong funding for basic research and a world-class pharmaceutical industry, these institutions should provide the necessary ingredients to promote entrepreneurial biotechnology companies. And indeed, by a number of measures the UK has developed Europe's most successful biotechnology industry. This success is consistent with varieties of capitalism theory. At the same time, however, the performance of UK firms lags behind that of the US industry to such an extent that the combined performance of companies in any one of the three largest regional US biotechnology clusters exceeds that of the entire UK industry.

This chapter attempts to explain this Janus-faced performance of the UK biotechnology industry. After presenting evidence on the general performance of the industry in comparative context, it follows the template of the previous two chapters in investigating how institutional frameworks in the UK structure patterns of economic coordination surrounding high-risk finance, flexible labor markets, and high-powered performance incentives within the biotechnology sector. This analysis will confirm that national institutional frameworks and resulting patterns of economic coordination within the biotechnology sector do conform to the LME model, though perhaps with weaker performance, particularly in venture financing, than in the United States.

The remainder of the chapter investigates more closely why, despite the strong performance of UK biotechnology within the European context, the country's industry has not matched the performance of the US sector. In comparing these two countries, important differences are found in the role nonmarket actors, particular universities, play within the biotechnology marketplace. These differences accrue in part from variations in public policy surrounding the commercialization of science in the United States and the UK, and from differences in the financial structure of universities. Empirical examples from the Cambridge region within the UK, home to Europe's most successful biotechnology cluster, are used to develop the analysis.

The UK Biotechnology Industry: Company Demographics

Systematic data on the activities of the UK biotechnology sector is generally less comprehensive than that for Germany or the San Diego region within the United States. Nevertheless, the data that is available suggests that the UK biotechnology industry has specialized toward radically innovative therapeutic discovery segments and, moreover, that the UK companies have performed well, particularly within the European context.

The UK biotechnology industry was established in 1980 with the founding of Celltech, a company launched with the help of a short-lived government agency focussed on industrial policy, the National Enterprise Council. As discussed below, however, financial markets and technology transfer arrangements within the UK created important obstacles to the widespread establishment of biotechnology firms during the 1980s. Beginning in the early 1990s, however, a large number of biotechnology firms were funded and a sizable market for IPOs developed. By the mid-1990s the UK had established Europe's largest biotechnology industry, with 275 companies in existence by 1998, and through the next several years the size of the UK industry remained at this level, growing to 293 firms by 2003 (Ernst & Young 2004). While from the late 1990s onward the German industry grew to contain more firms, the UK industry contained many more mature firms. During the 1993–8 period over forty biotechnology companies were able to take IPOs, and between forty and fifty companies were listed on UK stock markets from 1998 onward. In addition to a larger number of publicly listed companies, employment within the UK sector, at 22,000 in 2004, was twice that in Germany. Moreover, during 2004 eighteen UK biotechnology firms were profitable. While a seemingly small number, this is almost certainly a much higher

Table 5.1. Clinical pipeline of UK therapeutic compounds, 1999–2004

	Preclinical	Phase 1	Phase 2	Phase 3
1999	29	28	36	11
2000	32	37	46	13
2001	45	28	36	11
2002	65	50	56	23
2003	50	37	46	27
2004	49	36	50	30

Source: Ernst & Young (2000*a*, 2002, 2004, 2005*b*).

number than in Germany, where only the platform technology company Qiagen has demonstrated a record of sustained profitability.

UK biotechnology has specialized in radically innovative therapeutic discovery strategies. Table 5.1 displays the therapeutic discovery pipeline of UK biotechnology firms from the late 1990s onward. Compared to Germany, UK firms have had success in moving their compounds into the more costly stages 2 and 3 of clinical trials. Moreover, UK biotechnology firms have dramatically outpaced the rest of Europe in bringing its therapies to the market. As of 2004, UK biotechnology firms have discovered twenty-seven marketed biotechnology drugs. This compares to only one market drug (which was in-licensed from the United States) for the German biotechnology industry.

The UK is home to Europe's most successful biotechnology industry. However, is UK biotech performing as well as it could be? Compared with the US industry, the performance of UK biotechnology becomes markedly less impressive. Compared with typical firms located within the US industry's three well-performing clusters located in Boston, San Diego, and the San Francisco regions, UK firms are undercapitalized, smaller, and less successful at bringing products to the market. In fact, according to many metrics the aggregate performance of any one of the three large US biotechnology clusters surpasses that of the entire UK industry.

Figure 5.1 compares the performance of the aggregate UK biotechnology industry to the San Diego biotechnology cluster and Germany across a number of indicators. These figures demonstrate the clear lead held by the UK industry over Germany in all areas with the exception of total firms. However, the comparison of the San Diego region with the entire UK biotechnology industry is troubling. Biotechnology firms in the two areas have marketed the same number of products and, on the whole,

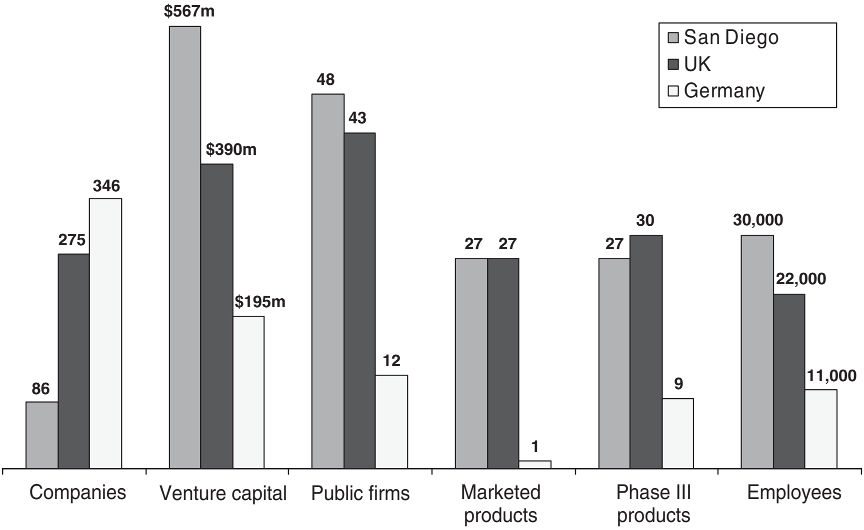

Figure 5.1. Performance comparison of UK, German, and San Diego biotechnology industries, 2004

Source: German figures from Ernst & Young (2005*a*); UK figures from Ernst & Young (2005*a*, 2005*b*) and UK Department of Trade and Industry (2006); San Diego figures from company web-pages, PriceWaterhouse Coopers MoneyTree data, and San Diego Sourcebook (2006).

have broadly similar pipelines of drugs in clinical trials. This suggests that the relatively small region of San Diego has matched the entire UK in biotechnology-related drug discovery. Moreover, the San Diego region has attained this performance record with about a third fewer firms, though these firms tend to employ substantially more people and attract more venture capital.

Statistics on the scientific intensity of patents also point to a divergence in the performance of UK versus US companies. The scientific intensity measure is computed through examining the average number of references to scientific articles cited in patents within a particular class, in this case biotechnology. While only a rough indicator, it is reasonable to assume that patents with a large number of scientific references might draw on more basic science than patents that do not. Figure 5.2 displays the average-patent intensity of biotechnology patents in the UK, United States, and Germany from 1985 to 1998. The scientific intensity of the UK sector, which has generally tracked the United States throughout the 1990s, declined precipitously during the mid-1990s and 1998 and fell to the same level as the German industry (see Casper and Kettler 2001).

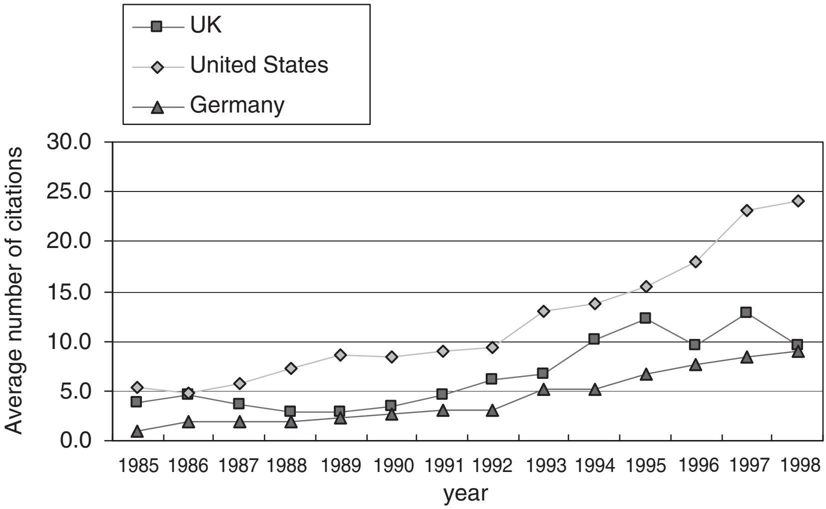

Figure 5.2. Patent intensity of biotechnology patents, UK, United States, and Germany 1985–98

Source: Casper and Kettler (2001), based on US Patent Data.

Given the strong emphasis of UK biotechnology firms on therapeutics, this is an indicator that UK companies might not be able to match the scientific intensity of their US competitors.

Patterns of Economic Coordination within the UK Biotechnology Industry

In sum, the UK has developed a relatively large biotechnology industry that has specialized in radically innovative therapeutics research and appears to be performing extremely well within the European context, and modestly well in comparison with the United States. To strengthen the argument linking national institutional frameworks in the UK to the country's performance in biotechnology, we now examine patterns of economic coordination in the areas of finance, high-risk incentives, and labor market.

Finance

Comparative studies of corporate governance and financing systems routinely group the United States and UK together as shareholder-dominated systems driven by large capital markets and an active market for corporate control (see Gourevitch and Shinn 2005). Compared to all other European countries, the UK has developed capital-market-based financial institutions that should facilitate investments within high-risk technology firms. Capital markets in the UK are large. Market capitalization of UK stock markets stood at more than 1.5 times the country's GDP throughout the late 1990s, a rate exceeding that within the United States and far exceeding Germany and other Continental European CMEs (Casper and Soskice 2004). The London Stock Exchange (LSE) has been able to absorb numerous initial public offerings for IPOs, and has established a subsidiary market, called the Alternative Investment Market (AIM), for smaller-, higher-risk stock listings. In addition to providing a viable financing for several dozen IPOs of technology companies from the mid-1990s onward, these stock markets have provided legitimate exits for VCs and other investors in UK technology start-ups.

While UK financial institutions strongly conduce toward the LME model of financial coordination, financial regulation toward high-technology industries generally lagged behind that within the United States, and up until 1993 generally inhibited the development of strong venture capital and public stock market support for biotechnology. Up until 1993, the LSE refused to allow pharmaceutical or biotechnology companies to be listed until they had at least three years of profitability and at least two products in clinical trials (see Kettler and Casper 2001). At the time no biotechnology company met this criteria.

During the 1980s the financial environment facing UK biotechnology firms was similar to that in Germany: the lack of a viable IPO exit option dampened venture capital investments into the industry. While data on biotechnology start-up activity and venture capital financing for the 1980s is unavailable, in an early study of the UK industry Senker (1996: 227) reports that the rate of firm creation was slow, and that many companies that did form were spun out of pharmaceutical companies rather than spun out of academic laboratories with private venture capital. While a few successful biotechnology firms, such as Celltech and Cantab, were launched earlier, the UK industry did not begin to take off until the mid-1990s.

As part of a general governmental initiative to better support biotechnology, reforms enacted in 1993 attempted to harmonize financial regulations surrounding biotechnology with the US model. An amendment to Chapter 20 of the LSE enabled "substantial scientific research-based companies without an adequate trading record to raise finance" (quoted from Kettler and Casper 2001: 77). This amendment waived the three-year profitability requirement for biotechnology companies, requiring only that evidence of support from "sophisticated" investors and that funds be used to bring products capable of generating "substantial" revenues to the market. The amendment also required that any biotechnology company seeking a stock listing have at least two compounds in clinical trials. Realizing that the new regulations would preempt many early-stage companies from raising funds on public markets, in 1995 the AIM stock market was created. This market had much more permissive listing requirements, only that the listing company have "sophisticated management with access to good technology" (Kettler and Casper 2001: 78).

Following the 1993 reforms and establishment of AIM in 1995 a vibrant IPO market for biotechnology stocks developed within the UK. Table 5.2 displays data on venture capital investments in the UK, with US and German comparison data. The ratio of US to UK biotechnology-venture capital investments is a good measure of the health of the UK biotech industry. The population ratio between the two countries is roughly 5 to 1 in favor of the United States. During the 1995–9 period the general funding level of biotechnology related venture capital lagged behind that in the UK, but the ratio of investments within the United States steadily improved during this period. During the 1999–2002 period UK venture capital investments declined substantially and fell dramatically behind those within the United States or Germany. However, from 2002

Table 5.2. Venture capital investments within the UK, Germany, and United States, 1995–2004

	UK ($ million)	Germany ($ million)	United States ($ million)	Ratio United States/UK
1995	71	16	737	10.3
1996	102	59	1,064	10.4
1997	102	61	1,257	12
1998	145	148	1,252	8.6
1999	229	247	1,698	7.4
2000	111	505	3,270	29.5
2001	104	497	2,074	19.9
2002	200	180	1,750	8.75
2003	323	233	2,135	6.6
2004	390	295	2,331	5.9

Source: UK from Lange (2005), based on data from the British Venture Capital Association and the US National Venture Capital Association. UK data for 2004 and data on deals from Ernst & Young (2005*b*). US data from NSF Science and Engineering Indicators (2006: Appendix A6-26), based on data from Thomson Financial Services.

to 2004 UK investments surged and in 2004 came close to matching US investments on a size of population-adjusted basis. UK venture capital investments appear more volatile than those in the United States. This was partly due to the large depreciation in technology stock markets following the shakeout of the Internet sector during 2001. However, it is also surprising that UK biotechnology investments did not surge during the 1999–2000 boom period, as they did in the United States and, though with the aid of state subsidies, Germany.

Stock markets within the UK have supported venture capital investments through backing numerous IPOs of biotechnology firms. At least forty-three companies were able to successfully take listings between 1993 and 1998. Combined, the LSE and AIM became the most important markets supporting biotechnology firms within Europe. Prior to the establishment of the German *Neuer Markt* and other NASDAQ inspired stock markets in several European countries in the late 1990s they were the only markets capable of systematically supporting new technology companies in Europe. While the funds raised during IPOs on the LSE tend to be modest, at about $100–$150 million (and much smaller on the AIM), UK investors have generally been willing to support biotechnology companies that have successfully reached important milestones and, in particular, have successfully launched products. Throughout the early 2000s the combined market capitalization of UK-listed biotechnology firms has hovered around $15 billion, about 5 times the market capitalization of the German *Neuer Markt* during its peak period in 1999 and 2000. Moreover, in addition to IPOs there have been frequent secondary offerings of biotechnology companies on the LSE, allowing additional rounds of investment capital to be raised.

The decline in venture funding into the UK biotechnology market during 1999 and 2000, generally a boom period for biotechnology investments in the United States and elsewhere, can be traced to a crisis within the UK biotechnology industry during the late 1990s. During these years highly visibile clinical trials setbacks impacted the availability of public financing for UK biotechnology firms. The most important setback was a series of late-stage clinical trials failures of one of the UK's leading firms, British Biotechnology. The failure of its anticancer drug Marimastat in four different stage three clinical trials between 1997 and 2000 depressed the firm's stock price by over 95 percent (Davidson 2000). Other setbacks among prominent UK biotechnology firms include poor clinical results reported by two other therapeutic firms, Scotia Holdings and Stanford Rock (Cooke 1999: 14). During the same period another prominent firm, Celltech, was rocked by the withdrawal of Bayer from its drug development efforts, while another firm, Oxford Gene Technology, became involved in a patent dispute over research on a DNA chip (Cooke 1994: 14). Between 1997 and 1999, share prices of all UK biotechnology companies were severely deflated (SG Cohen 1998).

The reduced level of venture capital investment during 2000 and 2001 reflects a loss of confidence in the ability of the UK venture capital and investment banking community to adequately govern projects. During this period criticisms of the UK financial community, and particularly the country's VCs, developed in response to a perceived crisis (see Casper and Kettler 2001; Kettler and Casper 2001 for reviews). A main thrust of this criticism surrounded a trend during this period of UK VCs to avoid early-stage investments in technology start-ups. In 1998, for example, less than 5 percent of UK venture capital was sourced to initial funding of start-ups, and only 20 percent of capital went to expansion phase activities. Instead, during 1998 over 70 percent of venture capital allocated during 1998 was invested in management buyout (MBO) activities (Kettler and Casper 2001: 78), an activity surrounding the use of private equity to buy out existing owners of a company with the expectation that new management and ownership structures may improve the performance of existing companies. As MBO activities are primarily financial transactions, their dominance of UK venture capital transactions during the late 1990s gives weight to a criticism that the UK VCs were overly composed of financiers drawn from the City of London, one of the world's chief financial centers, rather than individuals with deep technical and industry knowledge needed to adequately assess and advise new technology start-ups.

While there is merit to such criticisms, during the 2000s venture capital and public stock markets surrounding the UK biotechnology industry have recovered. This recovery has in part been fueled by an increase in the number of marketed drugs developed by UK biotechnology firms. However, there has been a pronounced emphasis on the development of VCs that are located within emerging technology clusters and can draw on technical and industry knowledge to help govern investments (Martin 1989). The most notable example of the shift to technology-oriented investment is the success of the Amadeus Capital Partners, a Cambridge-based venture capital company founded by Hermann Hauser, a successful Cambridge entrepreneur and founder of an early personal computer company, Acorn Computers, as well as several other Cambridge area technology companies. Hauser is well known in the Cambridge area for importing Silicon Valley-style investment practices (see Hauser 2000). During the early 2000s, the UK regained its former status of Europe's largest investment site for biotechnology, with close to $400 million invested.

Labor Market Organization

The UK has employment and company laws that are conducive to the development of active labor markets surrounding radically innovative industries. Labor markets are deregulated and open, while company law imposes few restrictions on how owners design employment contracts. In the UK, there exists a flexible labor market for managers and technical employees, and poaching employees is a common practice (see Charkham 1995; Lehrer 1997; Vitols et al. 1997). This makes the long-term employment contracts common within large German firms less viable. Furthermore, top managers of UK firms have flexibility over internal labor market policy. German-style works councils have no statutory organizational rights or consultation powers in the UK. This creates the opportunity for top managers to cut nonperforming assets and replace them with new groups of employees hired on the open labor market or, at times, employees poached from competitors.

Within the UK, there exists a particularly fluid labor market for mid-career managers and scientists with pharmaceutical industry experience. In terms of producing so-called blockbuster drugs, the UK pharmaceutical industry has been highly successful (see Casper and Matraves 2005). However, there has also been a series of mergers within the UK pharmaceutical industry, driven in large part by a drive for UK pharmaceutical firms to match the multibillion dollar R&D budgets of their US competitors. The merger boom began with Glaxo's acquisition of Wellcome in 1995, Zeneca's merger with the Swedish firm Astra in 1998, and culminated in 2000 with the merger of GlaxoWellcome with SmithKline Beecham to produce the world's second largest pharmaceutical company.

Each of these mergers has been accompanied by substantial restructuring and the dismissal of thousands of scientists and managers. Six thousand employees were laid off as a result of the AstraZeneca merger (Kalb 2006). Following Glaxo's acquisition of Wellcome in 1995 over 7,500 people, or 10 percent of the merged firm's staff were dismissed, most from Wellcome (*The Economist* 1997). The subsequent merger between GlaxoWellcome and SmithKline Beecham resulted in the dismissal of 12,000 individuals, again about 10 percent of the total employees of the merged companies (Kalb 2006). In sum, about 25,000 individuals, including a large number of managers and scientists, were cut during the restructuring of the UK pharmaceutical industry during the late 1990s, creating an abundant labor market of experienced pharmaceutical personnel.

An important concern, expressed frequently by managers of UK biotechnology firms during interviews, is that the large labor markets for mid-career scientists and managers created by these dismissals may be populated largely by less well-performing individuals, particularly given the fast-paced, competitive environment of most biotechnology firms. However, the dismissal of tens of thousands of managers and scientists as a result of mergers has amply demonstrated to professionals working within the industry that longer-term employment norms within the UK pharmaceutical industry do not exist and that, moreover, one should expect to work with several firms through one's career. As a result, there is an active headhunting market seeking to induce successful managers within pharmaceutical firms to relocate to biotechnology firms. Several prominent biotechnology firms within the Cambridge region, for example, are managed by former pharmaceutical executives that were headhunted to work at their current firm or, in two cases, Adprotech and Arrow Therapeutics, formed part of the founding team of the company.

To investigate the expectation that flexible labor markets should surround the UK biotechnology industry, careers of scientists employed within biotechnology companies located within Cambridge were collected during 2002. Based once more on bibliometric searches using the *Web of Science* and web-page biographies for senior scientists, career history data was obtained for eighty-three scientists, employed within ten companies that were selected on the basis of having at least one scientific publication that could be used to identify junior scientists working within the firm. These figures include both scientists occupying senior management positions (twenty-seven people) and scientists located through bibliometric searches (fifty-six), most of which were presumably more junior scientists.

Table 5.3 displays the results of this study, listing the type of most recent prior employment for each scientist prior to joining the current firm. The results demonstrate the diverse nature of the Cambridge labor market pool and probably are representative of labor markets in the UK more generally. Close to half of the scientists came to their current job from another job in the life-sciences industry, either a pharmaceutical company or another biotechnology company. The other half came directly to the firm from an academic science laboratory. While a significant number, 15

Table 5.3. Previous jobs of Cambridge, UK biotechnology scientists

	Junior scientists		Senior scientists		All scientists	
	Number	Percent	Number	Percent	Number	Percent
Founding academic laboratory	8	14	7	26	15	18
Other academic laboratory	27	48	3	11	30	36
Pharmaceutical firm	10	18	13	48	23	28
Biotechnology firm	11	20	4	15	15	18
Total	56		27		83	

Source: *Web of Science* and company web-pages; data compiled in 2002.

or 18 percent, came to the firm directly from its founder laboratory, a large number of scientists came to the firm from another laboratory (36%). As one would expect, a larger percentage of scientists occupying senior management jobs had work experience, in most cases from previous jobs within the pharmaceutical industry. Sixty-three percent of the senior executives came to their current job with industry experience, a figure that far exceeds the 21 percent experience rate found in Germany. Of the senior scientists coming from academia, most came from the academic laboratory that spun off the company, and were founders of the company. Only three individuals occupying top management positions came from academic jobs without ties to the founding technology.

In general, this data demonstrates that UK biotechnology firms are able to recruit a diverse scientific staff combining much-needed industrial experience with scientific prowess, indicating that an important degree of labor market flexibility exists within the Cambridge region. Moreover, several scientists came to their current jobs from firms that have failed, such as Axis Genetics, or companies undergoing major reorganizations and shifts of scientific direction such as Celltech or Cantab. The fact that scientists appear to have survived failure to find jobs in subsequent start-ups suggests that flexible labor market dynamics resembling those in Silcion Valley and other US technology clusters may be beginning to appear within the UK biotechnology industry.

The UK biotechnology labor market results also strengthen the argument that national institutions strongly shape patterns of labor market coordination. The UK results differ markedly from those found for Germany, where less than 10 percent of scientists working within companies had industry experience. As expected due to the turbulence within labor markets surrounding the country's pharmaceutical industry, there is a much stronger presence of pharmaceutical industry executives within the UK biotechnology industry. The UK biotechnology industry has been dramatically more effective than the German industry in pushing compounds discovered at its firms into the clinic and eventually to market. This superiority could at least be in part tied to the ability of UK firms to recruit executives with in-depth pharmaceutical development experience.

High-Powered Performance Incentives

Of the major European economies, the UK is unique in its embrace of flexible labor markets, giving the owners and top management of companies widespread latitude to hire-and-fire. While our discussion of high-powered incentives has stressed the possibility of large financial windfalls should a company succeed, a perhaps equally important driver of intense short-term work effort is the probability that, if the fortunes of a company decline, the company's board or top management will restructure the company, leading to widespread company dismissals. The existence of flexible labor markets is an important driver of the viability of high-powered employment contracts. The longer-term employment contracts which tend to predominate within large firms in Germany and other European economies are less viable in the UK. Furthermore, top managers have more flexibility over internal labor market policy. German-style works councils have no statutory rights within the UK. If particular research units are not meeting expected performance standards or, due to a change in strategy, are no longer needed, they may simply be cut.

If employment contracts can be limited in duration and there is an open market for valued scientific and managerial skills, it follows that strong incentives must be designed in order to foster loyalty to the firm. UK company law generally favors owner-driven patterns of corporate governance similar to that found in the United States. UK company law supports the crafting by company boards of high-powered performance contracts governing top management. Following again the US model, the most important incentive in such contracts is large stock options grant. The founders and top management of companies driven by equity-based finance can create similar high-powered contracts with scientists, engineers, and less senior management within the company.

Both the carrot of large financial windfalls for successful companies and the stick of dismissal should an individual, or company, perform poorly are viable in the UK. The turbulence within the UK pharmaceutical industry, as discussed above, has resulted in dramatic hire-and-fire episodes within this sector. The prevalence of milestone-related venture capital financing within the UK biotechnology sector exposes companies to similar restructuring episodes and the high probability of dismissal due to failure or acquisition. Within the UK, several prominent biotechnology companies, such as British Biotechnology, Celltech, and Cantab, have undergone restructuring episodes, while other companies have failed. Such turbulence reinforces relatively short-term project or milestone-oriented company strategies, supported by stock options or other high-powered performance incentives crafted for employees by senior management.

Within the UK, the existence of capital markets willing to invest in IPOs is crucial in providing credibility to this system. While, as in the United States, most biotechnology companies have not reached a successful "exit" via IPO, or less regularly, a high value trade sale, over fifty UK biotechnology firms have had successful IPOs. For most of these firms owners, top managers, and employees holding stock options were able to sell their shares on public markets, at times for relatively large financial windfalls. Stock options as performance incentives are thus embedded in highly credible financial market institutions.

However, within the UK it should also be noted that fewer biotechnology firms have achieved the pronounced long-term development of stock market capitalization seen in the United States by leading biotechnology firms such as Amgen, Genentech, and Genzyme. Within the UK low or volatile stock prices may have depressed the viability of stock options within the biotechnology sector. This contrasts with the generally strong performance of the leading UK pharmaceutical companies. One interesting comment heard during interviews with senior managers of Cambridge area biotechnology firms is that large differential in potential long-term performance rewards across the large-firm pharmaceutical sector and smaller-dedicated biotechnology firms creates incentives for many of the country's best life-science managers and scientists to take jobs within the pharmaceutical sector rather than the biotechnology industry.

The UK Public Policy Context and the Issue of Underperformance: Evidence from the Cambridge Biotechnology Cluster

The architecture of national institutional frameworks within the UK supports patterns of financial coordination, high-powered incentives within firms, and flexible labor markets needed to sustain radically innovative biotechnology firms. This evidence, combined with the UK's position as performance leader in European biotechnology, supports the theoretical expectations of the varieties of capitalism approach. Nonetheless, the UK biotechnology sector clearly lags behind the United States in most areas of performance. This performance difference is particularly evident when comparing leading biotechnology sectors within the UK. The three leading US clusters in Boston, San Francisco, and San Diego each support many more companies, more venture capital, a greater number of IPOs, higher employment, and a larger number of therapeutic products that have reached the market.

One line of argument to explain the superior performance of the US industry is that national institutional frameworks have provided more efficient patterns of company coordination. Financial markets within the United States provide, on average, more high-risk finance to radically innovative companies, while larger and possibly more flexible labor markets exist within the United States. Stronger market incentives would also impact the viability of high-powered performance incentives within US biotechnology firms, again compared to the UK. While difficult to empirically test, it is reasonable to assume that, particularly within well-performing US technology clusters, institutions conduce to superior patterns of economic coordination than in the UK.

A complementary explanation, however, centers on differences in public policy toward the biotechnology industry in the two countries. The general prediction derived from comparative institutional theory is that, as an LME, public policy toward biotechnology should be designed to complement generally supportive national institutions and focussed on creating a support system of sector-specific regulation and policies. Has UK public policy toward biotechnology provided an adequate support structure for the industry?

While some important differences exist, public policy toward biotechnology in the UK has, in important respects, been modeled on US policy. While the country's first biotechnology company, Celltech, was created through the activities of the state-owned National Enterprise Council, UK policy toward biotechnology has generally oriented around sector-specific framework policies augmented by occasional diffusion-oriented policies aimed at providing resources to universities. The most important framework policies include the 1993 financial reforms discussed earlier and legislation passed in 1985 to transfer ownership of publicly funded research to universities along a virtually identical legislative framework as the US Bayh–Dole legislation (Arthur Anderson 1998).

While the UK government has generally refrained from allocating resources to directly support biotechnology firms along the German model, the government has, in an effort to broadly support science-based industry, launched government commissions aimed at identifying the sources of competitive success in biotechnology and related industries. These commissions have at times resulted in the introduction of moderate support policies impacting biotechnology. A good example is the 1999 Lord Sainsbury Report on cluster policy, which was influential in developing regional and governmental policies toward the creation and support of biotechnology clusters (see UK Department of Trade and Industry 1999; Cooke 1999). A prominent national initiative focussed on cluster policy was the 2001 Genetic Knowledge Park initiative, which, through a competitive bidding process, eventually provided roughly $5 million to each of five regional programs for use in developing networking and industry–university collaborations surrounding genetics (UK Department of Health 2002). UK policies have also targeted the commercialization of sciences. The most important policy in this area, discussed in more detail below, was the 1998 University Challenge Fund, which provided about $200 million in funding for university technology transfer offices with the aim of strengthening university commercialization programs.

Have these programs, in combination with more overarching framework policies, provided an adequate framework to support UK biotechnology? Focussing on examples from the Cambridge cluster, the analysis here will stress important differences in the sectoral support system surrounding the commercialization of science within the UK as compared to the United States. The UK has adequate national institutional frameworks to generate a successful biotechnology industry. However, the resources, incentives, and rules surrounding the marketplace for ideas (Casper and Murray 2003) within which university officials, scientists, and entrepreneurs interact differ in important ways from common practices within successful US clusters, and through doing so provide important disincentives toward the commercialization of science within the UK.

The Cambridge Biotechnology Cluster as a Marketplace for Ideas

Cambridge is home to a leading European technology cluster. The region benefits from a diversified agglomeration of firms from many technology intensive industries. The Cambridge cluster originally formed around the computer and semiconductor industry in the 1970s and 1980s, but grew during the 1990s to house one of Europe's largest clusters of biotechnology firms as well as a thriving agglomeration of software, Internet, and telecommunications firms. The founding idea for many of these companies derived from the University of Cambridge, perhaps Europe's strongest science and technology-oriented university. In addition to their science base, the Cambridge colleges have also lent resources, in particular land owned within the region, for the development of the cluster. In 1980, Trinity College sponsored the development of the Cambridge Technology Park, which has grown to house one of the largest collections of technology oriented companies within the UK. Following the success of this park, another prominent Cambridge college, St John's, sponsored the development of a company incubator on its land. In addition to this infrastructure, over the 1990s Cambridge has developed one of Europe's largest local venture capital industries. In 2002, over 25 percent of all venture capital invested within the UK was allocated to Cambridge area firms (Martin, Sunley, and Turner 2002).

The development of the Cambridge cluster was incremental and organic. The region benefitted from no regional development policies or other government subsidies aimed at growing a technology cluster in the area. Insiders routinely refer to the growth of the cluster as the "Cambridge phenomena", a reference to the region's organic growth (Garnsey and Cannon-Brookes 1983). As such, Cambridge is a good region to assess how broad national institutional factors interplay with the sectoral support system surrounding biotechnology within the UK. The region's biotechnology cluster is clearly successful. But, given access to Europe's strongest biomedical research infrastructure, has it reached its full potential?

One metric by which to examine the Cambridge cluster is the number and origin of biotechnology firms launched. Between 1990 and 2002, the Cambridge region launched thirty-nine new biotechnology ventures, on average about three new companies per year (the following draws on Casper and Karamanos 2003). Half of these firms were spin-outs from various departments and institutes within the University of Cambridge. A wide diversity of laboratories were involved, ranging from pure science departments, such as chemistry, to more applied research institutes that have clear connections to biomedical research such as the Institute for Cancer Research or the MRC Center for Protein Engineering. A few departments have been involved in serial spin-offs. These include the Departments of Chemistry and Biochemistry and the MRC Center for

Molecular Biology, which has spun out two of Cambridge's more high-profile biotechnology firms, Cambridge Antibody Technology (CAT) and more recently Astex. However, only two Cambridge academic scientists have become serial founders (i.e. launched more than one biotechnology company), both from the MRC Center for Molecular Biology. Furthermore, some very significant research laboratories have not been active on commercializing science into spin-off firms. These include the European Bioinformatics Institute and the Sangre Center, two large laboratories active in high-profile genomics-related research.

While the University of Cambridge is the dominant source of ideas for new biotechnology firms in Cambridge, half of the region's firms did not derive from the university. Roughly a quarter of the firms were spun out from universities in other parts of the UK but decided to locate in Cambridge. There are also a significant number of industrial spin outs. These companies include new ventures launched by teams of managers formerly employed with Glaxo and SmithKline Beechem (before their merger), companies spun off from established biotechnology firms in the region, and in one case a biotechnology firm incubated by partners of a venture capital firm.

While several problematic issues surround the performance of Cambridge as a biotechnology cluster, and more generally with UK policy toward the industry, it is important to emphasize that Cambridge is Europe's most successful biotechnology cluster. While comparative data on the number of firms commercialized by European universities does not exist, the University of Cambridge in all likelihood leads Europe. Most years at least one or two new biotechnology ventures have been launched from its laboratories. The university has also successfully launched numerous companies from its engineering and computer science departments. The willingness of a significant pool of founder teams to relocate to Cambridge is strong evidence that Cambridge is performing well as a biotechnology cluster. Moreover, these companies were launched in all cases with private funding, a marked comparison to the German approach focussed on public venture capital subsidies to virtually all new technology start-ups launched from the mid-1990s onward.

Despite the Cambridge cluster's success, the 39 companies launched during 1990–2002 is significantly less than in the San Diego cluster, where 104 companies were launched during the same time frame. Given the existence of generally supportive frameworks within the UK, why have not regions containing leading biomedical research complexes, such as Cambridge, developed industrial complexes that rival those within the United States? Furthermore, can elements of the sectoral support system surrounding UK biotechnology help explain this performance difference?

As discussed earlier, much policy debate within the UK has focussed on cluster policy. A theoretical insight driving cluster policy is that economic success within knowledge intensive industries is driven primarily by proximity or tacit knowledge (see generally Winter 1987). According to this line of thought, an inability to codify knowledge brings people together, forcing research organizations, whether public or private, to collaborate in close proximity. A policy implication of this argument is that governments should take the initiative in facilitating the establishment of relationships between laboratories within regional universities and technology spin-offs. They can do so through sponsoring the development of incubator laboratories and technology parks in close proximity to university laboratories.

A second assumption behind cluster policy is that clusters are primarily driven by local networks and that these networks may be insufficiently formed due to their heterogeneity. A diverse assortment of entrepreneurs, university scientists and laboratories, technology transfer officials, and financiers must form ties if the commercialization of science is to succeed. Networking concepts suggest that due to the diversity of this community many useful relationships may not be realized. Networking policy can help by bringing people together and giving them resources to explore their complementary interests. The UK Genetic Knowledge Park Initiative, for example, was financed by the government with the intention that resources could be used to form communities of academic and commercial users of a wide variety of genetics-based science into networks that could be used to accelerate the production and commercialization of knowledge in this area (Watts 2006). Networking is also a key aim of many private groups in the Cambridge region, in particular those sponsored by the local biotechnology trade association, the Eastern Region Biotechnology Initiative (ERBI).

Cluster policy and related networking initiatives do not lack merit. Commercial biotechnology is underpinned by multifaced network relationships linking scientists, financiers, and entrepreneurs (Powell et al. 2005). Moreover, networks, not distant or unsocialized market relationships, underpin much of the Cambridge biotechnology cluster. Moreover, as we will see momentarily, there is reason to believe that important Cambridge area research organizations, particularly in the area of genomics, are not actively participating within the Cambridge cluster. Policies such as the Genetic Knowledge Park initiative could usefully develop networks of relationships that could strengthen their role in commercializing Cambridge area science.

Nevertheless, cluster policies aimed at facilitating networks of actors that can exploit local tacit knowledge links may be misdirected, overemphasizing network creation at the expense of other important elements of a successful sectoral support system. Network-oriented cluster policies have a strong bias toward existing, predominately local actors within particular clusters. However, the evidence on the origin of Cambridge biotechnology firms demonstrates that a core strength of Cambridge as a cluster is its ability to bring in a broad range of firms, organizations, and individuals from outside Cambridge. Such actors will not benefit directly from local cluster policies aimed at strengthening existing local ties. Cambridge is a magnet for local activities because of its strength as a general marketplace for biomedical research. Networks, or ties, must be important as sources of contact for individuals, collaborators, or firms entering this marketplace. But these networks most plausibly have their origin in other activities that fall outside the scope of traditional cluster policies—for example long-standing scientific research communities, or contacts forged through previous affiliations in firms or laboratories.

Could an institutionally focussed analysis provide a more useful lens with which to examine the relative underperformance of the UK biotechnology industry, particularly compared with the United States? National institutional frameworks interact with sectoral support systems to structure marketplace rules and incentives. Within the UK, institutions encourage patterns of economic coordination needed for the private sector, or market-oriented aspects of biotechnology to become sustainable. Moreover, elements of sector-specific framework policy surrounding finance and the commercialization of science are also broadly sufficient within the UK. Important differences exist across the United States and the UK, however, in how nonmarket actors participate within the biotechnology marketplace. While the broad national framework governing the commercialization of science is adequate within the UK, important constraints also exist.

Impediments to the participation of universities and other nonmarket actors to active participation within the UK biotechnology marketplace range from broad public policy issues surrounding commercialization of large-scale science initiatives to more narrow issues relating to frameworks governing relationships between biotechnology spin-offs and laboratories or the resource base of university licensing offices. A third important issue is the importance of ensuring that nonmarket actors, particular universities in the biotechnology case, have sufficient resources to play a strong role within the marketplace. Through focussing on these three issue areas, the following draws on examples from the Cambridge cluster to illustrate how important differences in the sectoral support system surrounding nonmarket actors active in the UK biotechnology impacts the vibrancy of the UK biotechnology marketplace.

PUBLIC POLICY TOWARD SCIENCE FUNDING

Following the Bayh–Dole Act precedent, UK science policy transfers ownership of government-funded research to universities. However, in funding science, and in particular expensive large-scale projects, the UK government has frequently adopted the rationale that government funding is needed to keep important scientific knowledge within the public domain and away from companies. Such policies reflect a pure spillover model of funding science, in which a common domain of scientific ideas is created, from which a variety of actors, both public sector and private, can draw to support downstream research (see Heller and Eisenberg 1998). The pure spillover model differs markedly from the more commercially oriented science funding policy found from the 1980s onward in the United States, in which publicly funded sciene projects are charged with the goal of adding to the public domain of basic knowledge, but readily accommodate the commercialization of key methods and results driven by publicly funded research.

A complex and important debate surrounds the identification of viable demarcations of what types of public science should or should not be commercialized. Moreover, the relatively pure model adopted by UK policymakers is commendable in placing human interest concerns above more narrow commercial concerns when funding science. However, it also has negative effects on the willingness of important actors within the UK science community to participate within commercialization projects.

An important example of negative implications for the commercialization of science created by a pure spillover model is the activities of UK actors involved during the 1990s and early 2000s in the International Human Genome Project (HGP). The UK was a major sponsor of this project, contributing about $400 million toward the sequencing of the human genome. Much of this funding was contributed by the Wellcome Trust to the Sanger Center and, to a lesser extent, the European Bioinformatics Institutes, both located in Cambridge. The Sanger Center is one of the world's largest gene sequencing centers, responsible for decoding over one-third of the genome as part of the public HGP (Sulston and Ferry 2002). The director of the Sanger Center during this period, John Sulston, was awarded the 2002 Nobel Prize in medicine for his contributions to gene sequencing. The EBI is located in close proximity to the Sanger Center and is a leader in developing the software used to manage huge databases of genetic code created by new genomics technologies.

Particularly during the latter stages of the human genome sequencing effort, a fierce rivalry erupted between members of the public project and Craig Venter, a prominent geneticist who in 1998 started a well-funded company, Celera, which aimed to employ alternative sequencing method to more rapidly assemble a complete genome sequence which could be used as a basis for comprehensive data mining and gene patenting. Following the founding of Celera, funding for the HGP was justified around the goal of keeping the human genome in the public domain, and away from patent-minded biotechnology companies. Sulston became an international spokesman for this movement and emerged as a fierce critic of the patenting of genes (see Sulston and Ferry 2002).

One consequence of the strong orientation of the UK participants in the HGP against gene patenting and related commercial activities is that UK institutions involved with the project refrained from engaging in commercial activities. In a survey of the commercial activities of major public laboratories within the Cambridge region (Casper and Karamanos 2003), almost no commercial activity was identified by either of these two organizations. Neither organization has spun off a firm or collaborated in a published scientific project with any Cambridge area biotechnology firm. No scientist employed within these two organizations is listed as a scientific advisory board member of any firm. In the Cambridge labor market survey discussed earlier, only one scientist who had previously worked at the EBI is now employed within a Cambridge biotechnology; no Sanger Center scientists have moved to the local biotechnology community.

The Sanger Center case is particularly intriguing due to comparisons with one of its key collaborators in the international HGP, the Whitehead Institute at MIT. The leaders of the US human genome sequencing project, Francis Collins and Eric lander, were also fierce critics of Venter. Lander was director of the Whitehead Institute, an MIT affiliated laboratory that contributed the largest share of the US sequencing effort. Following the more permissive US policy context toward commercializing science,

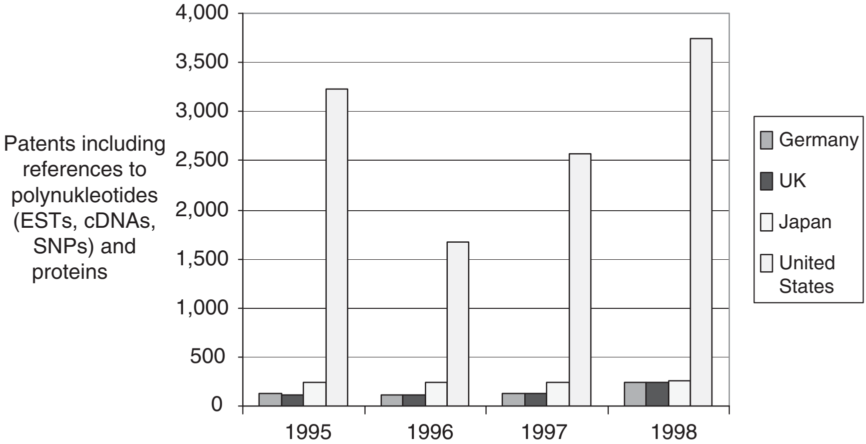

Figure 5.3. National comparisons of genomics-related patenting, 1995–8

Source: Ernst and Young (2000) based on EPO patents.

Lander was able to orient the Whitehead Institute toward both pure science and also commercially oriented projects. The most important latter project was the launching of Millennium Pharmaceuticals, an important US biotechnology firm that was founded using genomics technology originally developed at the Whitehead Institute. Within the more permissive US model toward the funding of science, the Whitehead Institute used public funding to contribute to the public genome project, but transferred many of the techniques developed through the project into Millennium.

The ability of US companies to draw upon genomics techniques funded through US science policy contributed to the country's biotechnology companies developing an enormous lead in genomics-related R&D. One indicator of this lead is genomics-related patenting. Figure 5.3, based on European Patent Office statistics, compares genomics-related patenting in the late 1990s across the United States, UK, Germany, and Japan. Companies located within the Untied States are responsible for over 85 percent of all genome-related patents during this period. As Germany and Japan were only minor contributors to the HGP, their weakness in genomics patenting is not surprising. The minor contribution by UK firms, despite the country's strong leadership in basic genomics research, is indicative of the country's stance toward the commercialization of large science projects.

The poor performance of the UK in gene-related patenting can be attributed in large part to public policy toward the commercialization of science. The commercial exploitation of the human genome is clearly a complex public policy issue, for which few simple, clear policy recipes exist. Starting in 2002 changes have begun to occur. Both the Wellcome Trust and the Sanger Center have indicated that they will take a more active stance toward commercializing their technologies, and the Sanger Center has developed a consulting relationship with a gene sequencing technology firm located in Cambridge, Solexa.

However, at the same time general public policy toward the commercialization of science remains unsettled, with negative implications on the development of commercial marketplaces surrounding UK basic science. In 1999, for example, the UK Medical Research Council and the Wellcome Trust unveiled an ambitious population genetics project, called the "UK Biobank", to run in conjunction with the UK National Health Service (Watts 2006). The project was funded for $115 by the UK Medical Research Council and the Wellcome Trust, and will collect biological samples and health histories from 500,000 UK adults. This is another area with strong commercialization possibilities, as seen by the development of very successful biotechnology firms focussed on population genetics in Iceland (Decode), the United States (Myriad Genetics), and elsewhere. While privacy concerns and issues surrounding the informed consent of patients within large-scale population studies strongly impact this debate, much of the discussion of the proposed project mirrored an anticommercialization of science discourse resembling that surrounding the UK contribution to the HGP during the 1990s. As funded, the project precludes commercial participants and the direct patenting of findings generated through the Biobank (Blackburn 2006).

SUFFICIENT RESOURCES FOR TECHNOLOGY LICENSING OFFICES

A second issue impeding the development of richer biomedical research clusters surrounding most UK universities is a relative lack of resources within university technology licensing offices (TLOs) compared again with the United States. As discussed in Chapter 3, TLOs in most major US research universities are well financed due to the existence of substantial, often multibillion dollar, endowments within universities. Universities can draw on these endowments to finance TLOs to cover expensive patenting costs and recruit highly trained technical experts to supervise spin-offs across a number of disciplines, expecting a return in the long term. Most UK and continental European universities lack a tradition of endowment fund-raising, and as a result have relatively paltry funds available to finance TLOs (see Anderson 1998).

While few reliable estimates exist, it is commonly asserted by TLO staff that it now costs several hundred thousand dollars for a university to spin off a biotechnology company. These costs comprise patenting and related legal costs and in some cases initial business plan development and company incubation. These are substantially more resources than TLOs in most UK universities have on hand, leading to undersized TLOs lacking sufficient expert staff or funds to cover patenting costs. As mentioned above, in 1998 the UK government funded an aid program to universities called the University Challenge Fund to promote the commercialization of more science. Through this scheme, qualifying universities receive approximately £1 million per year, of which they can spend no more than £250,000 on any one investment (see Kettler and Casper 2001: 58). Through encouraging universities to enhance their TLO capabilities, the University Challenge Fund is an important example of a policy instrument designed to strengthen the position of nonmarket actors within local marketplaces surrounding biotechnology and other science-based industries.

While providing some extra leverage to university TLOs, given the high costs of spinning out firms in the biomedical area, schemes such as the University Challenge Fund may not be enough to cover the costs of large TLOs, particularly in the short to medium term, before sufficient revenues from successful investments can be used to offset costs. One general implication of the lack of resources within university TLOs is that private funding foundations in the UK, including the Wellcome Trust and the Imperial Cancer Research Fund, have developed their own technology transfer facilities. While in the short term this might facilitate the commercialization of some scientific projects that would lack sufficient resources from university TLOs, policies by foundations to take control of intellectual property rather than transfer it to universities will also diminish the stock that science university TLOs have to commercialize. Moreover, as many academic science projects receive funding from more than one source, intellectual property ownership covering such projects could become fragmented, creating new transaction costs surrounding the commercialization of such projects.

FRAMEWORKS STRUCTURING RELATIONSHIPS BETWEEN LABORATORIES AND FIRMS

A final issue surrounding Cambridge and potentially other UK biotechnology clusters is a lack of clear and transparent rules structuring the interface between the nonmarket and market sectors. Procedures and norms surrounding the commercialization of science are vague or change from project to project. Interview research in Cambridge during the 2000–2003 period revealed uncertainty surrounding the proper role of academic founders within commercial enterprises, or, perhaps more mundanely, the existence of transparent procedures surrounding the transfer of intellectual property from universities to start-up companies (see Casper and Murray 2003).

A lack of transparent frameworks structuring the commercialization process increases the transaction costs for participants within the marketplace, in particular academic scientists. One disturbing finding from the survey of Cambridge biotechnology firms is a lack of repeat or serial founders. Interviews with several academic founders of companies revealed a common complaint that the process of starting companies is opaque, time-consuming, and difficult. Rather than founding several companies over their careers, a common trend of entrepreneurially minded professors at MIT, UCSD, Stanford, and other major US research universities, many academic scientists at Cambridge choose to develop long-term relationships with a single firm spun off from their laboratory. In a few cases, such as Kudos and Cyclacel, a major Dundee company with an R&D center in Cambridge, scientific founders have become chief scientific officers of a firm while retaining professorships within university departments. There is a risk in such cases that firms, in some respects, can become extensions of basic research laboratories. While this may lend prestige to particular firms and over time channel tacit intellectual property to the firm from the laboratory, lack of clear frameworks structuring relationships between laboratories and firms can also impede the success of both individual firms and the broader cluster.

From the point of view of the broader cluster (and universities that have equity stakes in firms), the lack of serial spin-offs from senior scientists reduces the number of firms in the area. In an industry in which only a small percentage of early-stage firms succeed, this diminishes the ability of both VCs and universities to profit from portfolio strategies. Having fewer firms in an area also diminishes labor market externalities that we have linked to the innovative capacity of firms. From the point of view of the firm, it is not immediately clear why a brilliant academic research scientist should necessarily be a successful line manager, particularly if dividing time between two jobs. Furthermore, as a firm begins to mature, commercial priorities may diverge from a founder's basic research stream, leading to conflicts between the two agendas. On the other hand, the success of the US biotechnology industry indicates that academic scientists may serve well as scientific advisers on SABs.

One important difference in frameworks governing relationships between university scientists and firms in most major research universities in the United States with the UK (and much of Continental Europe) is that in most US universities academic researchers are prevented from taking line positions in companies so long as they maintain their university jobs. Furthermore, university-based scientific founders of companies must make a clear choice between taking an equity position or receiving research funding from the company. This tends to demarcate boundaries between laboratories and firms in a clearer way than seen in Cambridge, and through doing so promoting serial spin-offs from laboratories. This is again particularly true at MIT, where some professors have spun off more than a half dozen firms (Casper and Murray 2003).

Conclusion

Has a varieties of capitalism perspective enriched the analysis of UK biotechnology? The perspective helps explain the superior performance of UK biotechnology compared to Germany. UK biotechnology is heavily specialized around radically innovative therapeutic research and has adopted the key elements of the Silicon Valley model. Moreover, financial markets, corporate governance systems, and labor market organization all closely follow the LME model, plausibly providing UK companies with a comparative institutional advantage in biotechnology. The leading position of UK firms within Europe, seen through the relatively large number of therapeutic products brought to market and the existence of a critical mass of profitable firms, is also consistent with the comparative institutional advantage explanation.

Nevertheless, the relatively poor position of UK biotechnology when compared with the US industry is a surprising finding, suggesting that one cannot "read off" industrial outcomes from the orientation of institutional frameworks alone. Analysis of the UK public policy context surrounding biotechnology and the Cambridge cluster demonstrates that, compared with typical patterns within the United States, UK universities do not have the resources or, at times, incentives to fully participate within the marketplace for ideas surrounding commercial biotechnology. This finding provides support to perspectives emphasizing the importance of public policy in stimulating success in science-based industry (see Henderson, Orsenigo, and Pisano 1999). The usefulness of the varieties of capitalism perspective, within this context, is its ability to help define the scope of policies needed to succeed. Unlike CMEs such as Germany, where policies would need to replace or circumvent overarching national institutional frameworks, in the UK policies could usefully complement national institutions that are generally incentive compatible with the Silicon Valley model by, in the biotechnology case, providing resources and incentives for nonmarket actors to effectively commercialize science.

6

Alternative pathways to competitiveness within CMEs: the subsector specialization argument

In discussions of biotechnology, public attention has focussed primarily on the drug discovery segment of this industry. This is the area where spectacular advances are occurring in the harnessing of molecular biology and genetic engineering techniques to design new treatments against disease. However, industry analysts have long noted that within biomedical-related fields several market segments exist, including diagnostics, drug discovery and, of particular importance here, a wide assortment of platform biotechnologies (see Ernst & Young 1998*a*: 5–6). Firms in this field develop a variety of tools designed to increase the efficiency of research methods in the life sciences. A German company, Qiagen, is a world leader in one of the largest platform biotechnology markets, surrounding the creation of automated devices to isolate and prepare DNA for research purposes.

A similar parallel exists within software. While project-based firms focussed on radical innovation dominate the standard software and, we'll see in Chapter 7, so-called middleware segment of the Internet software market, there are large markets focussed on the design and customization of software platforms for business. Market segments within the enterprise software category include enterprise resource planning (ERP), customer relationship management (CRM), groupware, systems integration, e-commerce software providers, and a variety of firms creating sector-specific enterprise tools. As with platform biotechnology, a German company, SAB, has grown into a world-leader, having parlayed expertise in developing ERP software platforms to become the fourth largest software company in the world.

The industrial organization surrounding platform biotechnology companies and enterprise software is in many ways similar to that of machine tool firms, a sector in which Germany has long displayed a competitive advantage. Could German new technology companies achieve a similar competitive advantage in platform biotechnology and enterprise software? This chapter investigates pathways by which entrepreneurial technology firms located within CMEs can become sustainable. It argues that a viable strategy for new technology companies within CMEs is to specialize within subsectors of new technology industries with technological and market characteristics demanding the creation of company capabilities in which firms may draw on comparative institutional advantage. To develop this argument, the chapter starts by exploring the technological characteristics of incrementally innovative new technology and explores the validity of the argument through examining patterns of subsector specialization of publicly listed biotechnology and software firms across the UK, Germany, and Sweden. The explanation is then further strengthened through a qualitative analysis of the generally strong performance of German firms in the platform biotechnology and enterprise software markets.

Technology Regimes and Organizational Dilemmas for Incrementally Innovative Technologies

The analysis so far has associated new technology industries with radically innovative innovation strategies, such as those commonly found in therapeutics and standard software, and found that attempts to sustain large numbers of therapeutics firms within Germany have been problematic. The subsector specialization argument suggests that markets within a high-technology industry such as software or biotechnology may vary tremendously in terms of market and technological characteristics. If the technological regime characteristics underlying platform biotechnologies and enterprise software differ from those within therapeutics or standard software, so will the typical organizational dilemmas facing managers of these firms and, presumably, the ideal types of national institutional frameworks needed to support their governance.

Table 6.1 summarizes the different technological characteristics surrounding radical and incremental systems of innovation. The key idea motivating this comparison is that, unlike radically innovative industries, platform biotechnology and enterprise segments face more cumulative

Table 6.1. Technology characteristics for radical and incremental innovation sectors

	Radically innovative sectoral systems (e.g. therapeutics biotechnology, standard software)	Incrementally innovative sectoral systems (e.g. platform biotechnology, enterprise software)
Appropriability regime	Strong	Weak
Level of cumulativeness	Low	High
Knowledge property	Generic and codified knowledge	Firm-specific and tacit knowledge

trajectories of technological change. Incremental paths of technological change imply that firms face less risk of competency destruction, compared to firms operating within radically innovative segments. However, increased cumulativeness is usually accompanied by two important new risks not faced by radically innovative firms: market risks created by increased difficulty of firms in appropriating, or capturing value, from innovations, and organizational dilemmas created by the prevalence of tacit and firm-specific knowledge.

When appropriability regimes are weak, technological assets developed by the firm may become generic and are easily mimicked by competitors. While patents on a given method may be available, alternative technological approaches exist, leading to widespread entry once large markets for a given process innovation are demonstrated. Weak appropriability regimes create market risk: firms may innovate in creating a new technology, but then face the problem of expropriation as competitors quickly introduce similar products. David Teece (1986) has provided the leading analysis of strategies available to firms facing weak appropriability regimes. Building on Porter's idea (1985) of the value chain, Teece suggests that to build a defensible market position surrounding a generic technology, firms must develop what he calls "co-specialized assets". Firms do so by bundling their generic technologies with complementary activities within an industry's value chain that are more specialized, creating more defensible market positions.

Co-specialized asset strategies often involve horizontal integration along a value chain or vertical integration within an industry. This strategy often entails the integration of R&D activities with specialized marketing and distribution capabilities aimed at customizing products for particular market niches or individual customers. The bundling of assets can reduce appropriability risks by increasing the value of a product for particular customers and can also increase retention through creating sunk costs. For example, within the enterprise software sector, firms usually offer generic software platforms at relatively low cost, but create additional revenue streams through customization work needed to optimize the software for a particular client's business (which often creates sunk costs that can be used to generate revenue through software updates and service contracts). Vertical integration strategies attempt to bundle several potentially generic technologies into an integrated technology platform, again with the aim of increasing value to customers while potentially locking them into follow-on revenue streams. In addition to maintenance contracts, many firms, following Hewlett Packard's strategy in the ink-jet printer business, attempt to create follow-on revenue streams through tying their machinery to the use of proprietary consumable kits needed to perform various tests.

Incrementally innovative technologies generate more complex organizational structures within companies, which can be called collaborative firms (see Casper and Whitley 2004). As with most entrepreneurial firms competing in new markets, collaborative firms focus on incentives needed to foster commitment to fast paced, stressful environments. But more cumulative innovation trajectories lead to the success of collaborative firms being driven by routines that develop over multiple development and implementation cycles. Due to the importance of customization, integration, and other co-specialized asset strategies, a key attribute of a collaborative firm's competitive success becomes its ability to develop an organizational culture or set of routines enabling different types of professional employees to work well in cross-functional teams. Firms must create routines encouraging collaboration between specialists in different technological and business fields.

Collaborative firms generate investments in firm-specific and often tacit knowledge among employees (see Winter 1987). Firm-specific knowledge exists when companies develop routines, skill-sets, or technological processes that are not easily transferable to other companies. While project-based firms revolve around the completion of relatively short-term R&D milestones, the success of collaborative firms is driven by the development of integrative competencies that develop over multiple development and implementation cycles. Firm-specific knowledge is often embedded within teams, composed, for example, of core R&D personnel and technicians working to customize technologies for particular customers. Shared knowledge also tends to be tacit, or difficult to codify. Customization strategies, for example, often create incremental improvements in technologies as new ideas developed through various projects are integrated back into a firm's core library of technologies. When research results remain tacit, it becomes difficult for management and outsiders of the firm to assess the value of research results over the short to medium term, until projects are brought to market.

The existence of firm-specific and tacit knowledge within companies creates commitment risks faced by employees within collaborative firms. Employees within collaborative firms must worry about managers pursuing opportunistic employment policies, such as holding wages below industry norms, once extensive firm-specific knowledge investments have been made. Unless managers can assure employees that they will not exploit firm-specific knowledge investments, employees could refuse to make long-term knowledge investments within cross-functional teams, creating patterns of suboptimal work organization that could hurt the performance of the firm. Performance incentives may also be difficult to develop, as extensive teamwork across employees with different skill-sets makes it difficult to award individual employee performance (see Miller 1992). Such opportunism may be seen as unlikely given the overarching desire from management to create high-powered incentives for employees working within entrepreneurial settings. However, should the firm need to lay off employees due to financial difficulties, employees with substantial firm-specific skills are disadvantaged compared to those with more general skills.

Managerial holdup risks are difficult to reduce within short time periods. Managers must generally create a series of "credible commitments" (Kreps 1990) not to hold up employees. The norms and rules comprising these commitments are political in nature (see North and Weingast 1995; Sabel 1996). Their purpose is to transform short-term, single iteration transactions between managers and employees (lasting, for example, one cycle of product development), into long-term relationships. Credible commitments often comprise formal, though often unenforceable norms or rules made by managers. Examples of such relational contracts are commitments to refrain from or develop a strict code to govern hire-and-fire practices within the firm, or to develop consultative workplace practices or other forms of stakeholder decision-making. Reputation-based incentives, for instance regarding norms followed in creating promotion systems, procedures used to award bonuses, or consultative practices between top management and skilled employees regarding major strategy decisions can also create a long-term equilibrium toward risky skill investments.

Institutional Frameworks and Subsector Patterns of Specialization Across Publicly Traded Firms in Germany, Sweden, and the UK

In terms of encouraging different kinds of entrepreneurial technology firms, the subsector specialization analysis generates a more nuanced set of propositions concerning the comparative institutional advantages of CMEs and LMEs in promoting new technology firms. As discussed in the first part of the book, LMEs enjoys comparative institutional advantage in the governance of radically innovative project-based firms focussed on developing competence-destroying technologies with high failure risks, while CMEs have a corresponding disadvantage. However, CMEs may have a comparative institutional advantage in creating organizationally complex collaborative firms, while firms located within LMEs may have a corresponding disadvantage in developing firm-specific competences in cumulative technologies.

Pervasive patterns of nonmarket coordination within CMEs, particularly surrounding labor market regulation and organized skill-development systems, strongly favor the development of managerial commitments needed for employees to willingly make firm-specific knowledge investments that are not easily salable on open labor markets. Such arrangements tend to "lock-in" owners, managers, and skilled employees into long-term, organized relationships. Strong norms and legal obstacles to "hire-and-fire" combined with a long-standing tradition, buffered by co-determination laws, of consultative patterns of work organization, favor competence-enhancing human resource policies. As Streeck (1984) has argued with respect to Germany, within CMEs management must treat employees as "fixed" rather than "variable costs", and as a result have a strong interest in developing long-term career structures for all skilled employees. CMEs should have a comparative institutional advantage in the governance of organizationally complex collaborative firms developing firm-specific competences in cumulative technologies.

At the same time, institutions within LMEs may, over time, provide disincentives for companies employing the collaborative model of organizing the firm. LMEs tend to develop far more market-based forms of industry coordination, generally supported by less government regulation, particularly within labor markets. Companies embedded within LMEs face far less institutionalized “lock-in” regarding employees or other stakeholders to the company. Hire-and-fire, when embraced by most companies within a sector, can be used to create large external labor markets for most skills. On the other hand, employees facing this pattern of labor market organization should be reluctant to develop patterns of firm-specific skill development needed to support entrepreneurial strategies relying on the development of high organizational complexity. LMEs should have a comparative institutional disadvantage in the governance of entrepreneurial firms where organizational complexity is high.

The subsector specialization framework represents a potentially important extension of varieties of capitalism theory, as it demarcates a pathway by which Germany and other CMEs may foster new technology firms, but in subsectors compatible with their broader national institutional frameworks. To demonstrate the plausibility of this theory, we draw on findings from an earlier article by Casper and Whitley (2004), which tests the subsector specialization theory through examining patterns of industry specialization during 2001 across publicly traded software and biotechnology firms in the UK, Germany, and Sweden. In terms of national institutional framework orientation, Sweden has long been characterized as a CME, with patterns of union dominated industrial relations and skill-development, regulated labor markets, and stake holder-oriented corporate governance broadly mirroring the German system (see Pontusson and Swenson 1996).

The inclusion of Sweden thus provides two CME country cases with which to test the theory, along with the UK as a benchmark LME case. While the subsector specialization of these firms does not necessarily reflect superior performance, firms performed well enough during their initial start-up phase for investment banks and private investors to invest in their further growth through IPOs on the stock market. If a country has a high number of public firms specialized in a particular subsector this is a good indicator that competences associated with that subsector can be efficiently governed within the country’s institutional frameworks.

The primary business of each company was classified through an analysis of their web pages. Company summaries and subsector classifications published on the Internet by financial service companies were also used to verify classifications. All biotechnology and software firms listed on technology-oriented stock markets in the UK, Germany, and Sweden were included. As the theoretical analysis rests largely on nation-specific institutional effects on the organization of firms, a check was made to ensure that all companies included in our analysis had corporate headquarters in Germany, Sweden, or the UK. This led to the removal of three companies listed on the German *Neuer Markt* that had headquarters outside Germany.

For many biotechnology companies determining whether the primary orientation was toward development of platform technology or therapeutic products was simple. Therapeutic companies presented themselves as specialists within particular therapeutic areas, such as immunology or cardiovascular diseases, and had extensive internal expertise in disease-specific areas. Platform technology companies focussed extensively on their technological competencies that are usually presented as applicable across a wide array of therapeutic research areas. However, some companies, particularly in the genomics area, develop technology platforms that can then be used to generate therapeutic targets (so-called "gene to lead" strategies). For these companies, it was determined whether their primary technological orientation was toward the improvement of a general purpose technological platform and its licensing to other firms, or toward in-house therapeutic development.

Software companies were classified as focussed on enterprise software, an incrementally innovative subsector, or one or two more radically innovative subsectors, standard or middleware software. Classifying the software firms was in most cases straightforward. Middleware software firms usually identified themselves by this product category, and were focussed on the development of software to improve the efficiency by which different computing systems interfaced within communications networks. To differentiate standard and enterprise software vendors we focussed first on well-known standard and enterprise software categories (e.g. ERP and CRM products are well-known enterprise software segments, while multimedia, entertainment, and graphics software are well-known standard software segments). For firms difficult to classify, we examined the degree by which the company offers to customize its software for clients. Companies offering extensive consulting, implementation, or systems integration services were classified as enterprise software firms. Standard software companies, on the other hand, generally licensed software "as is" to clients and did not engage in extensive consultancy-related services.

Table 6.2. Subsector distribution of biotechnology companies, 2001

	Germany		UK		Sweden	
	Number	Percent	Number	Percent	Number	Percent
Platform biotechnologies	13	81	6	15	8	73
Therapeutics/product-based biotechnologies	3	19	34	85	3	37
Total	16	100	40	100	11	100

Source: Casper and Whitley (2004).

The subsector distribution of biotechnology firms in Germany, Sweden and the UK is summarized in Table 6.2. These results indicate that the UK is the only one of these three countries with a well-developed concentration of therapeutics biotechnology firms (thirty-four). This supports the earlier analysis of radically innovative biotechnology firms in Germany and the UK in Chapters 4 and 5. Neither the German nor Swedish sectors have a critical mass of publicly listed therapeutics biotechnology firms (only three in each country), while each has a larger number of platform biotechnology firms. While supporting the expectations of the varieties of capitalism approach, these results should not be considered conclusive due to the small number of public biotechnology firms existing in Sweden and Germany.

Table 6.3 summarizes the software cases. The German evidence strongly supports the expectations of the subsector specialization argument. While a relatively large number of German software firms are traded on the German stock market for growth companies, 90 percent of firms (fifty-four in total) are in enterprise software, while there are only three firms in either standard software or middleware. The UK data are also supportive. The UK has the largest software industry in Europe and 74 percent of these firms are in "radically innovative" segments, standard software or

Table 6.3. Subsector distribution of software companies, 2001

	Germany		UK		Sweden	
	Number	Percent	Number	Percent	Number	Percent
Enterprise software	54	90	23	26	20	44
Standard software	3	5	58	66	16	34
Middleware software	3	5	7	8	10	22
Total	60	100	88	100	46	100

Source: Casper and Whitley (2004).

middleware. This combined with the smaller number of enterprise software firms generally supports our predictions. However, the UK case is puzzling in another respect. Why are most of the UK software firms in standard software, with so few in middleware software?

The pattern of Swedish software firm specialization, on the other hand, is problematic. While a large number of enterprise software firms exist (20, or 44% of the total), over half the Swedish software firms are in radically innovative areas, and Sweden has Europe's largest concentration of publicly listed middleware firms. Moreover, the 10 publicly listed middleware firms represent only a small percentage of a much larger population of recent start-ups in this area (see Glimstedt and Zander 2003). The Swedish concentration of middleware software firms poses a strong challenge to the theoretical predictions of the varieties of capitalism framework, as "coordinated market economies" should not have a comparative institutional advantage in this area. Motivated by this unexpected finding, Chapter 7 investigates the Swedish middleware software industry more carefully.

Overall, these statistical data, despite limitations, provide good support for the theory that subsectors of new technology vary, and respond to different patterns of institutional incentives and constraints. Of the 15 cases, 12 could be interpreted as confirming the expectations of varieties of capitalism theory (UK middleware, Swedish middleware, and standard software being problematic). For these three European economies, the claim that national institutional frameworks influence patterns of competitive advantage, and specialization, should be taken seriously.

Germany's Performance in Incrementally Innovative New Technology Industries

To further strengthen the claim that firms located within CMEs can develop competitive advantages in incrementally innovative subsectors of new technology industries, the German case is now examined more carefully. Process tracing based on field research, supplemented at times by additional descriptive statistics, can help to examine the link between institutions and firm organizational strategy more sharply. Both platform biotechnology and enterprise software are examined in more detail, providing richer evidence that German entrepreneurial technology firms have experienced important successes in these two subsectors.

Platform Biotechnology

Platform biotechnology markets are driven by multibillion dollar R&D budgets of the large pharmaceutical companies, R&D investments by hundreds of smaller therapeutic biotechnology firms, and multibillion dollar public funding of academic bioscience research. While there has long been a market for the provision of reagents and other laboratory supplies, the development during the mid-1970s of recombinant genetics techniques created new market opportunities for platform biotechnology start-ups. Most common molecular biology techniques, such as the filtration or amplification of DNA, were originally performed by junior scientists and laboratory technicians, took multiple days to complete, and were prone to human error. The advent of commercial biotechnology in the early 1980s created a large potential market for consumable kits used to automate and speed up common molecular biology procedures. One of the first and most profitable techniques developed is the polymerase chain reaction (PCR), discovered in 1983 at the San Francisco biotech start-up Cetus by Kary Mullis, who won a Nobel Prize for the discovery (Rabinow 1996). PCR is used to amplify tiny DNA samples into larger volumes needed to perform a vast number of common genetics experiments. PCR has also helped establish new downstream markets, including diagnostic tests for inherited disease, genetic fingerprinting procedures used in police work, and a variety of services, such as paternity testing and DNA banking.

The success of PCR created large markets for other platform biotechnologies. Among the first were technologies to filtrate DNA and other nucleic acids out of broader molecular soups. Early procedures for nucleic acid filtration were labor intensive and could take over two days to complete. The German firm Qiagen was first to enter this market, having invented a consumable kit that could filtrate nucleic acid in a number of hours. Other platform biotechnology markets developed around the automation of assays, first through robotic assembly line approaches that allowed dozens of experiments to be conducted simultaneously, then by the entry of firms focussed on "laboratory on a chip" technologies that allow thousands of experiments to be conducted simultaneously on small chips. The commercialization of genomics technologies during the late 1990s created additional platform biotechnology markets. Examples include a variety of equipment-related markets for proteomics-related technologies and markets surrounding development of software to develop bioinformatics databases, map genetic regulatory networks, model protein structures, or create new small molecule libraries through in silico combinatorial chemistry (see Nightingale 2000).

German firms have had success in platform technologies. Referring back to Table 6.2, thirteen of the original sixteen German biotech firms to complete IPOs during the pre-2001 boom had their origins within platform biotechnology. The three largest German biotechnology firms are in this area. In addition to Qiagen, this includes Lion Biosciences, a leader in the creation of bioinformatics software, and Evotec, a firm first founded to commercialize high-throughput biological micro-arrays, but which has subsequently expanded to offer a range of tools and services designed to aid the drug discovery process. Due to the similarity with the machine tool industry, early studies of the German biotechnology industry predicted that German firms would come to specialize, and possibly even dominate, platform biotechnology segments (see Casper 2000; Casper and Kettler 2001). While early patterns of German subsector specialization did show a pronounced focus in this area, the majority of German firms began moving into therapeutics during the early 2000s. However, recent industry surveys (Ernst & Young 2005*a*, 2005*b*) report a sharp migration of many German start-ups from pure therapeutic approaches to so-called hybrid business that incorporate a platform technology sales approach into their core business.

The technological characteristics of platform biotechnology firms strongly resemble those underlying new technology firms represented by the collaborative firm model. Most platform biotechnologies, once developed, experience relatively cumulative technological trajectories. Technological assets are more stable and less prone to sudden shifts in value or usefulness. Many platform technology firms in the biosciences originate as novel laboratory methods that are developed to facilitate academic research programs, but can be applied to a particular group of common life science research activities. Once commercialized into a company, R&D efforts commonly focus on improved instrumentation, process improvements, and documentation needed to make the technology commercially salable. After initial products or services are launched platform biotechnology companies also commonly expand into related areas on new ideas generated through the completion of particular projects. For example, Qiagen was founded in 1984 on the basis of the founder's doctoral thesis on the creation of nucleic acid filtration devices. Over the last 15 years the firm has generated over 225 products that largely represent extensions of this initial technology.

Unlike therapeutic discovery sectors, most platform technology segments are characterized by market risks created by weak appropriability regimes. They have difficulty in capturing value from innovations. Despite their complexity and frequent origins within basic research laboratories, most important platform technologies, once validated as potentially large markets, have quickly attracted numerous entrants. Within the laboratory technology area, technologies seen as exotic a few years ago, such as the cloning of target strains of DNA for laboratory work (PCR), are now widely available. A similar phenomenon has occurred within the genomics field. Providing access to libraries of genetic sequences, a high-profile activity during the mid-1990s, has become only a few years later a readily available service. Competition within particular product markets allows pharmaceutical firms and other major customers to negotiate lower prices for services than those expected by the biotechnology firm, especially for high-volume purchases.

Many platform biotechnology firms have adopted Teece's co-specialized asset strategy as a response to commoditization. Two prominent co-specialized asset strategies exist within many platform biotechnology markets. The first is customization. The idea here is to bundle a firm's core R&D activities with sizable investments in technical sales and distribution activities that can be jointly used to develop and market products for narrow classes of users. Customization can dramatically increase the value of products for users. Such projects often entail large up-front sunk costs as specialized applications of a technology are developed for the client. This creates additional revenues for the platform biotechnology company and may lead to the development of so-called switching costs facing the client, helping to ensure repeat business. Moreover, once customers have purchased a particular firm's technology, lock-in effects often develop due to the sunk costs of purchasing entirely new systems. This can lead to follow-on business as technological upgrades or new services tied-in to established platforms are introduced.

Some platform biotechnology firms have worked to expand the competitive scope of its products, creating lines of products with different technological specifications. Qiagen, for example, has identified over two dozen distinct markets for its nucleic filtration products, for which it has created a broad line of products designed for different yields, types of nucleic acids, and other parameters. Many platform technology firms take customization even further, aiming to develop specialized products or services for individual customers. This is common with "laboratory on a chip" technologies developed by companies such as Evotec, which usually need to be designed for the specific experimental needs of individual users. Early in its history, Lion Bioscience developed a similar approach by developing multiyear collaborations with Bayer and other large pharmaceutical companies to create customized bioinformatics platforms to aid these firm's move into genomics technologies.

A second strategy used by platform biotechnology companies is to vertically integrate, embedding two or more complementary technologies into systems that may be sold to customers. Vertical integration often creates financial barriers of entry to competitors and may also help increase customer retention through developing a "one stop shopping" approach that simplifies purchasing decisions. Qiagen and Evotec have both adopted this strategy. Facing competition in the market for its consumable products, Qiagen in the late 1990s decided to move into an emerging market for automated laboratory equipment that could perform a series of techniques involving several dozen simultaneous experiments. This allowed Qiagen to market laboratory automation systems instead of simple test kits. Qiagen also hoped to develop product lock-ins through its integration strategy, as its laboratory automation equipment was designed to only use consumable products sold by Qiagen, creating a long-term revenue stream for these products and potentially dampening the threat posed by increased competition for its consumable products. Evotec developed a similar strategy, starting life as a biology-focussed company with expertise in conducting high-throughput assays, but soon acquiring a company with a complementary technology, the design of large chemical libraries. Through integrating high-throughput biological and chemical methods, the company could credibly position itself as a full-service provider of drug discovery technologies.

In summary, German firms have enjoyed far more success within platform biotechnology markets than in therapeutics. One reason for the widespread move by German firms into platform biotechnologies is more attractive short-term business prospects. As research tools, most platform technologies can be sold without undergoing expensive and lengthy regulatory approval processes, such as clinical trials. Given the uncertain funding environment and probable lack of a labor market for experienced professionals in the area of pharmaceutical development, the platform technology orientation makes sense for German firms. However, German firms may also enjoy a comparative institutional advantage in this subsector of the biotechnology degree. Referring once more to the machine-tool comparison, platform biotechnology segments share similar technological and market characteristics of these more incrementally innovative industries, and as a result may generate organizational dilemmas for managers and skilled workers that resonate with patterns of consensual decision-making, skill-development, and career management found within CMEs.

Though it is too early to confirm empirically, most German platform technology firms are likely to develop long-term employment patterns in order to develop relational contracting structures with employees. Interviews at several platform biotechnology companies during the early growth of the German industry (1999 and 2000) confirmed this expectation: skilled employees working within platform technology start-ups would readily acknowledge the risk of working within a start-up, but had the expectation that if the firm succeeded, they would develop a career at the firm. If following the shake out of therapeutics firms more and more German biotech companies adopt more incrementally innovative platform technology approaches, it is possible that the German biotechnology industry could stabilize. Ironically, however, patterns of generally long-term employment produced will reinforce the difficulty experienced by German therapeutics firms in adequately staffing their firms with experienced mid-career professionals.

Enterprise Software

Sustained corporate investments in information technology hardware have driven the creation of numerous software markets aimed at using these machines to reduce administrative costs and improve productivity. The largest of these markets is ERP software, which aims to help companies manage all resources within their firms, including accounting, inventory management, logistics and supply-chain management, human resource management, and manufacturing. Within large firms ERP suites typically involve hundreds of users and are extensively customized for particular industries and firms. The global ERP market during the height of the German new technology boom, in 1999, was $19 billion. Other large enterprise software markets include CRM software (CRM, a $3 billion market in 1999) and markets surrounding the implementation of e-commerce activities (a $2 billion market in 1999, and growing rapidly) (figures from Casper 2003*b*).

Viewed through the lens of stock market offerings, software was the most vibrant area of entrepreneurial activity during the pre-2001 boom period in Germany. Sixty software companies were able to complete IPOs on the *Neuer Markt* between 1997 and 2002. Only six of these firms were attempting to compete in market segments generally characterized by radically innovative technological characteristics, standard and middleware software. Most of the German firms were competing in one or more enterprise software markets, such as ERP (four firms), CRM (five), sector-specific enterprise tools (eight), systems integration and groupware (thirteen), e-commerce software (seven), document management (nine), and network security (seven) (data from Casper 2003*b*). German firms appear to be gaining competitive success primarily within markets characterized by the collaborative firm model.

The following focusses on firms in the traditional ERP dominated markets and the newer e-commerce software segment. Doing so helps compare the strategies of two generations of German start-up firms. Most of the traditional German enterprise software firms focussed on the ERP, CRM, and enterprise tool segments were established in the 1980s or early 1990s, in many cases following the lead of worldwide ERP leader SAP. These firms were founded well before the current entrepreneurial technology boom in Germany, and developed business models and related growth strategies accordingly. IPO opportunities created by the rise of the *Neuer Markt* have created opportunities for these firms to become retooled for the Internet economy. The e-commerce software firms are much younger firms, founded explicitly to exploit market opportunities created by the Internet as well as venture capital financed rapid growth opportunities. While these firms have used the increased viability of venture capital-based growth models to expand rapidly, we will see important continuities compared to enterprise software in both the business models and underlying patterns of human resource deployment.

TRADITIONAL GERMAN SOFTWARE FIRMS: ENTERPRISE RESOURCE PLANNING

Many of the older German enterprise software companies appear to have at least initially focussed on corporations within the German speaking areas of Europe, suggesting that language skills and familiarity with German business practices may have created competitive advantages for some firms. However, the stunning success of SAP in dominating the international market for ERP software during the 1980s provided a template used by many other German software firms. While few if any technological spillovers have been created by SAP's dominance of the ERP market, the firm has produced an important demonstration effect within the German technology sector. Initially backed by IBM, SAP was one of Germany's first firms to loudly proclaim itself "entrepreneurial" in organization (Lehrer 2006). In addition to an early IPO and the widespread use of stock options and performance-based incentives, the firm has actively distanced itself from the German industrial relations system through refusing to organize an employee works council.

SAP's innovative business model established it as the only non-American firm to be counted in the top ten world software giants in terms of market capitalization; it was the fourth largest in 2000. Over much of its history, SAP's core business has been the sale, customization, and periodic updating of a large spreadsheet-based software system called R/3 that allows corporations to manage a huge array of corporate controlling functions within an integrating system. Corporations installing R/3 often face substantial and costly implementations, as corporate process information is translated and customized into R/3 software modules. While implementation work for very large (and thus profitable) customers is provided by SAP itself, the majority of R/3 implementations are performed by software consultancies accredited by SAP to install the system. Several of the older ERP-based enterprise software firms listed on the *Neuer Markt* started as dedicated R/3 implementation firms, often with sector-specific expertise.

A key factor of this business model is that the software used to run most enterprise software systems is not particularly technologically intensive. Statistics derived from annual reports of the German enterprise software firms in 1999 show that R&D intensity of these firms was relatively low, at only 8.4 percent of total costs (Casper 2004). While the emergence of Internet-based corporate networking has created a technological shock to many enterprise software firms, most of this software is fairly simple in orientation: firms develop libraries of core software modules, which are then customized and licensed to firms as part of implementation contracts.

Within most enterprise software markets a variety of competing platforms exist, as outside a particular corporate network, the so-called network externality benefits derived by the widespread use of particular software platforms across firms are low. Moreover, intellectual property surrounding most software has traditionally protected only the source code used to create particular software functions, but not the "look and feel" or general concept behind a given software platform (see Mowery 1999). This limits the development of "winner take all" markets often characteristic of standard software. But it also creates strong opportunity conditions encouraging the entry of new competitors once a new niche is discovered and popularized. Appropriability issues thus dominate the strategic calculations of most enterprise software firms.

How can firms generate sustained profits from rather low-cost and generic technological investments? SAP has managed appropriability risks through the creation of a huge user-base of firms that, once they have undergone expensive R/3 customizations, face high switching costs in changing to an alternative system. SAP can also generate long-term revenues through adding new functionality to its software, which is then resold to customers through periodic upgrade cycles. Complementing this installed base has been the creation of a network of smaller firms involved in the distribution and installation of SAP software. The existence of a well-developed distribution aids the marketing of SAP products and expedites the availability of SAP-based ERP software. Building this network is difficult, as the core software provider must convince these satellite firms to develop specialized installation skills that might not be easily transferable to systems sold by competitors.

In sum, SAP's success demonstrates that firms can create a competitive position within the international software market that is possible without the development of market leading technologies. This helps explain why so many firms are in the German enterprise software segment: the competencies needed to succeed, while complex, do not depend on the creation of privilege access to newly emerging technology. Rather, competition takes place in the form of business model innovation: packaging rather generic technologies with complementary and specialized assets in distribution, installed user-bases, or marketing.

Moreover, capabilities generated within enterprise software companies fit well within the CME model. The human resource organization of enterprise software firms typically includes a cadre of core software developers that create and maintain core software libraries. Developers work intensively with a larger group of technicians, consultants, and marketing personnel involved in implementation and customization work. Technology within these firms is relatively cumulative, evolving as new functions are designed to include in periodic upgrades. As a result, the ability to "hire-and-fire" to rapidly change the technological orientation of most enterprise software firms is rare. Rather, more "competency preserving" personnel practices are important. Teams of technicians, consultants, and sales people must work in conjunction with software engineers to quickly customize core software libraries for use by clients, while ensuring that innovative routines developed through particular projects feed back into the firm's core repertoire of enterprise software solutions. This human resource structure is broadly consistent with restraints on "competency destruction" that have long characterized German business institutions.

GERMAN FIRMS CREATED AS PART OF THE INTERNET BOOM: E-COMMERCE SOFTWARE

The e-commerce market is one of the largest application-based infrastructure areas within the Internet sector. E-commerce software firms develop customizable software modules designed to help client firms organize e-commerce. The business model here involves the creation and updating of a kernel of e-commerce applications—inventory tracking, accounting, order completion, as well as the creation of visible web-interfaces used by customers—which are typically installed and customized by third-party software consultancies trained and accredited by the e-commerce software producer.

While American firms dominate several segments, particularly in the provision of software for "business to business" transactions, in the "business to consumer" area as well as finance dominated "vertical" markets several German firms are strong. These include most importantly Intershop, a global player in the provision of so-called business to consumer e-commerce software to medium to large firms, as well as several firms such as Internolix and Openshop, both of which have developed similar business models for related markets. Another firm that developed a strong international presence during the late 1990s was Brokat, a Stuttgart-based firm that integrates secure transaction software into e-commerce platforms sold to financial institutions. Both Openshop and Brokat experienced dramatic stock fluctuations during the *Neuer Markt's* crisis during the 2002 period and were eventually acquired. Nevertheless, e-commerce software is one of the only core Internet infrastructure areas in which German firms established substantial market share in non-German language markets, an important sign of competitive advantage.

Over the late 1990s Intershop emerged as Germany's most successful Internet start-up (see Casper 2003*b*). It has developed a successful series of integrated e-commerce packages combining back-end inventory and accounting support with front-end web-interfaces that customers can use to develop electronic commerce platforms. In addition to offering integrated packages, the firm has been a leader in exploiting

Internet programming interfaces, such as XML, to allow customers a wide degree of leverage in customizing the basic software. The firm's curious history is also notable. The firm was founded in 1992 in Jena, one of the technology centers of the former East Germany, by several people with expertise in organizing inventory tracking and accounting systems gleaned from prior experience developing software to manage East European trade flows under the now defunct Comecon trading block.

While e-commerce software firms may compete to introduce software with enhanced functionality, especially in the "ease of use" area, the software itself is relatively generic. E-commerce software platforms rely on middleware software and standards developed elsewhere. Important examples include the SET electronic payment protocols, encryption tools, and related website security software, as well as commonly used database software from Oracle and other vendors. The e-commerce software platforms themselves are proprietary systems owned and maintained by the developer. Patenting over core e-commerce processes appears weak; a quick web-search reveals dozens of e-commerce software firms, most of which offer relatively similar technologies.

The business model underlying e-commerce software is virtually identical to the one SAP pioneered for the ERP market. As in the enterprise software area, appropriability concerns dominate. Firms must tie relatively generic technological assets with more specialized competencies in marketing, sales, and distribution. As with SAP's R/3 platform, creating large user-bases facing high switching costs that can then be captured into long-term upgrade cycles is a core strategy. Developing strong third-channel distribution channels is an additional goal. During its peak growth period, in 2001, Intershop had certified over 4,000 consultants trained in the installation of its two core e-commerce platforms (see Casper 2003*b*). Customer sharing through corporate alliances with producers of complementary software products is an additional tactic. Intershop, for example, has developed an alliance with CommerceOne, one of the leading b-b e-commerce software providers. Internolix, a German e-commerce firm specializing in software for small business, has had its fortunes enhanced through a deal with Microsoft to become its exclusive supplier of e-commerce software for firms using Microsoft NT-based web servers. While Microsoft hopes to expand the relatively weak presence of NT-equipped servers in small business, the inclusion of Internolix as a partner in various Microsoft developers' conference and related marketing activities has been a huge benefit for the firm. According to interviews with managers at

Internolix, it has also invigorated the firm's activities in creating a distribution network of independent contracts specializing in the installation of its software.

Overall, it would be fair to categorize e-commerce software as a primarily marketing and distribution dominated application area, sharing a broadly similar business model with enterprise software specialists. On the other hand, these firms are much younger on average than the enterprise software firms, in all cases founded with the exploitation of Internet-related markets as a core goal. Most have received substantial private venture capital placements, facilitating much faster growth before IPOs. Rather than relying on "organic" driven growth based on earnings, they have had the opportunity to invest lavishly to create large organizational structures in an attempt to quickly grab substantial market shares. This reliance on equity leveraged financing models is a good example of how the growth of technology-driven capital markets has allowed more aggressive start-up strategies to flourish in Germany.

Field research conducted during 2001 at several German e-commerce firms suggests that "new economy" forms of entrepreneurial start-up organization are far more prevalent than at older German software firms. Each of these firms has stock-option plans with very wide dispersal across employees, as well as relatively flat managerial hierarchies to help enable a more decentralized, employee-empowered work environment. This facilitates faster growth and a clearer "new economy" focus in terms of personnel organization, particularly with regard to relatively intense work environments.

However, Germany's e-commerce software specialists also resemble most German firms in developing human resource policies that are broadly "competency enhancing" in nature. Human resource competencies are similar to those in enterprise software. Firms usually organize a group of programmers with advanced degrees who update the core software platform, along with a much larger group of lower trained technicians involved in implementation and service issues. Proprietary programming environments tend to keep competency destruction low—new programmers may be added to accommodate inevitable "feature creep", but existing staff should have high job security due to the need to periodically update the code. Job security is high, with the trade-off that, compared to more technologically volatile sectors, extremely challenging technical challenges will be few. While this might keep the best programmers away from these firms, in terms of skill-requirements "good" should suffice.

In sum, e-commerce software firms are primarily marketing and distribution-driven entities. Interesting, both Intershop and Internolix have located their software development laboratories in different parts of the country than their corporate headquarters. They can succeed in Germany precisely because the core business model does not depend on the creation of world-beating technology. Rather, competitive success is driven by the bundling of rather generic technologies into proprietary systems promoting through marketing and sales organizations designed to create large user-bases facing high switching costs. As with Germany's older enterprise software firms, e-commerce software firms resemble collaborative firms, which respond well to incentives provided by the country's coordinated pattern of institutional organization.

Conclusion

Germany's success in platform biotechnology and enterprise software holds a valuable lesson for understanding of how CMEs might develop competitive success in new technology industries. As discussed in Chapter 4, German technology policies have done little to change institutions influencing company organization. German new technology companies may draw on venture capital and technology transfer opportunities created through the country's policies to compete in the new economy. But these firms remain embedded within a business system in which most firms, governed through a stakeholder system of corporate management and employee codetermination norms, aim to accommodate long-term employment and skill-development. Ironically, it is the "long-termism" inherent within the German model that facilitates the competitive success in platform biotechnology and enterprise software. Germany's current juxtaposition of long-term-oriented labor market institutions and career development paths with more entrepreneurial patterns of start-up firm development and growth could foster a comparative institutional advantage for firms specializing in incrementally innovative technologies.

The trailblazing success of SAP in the ERP market and Qiagen in platform biotechnology has provided demonstration effects to guide the construction of business models sustainable within the present German institutional landscape. These firms represent the banner of change in Germany, but of a particular kind. Their success likely indicates an extension of the German business system to include new organizational structures, rather than a transformation into something new. Particularly in the key area of human resource development, successful German software and biotechnology firms generate “competency enhancing” employment and knowledge development patterns similar to most “old economy” firms in Germany.

In sum, within liberal-market institutional environments, it is difficult for high-technology firms to engage in technology profiles that generate substantial amounts of firm-specific skills or knowledge that cannot be codified in the relatively short term. National institutional frameworks within Germany and other CMEs, on the other hand, strongly encourage competency preserving human resource development through restraints on hire-and-fire that facilitate long-term employment. This presents a viable explanation of why so many German firms have selected areas of the biotechnology and software segments characterized by incremental innovation. In addition to the lower financial and competency destruction risks, it is likely that the higher degree of technological cumulativeness in these markets creates a combination of tacit, firm-specific knowledge risks. As a result, German entrepreneurial technology firms should enjoy a comparative institutional advantage in the creation of competencies needed to support innovation in areas where long-term knowledge investments are important.

7

Regional strategies to sustain radical innovation: Internet software

The general failure of German technology policies to succeed in creating large numbers of viable therapeutics biotechnology companies is a strong indicator that the pessimistic predictions from varieties of capitalism theory surrounding the viability of the Silicon Valley model in CMEs have merit. Does this mean governments and firms within CMEs should abandon the idea of competing within market segments characterized by radical innovation? Are there alternative strategies available to CMEs?

Applied to accounts of regional technology development, institutional theory neglects the role of entrepreneurs, especially when facing potentially vast new markets, in engineering successful organizational structures in the face of inhospitable business climates. Germany's oldest "new economy" firms, such as SAP and Qiagen, while now large, emerged as entrepreneurial start-ups in the 1980s and early 1990s to exploit technology innovations by their founders. Both firms were founded in an era where few if any of the 'appropriate' institutions for entrepreneurial technology businesses existed.

Moreover, the earlier analysis of San Diego biotechnology demonstrates that even within LMEs patterns of economic coordination within successful biotechnology clusters differ from "normal" patterns within LMEs. While institutions within these systems create a logic of institutional coordination that encourages the development of radically innovative firms, other catalysts are necessary. Within the San Diego case we saw that, in addition to the existence of several world-class biomedical research institutions, career affiliation networks originating with the founders of Hybritech helped create a network backbone used to help launch founding teams of an increasingly large number of firms through the early history of the cluster. Patterns of economic coordination within the

San Diego biotechnology cluster were incentive compatible with normal patterns of labor and financial market coordination within LMEs, but differed from normal patterns within the United States.

The finding that there is a regional component to the successful creation of Silicon Valley-type technology clusters within LMEs opens the question of whether regional mechanisms could also emerge in CMEs to achieve patterns of economic coordination needed to support radically innovative companies. The emphasis on mechanisms exposes a weakness of institutional theory, a difficulty in examining the role of agency in developing mechanisms of change. While explanations focussed on the activities of individual entrepreneurs make it difficult to develop theories capable of generalization, it is possible to examine the role of technology drivers. How do patterns of technological leadership, for example in telecommunications technologies, influence patterns of technological specialization within economies? Can large firms playing dominant roles in the provision of particular technologies develop strategies within regional economies that can “override” normal institutional constraints?

This chapter examines the branch of Internet-related technology known as middleware software development. Within this sector technological interdependencies linking large and small firms are strong. Focussing on Sweden and Germany, it examines whether technological leadership can act as a stimulus to foster clusters of radically innovative middleware software companies within CMEs. The statistics on subsector specialization reported in Chapter 6 showed that Sweden has developed a pronounced specialization in middleware software. The successful creation of a cluster of radically innovative software firms within Stockholm, Sweden will be linked to the technological leadership and human resource policies of a local telecommunications systems manufacturer, Ericsson. To broaden the analysis, the lack of specialization within middleware technologies within the German software industry will be linked to the inability of Siemens, the country’s leading telecommunications provider, to provide similar technological leadership.

Technological Dynamics of Internet Telecommunications Technology

Due to its vast growth and commercial success, the Internet has emerged as the dominant infrastructure underlying communications from the mid-1990s-onward. A key concept driving competitive dynamics surrounding the development of Internet technology is that of network externalities. This concept refers to the idea that the power, or usefulness, of a network increases with its size (see Shapiro and Varian 1999). Applied to competitive strategy, many analysts have noted that companies controlling the provision of hardware or software impacted by network externalities can reap tremendous competitive benefits as such markets grow in size. The tremendous growth of the Internet, combined with rapid technological advances in key technologies underlying computer and telecommunications hardware, has created volatility for companies active in providing network communications technology. Technological dynamics surrounding large telecommunications equipment manufacturers can dramatically impact entrepreneurial companies writing software to increase the performance and functionality of these systems.

The Internet, as originally defined, is not a network but the "network of many networks" (see Casper and Glimsted 2001, from which the following section draws). At the heart of the Internet is a set of open, or public, protocols, that all devices connected to the Internet use to transmit information. As an open system, any network device that is able to communicate using a set of communication standards called the Internet Protocol (IP) is able to become part of the Internet. Many of the benefits of such an infrastructure can only be realized if the means to transfer information and interconnect its parts is effective and reliable (Dodd 1999). Because a diverse spectrum of computers and devices exist and are continually being created, most using unique hardware and software operating system architectures, the communications industry has faced continual pressure to develop equipment and software needed to ensure that devices connected to the Internet can easily communicate, or are interoperable. A second dynamic of continual investment surrounds the development of hardware and software needed to increase the capacity and speed of digital communication networks. While the Internet is widely described as an "open" system, competitive dynamics surround the creation of both telecommunication hardware and software used to increase the productivity and interoperability of the Internet. Driven by the logic of network externalities, companies often compete to promote the adoption of standards that they own, in part as such ownership can drive users of the Internet to purchase their companies equipment or, at times, ancillary software.

To describe the technological architecture of the Internet, the world of communication engineering relies on the so-called "layered functional

Table 7.1. The layered functional model of the Internet

Layer	Service	Typical firm types
1	*Network Layer*: trunk networks, fixed local access networks, radio networks, Ethernet LANs	Large, integrated network equipment manufacturers
2	*Connectivity Layer*: Internet access, web server parks	Primarily large firms due to sunk costs of network provision
3	*Navigation and Middleware Layer*: W.W.W. browsers, electronic payment systems, WAP-related applications, search engines	Entrepreneurial software firms
4	*Application Layer*: e-mail, FTP, web design, including online information for business or private use, software platforms for B2B and B2C e-commerce, etc.	Entrepreneurial software firms

Source: Casper and Glimstedt (2001).

model". This model enables engineers and companies to handle increasingly complex technology. The principal means of developing a common infrastructure is the adoption of technical standards that provide rules for interconnecting parts of the communication system. This model is helpful in that it helps frame discussions of technical interdependencies between large and small companies operating at different layers of Internet technology provision.

The first two levels of the Internet-based communication system are composed of generally large firms that develop the equipment and infrastructure underlying the Internet. The network layer involves the core network functions for transportation of data, including fiber optics in trunk networks, routing and switching technologies, local access network technologies, and cellular mobile communication networks. The main suppliers of network elements are the large communications equipment vendors (Nortel, Lucent, Ericsson, and routing equipment specialists such as Cisco). The connectivity layer describes the technologies used for having access to the Internet from private homes or the office. In the competition for business in this layer are mainly Internet Service Providers, such as AOL and the telecom operators but also much smaller firms. This layer also includes providers of physical network capacity, such as Qwest.

The bottom two layers of the Internet technology model comprise primarily smaller, entrepreneurial firms. Firms operating within the navigation and middleware (henceforward middleware) compete to develop new interface technologies that are used to link the basic architecture of communication networks to standard application software. Most middleware software projects involve implementations of protocols developed by the designers of telecommunication network architectures, usually large firms working within the network layer. Typical middleware products include secure payment systems used in Internet banking and e-commerce, software that transforms the content of web servers into a format that can be used in small mobile telephones or Palm Pilot devices, and search engines that are used for navigation on the World Wide Web. Most firms in middleware software race to create new technologies with superior functionality or speed to market. Middleware firms create software solutions to help firms at "lower" levels of the layered model—primarily application software providers—seamlessly connect their software to emerging network technologies.

Finally, application-related Internet activities pertain to the creation of software platforms used by end-users. Products use standards developed at the middleware levels as building blocks with which to develop proprietary platforms aimed at particular market niches. These include a number of well-known mass market application areas, such as email and Internet-related file management programs (e.g. FTP), as well as large numbers of primarily corporate services, such as web design and consultancy, and, as discussed in Chapter 6, e-commerce software, a variety of enterprise tool software (e.g. logistics, web-related billing, and time management software) and software for the management of corporate intranets.

In sum, the Internet consists of a coordinated set of technologies. The characteristics of these technologies differ from layer to layer, as do the type of firms that are competing for business in the different layers. While the suppliers of basic network elements consist of the large and vertically integrated network specialists, both middleware and application layer firms are typically rather small entrepreneurial firms primarily engaged in the development of software.

Technological Characteristics of Middleware Firms

Middleware software firms display technological characteristics of radically innovative firms. They are usually closely tied to larger, system-oriented firms operating at the network layer of the telecommunications hierarchy. Most middleware software projects involve implementations of protocols developed by the designers of telecommunication network architectures—typically large firms working within the network layer. Middleware firms create software solutions to help firms at "lower" levels of the layered model—primarily application software providers—seamlessly connect their software to emerging network technologies.

Network layer firms, to an extent, may be thought of as bundles of technologies. While particular network layer firms have become associated with particular types of networking equipment—Cisco for example is most well-known for commercializing routing equipment—most network layer firms today provide a broad assortment of networking gear. Within particular technology segments, network layer firms compete on the development of networking gear for newly emerging transmission technologies. For example, the design of equipment for high-capacity transmission protocols, such as CDMA, drove much competition for next generation wireless Internet equipment during the early 2000s. Standardization processes associated with the introduction of new technologies in unbundled systems drive strategies of horizontal specialization strategies by smaller firms; middleware firms can specialize in creating extensions for a subset of technologies without actually having to tackle the more complex task of mastering all the technologies that make up the network structure.

Because successful innovations in this subsector are developed with a variety of different kinds of knowledge that are interdependent technical standards, design interfaces, and other product architecture-related issues have to be integrated if firms are to have a high probability of success (see generally Perrow 1984; Kitschelt 1991). For middleware firms, low technological cumulativeness and the need for coordination across groups of firms in complementary markets create high standards related risks (Arthur 1994). To succeed, firms must successfully coordinate technical specifications or designs with other firms in a technology area.

The interdependence with network layer firms highlights core technological regime characteristics facing middleware firms—generally high knowledge complexity and a relatively low degree of cumulativeness. High knowledge complexity is created by the interdependence between evolving network architectures and the activities of the firm. Successful middleware software is usually produced at the initial rollout stage of new telecommunication standards, well before they become standardized. Knowledge complexity is also created by the linking role played by most middleware firms, as they must have excellent knowledge of complex system architectures surrounding new platforms, but also expertise in the organization of technologies and business processes within downstream application layer markets.

Low technological cumulativeness is also driven by the racing nature of much middleware software development. Failure rates are high, particularly when the software is associated with "winner take all" markets created by standard-related network externalities. Low cumulativeness is also created by a dependence on network layer firms in successfully promoting new network protocols and system architectures. Within the wireless communications area, for example, the WAP standard for wireless Internet transmissions, despite sponsorship by Ericsson and Nokia, failed to gain widespread acceptance outside Europe during the early 2000s. A rival standard developed in Japan by NTT DoCoMo, called I-Mode, quickly dominated the Japanese market, while CDMA has dominated the US market. Dozens of tiny middleware firms were founded to develop software around WAP; many of these firms have failed or moved on to I-Mode or more advanced "third-generation" technology. A similar experience surrounds the development of new protocols to achieve higher levels of interoperability across different computing environments over the Internet. During the early 2000s, rival platforms were sponsored by Microsoft (".net"), Sun and IBM (Java extensions) and Oracle. Dozens of small middleware firms designing software to drive newly developing markets for web-based business services must orient themselves to one or more of these platforms, but could face collapse if their technology bets prove misplaced.

On the other hand, appropriability risks and employee knowledge characteristics tend to be relatively permissive for middleware companies. Middleware software platforms are technologies with strong appropriability regimes, in the sense that they are protected by a combination of software architecture expertise within the firm as well as interfirm links within emerging standards communities. Finally, because middleware software firms tend to work newly emerging areas with strong interdependencies across firms, knowledge bases within the firm tend to be generic and thus relatively easy to manage within the firm. As a result, most companies can adopt the project-based firm pattern of organization typical of radically innovative firms.

Large Firm Technology Strategy as a Mechanism for Developing Clusters of Radically Innovative Firms

Though governments have at times played important roles within telecommunication standards (see Glimstedt 2001), within much of the middleware software sector most firms are dependent on large corporations, typically telecommunication equipment manufacturers and established companies active in network intensive standard software products, for the provision of standards to help products become interoperable (see Casper and Glimstedt 2001). Examples of the former include large network equipment manufacturers such as Cisco Systems, Lucent, or Ericsson, while Microsoft, Sun, or Oracle exemplify the latter. Each of these firms has been involved in the creation of technology platforms for emerging network communication markets. These firms hope to provide technology platforms that function as "club goods" to middleware software companies, enticing them to develop a variety of follow-on technologies aimed at eventually creating new software platforms. Large firms are self-interested when providing these standards. Through controlling emerging network communication protocols, they hope to secure large markets for equipment and software using the standards.

Large network layer firms can help stabilize technologies through attracting middleware firms to create applications for their standards. As a result, middleware software firms are most likely to exist within technology clusters dominated by large companies that can entice them to commit to a technical standard, either through a reputation of past success or through other means such as financial incentives or technical support. Through locating within regional economies dominated by such firms, middleware firms can plausibly hope to insert its software engineers into emerging communities of experts surrounding new platforms. Privileged access to such communities can provide a competitive advantage for middleware firms, through, for example, supplementing codified technical knowledge (protocols, languages) with tacit knowledge surrounding their efficiency.

If social networks linking experts in emerging communications technologies are indeed important, this creates a potential mechanism by which career management risks faced by employees middleware firms may be managed. By locating in a region populated by important network equipment manufacturers and broader technical communities of engineers, a company can hope to gain access to sophisticated knowledge about new technologies and often participate in consortiums to create protocols or standards. From the employee point of view, membership in technical communities helps strengthen one's knowledge base while also reducing the career risk of participating on projects that may fail; networks can be used to find new jobs. From the middleware firm's point of view, hiring developers with good reputations within particular technical communities assures the firm that it is hiring the best talent and also helps reduce technological risks.

National Institutional Frameworks as an Intervening Variable in Cluster Creation

The middleware software case is useful for exploring the interplay between human resource coordination across CMEs and LMEs and technology coordination driven by large companies. From this perspective, what constellation of policies must the large firm take to induce engineers, managers, and financiers to make commitments to projects that are normally extremely risky within their societal contexts? What are the mechanisms by which regions move from a starting position in which neither the agglomeration of companies nor social networks underpinning mobility exist to one in which they do? If their development has collective action problems, how do social ties develop into useful and sustainable networks? Can dominant actors take actions to “tip” labor market institutions in a direction contrary to “normal” institutional incentives within an economy?

The decentralized social infrastructure characterizing successful technology clusters is in some ways analogous to a collective or public good: its benefits accrue to most if not all individuals and companies within the regional economy. However, unlike traditional public goods (roadways, the air), social infrastructures are not maintained in any systematic fashion. Within the biotechnology industry social networks linking firms were, at least in the San Diego case, an emergent property, a product of the collective behavior of individuals and firms within a regional economy. A relatively large number of individuals must develop and mobilize social ties in order to develop a density of ties sufficient to generate useful networks.

We also saw in the San Diego case that social networks developed slowly or incrementally. Early entrants to a cluster might be particularly risk acceptant individuals. Over time, they could plausibly seed a nucleus of companies and establish social ties between them. As these ties expand, they become a so-called backbone to a social infrastructure that other entrants, both individuals and new companies, can draw upon. It is possible that, after reaching a certain size and rate of mobility, a tipping point could be reached whereby the cluster becomes sustainable and regional innovation effects begin to accrue. Once sustainable, agglomeration effects might become established as jobs within the cluster become attractive to more risk averse individuals.

If large network equipment manufacturers do in fact have an interest in developing technical communities needed to support technical standards to develop network externalities for their telecommunications equipment, their actions in supporting regional agglomerations of middleware software companies may signify an important mechanism by which clusters of radically innovative companies might emerge. In other words, large firms may have an interest in overcoming collective action problems that typically thwart the development of effective social networks within regional clusters. This leads to the hypothesis that clusters of middleware software companies should only develop in regions populated by a large network equipment manufacturer active in developing Internet technology standards.

However, institutional framework considerations surrounding LMEs and CMEs are still important. It reasons that very different mechanisms of emergence should take place across the two types of economies. Within LMEs, normal patterns of economic coordination, that is deregulated labor markets, capital-market-based financial systems, and readily available high-powered incentive mechanisms within firms, all conduce toward the governance of radically innovative firms. By creating successful telecommunications standards and, with them, technical communities linking engineers within a regional economy, large network equipment developers within LMEs may serve as a catalyst toward creating clusters of middleware software firms within regional economies. Given the generally deregulated nature of labor markets within LMEs, the creation of social networks linking engineers within a region might be enough to tip patterns of social relationships linking managers and engineers within regional economies toward the pattern of decentralized labor market coordination needed to support radically innovative firms.

Within the three European economies examined here, our example of an LME, the UK, is not home to a dominant network technology firm. Its core telecommunications equipment manufacturer, Marconi, is widely seen as failing to succeed in its efforts to innovate within broadband digital equipment markets, and, facing bankruptcy, the firm was acquired in 2003. This helps explain the finding, from Chapter 6, that so few UK firms are in middleware technology. The UK has deregulated labor markets needed to facilitate flexible forms of human resource coordination, but does not have a hegemonic network communications player capable of sponsoring emerging middleware software standards. This helps explain why UK software firms have instead gravitated to standard software segments, for which technical intensity remains high, but interfirm coordination is low.

Middleware firms existing with LMEs that are home to dominant technology firms should excel in creating clusters of middleware firms. The United States is an example of a country that has developed such clusters. The New Jersey area, for example, is home to a concentration of networking equipment and software start-ups centered around Lucent, which was spun off from Bell Laboratories. A large cluster of middleware software and related networking start-ups also exists in Silicon Valley, many of which are geared toward the extension of Internet networking standards developed by Cisco Systems, long the dominant provider of routing equipment for the Internet. Cisco is well known for cultivating a technical community surrounding IP-based networking technology, both through its promotion of open technical standards, but also its reputation of acquiring and integrating numerous small companies (Paulson 2001). These examples are merely indicative, as no research exists on patterns of labor market and technological coordination within these sectors. However, the existence of numerous start-ups working within networking software within both clusters gives credence to the idea that technology spillovers, combined with "normal" flexible labor market institutions within LMEs, gave rise to clustering effects within both regions.

Simard (2004) has documented the link between large networking equipment firms, technical communities, and social network formation in driving the development of a large concentration of wireless telecommunications equipment and software companies in San Diego. Simard traces the origins of San Diego's wireless telecommunications industry to the existence of a technical community surrounding wireless signal processing technology. This community initially emerged as the result of US Navy R&D activities in the area during the 1970s, which eventually led to the founding of a wireless communications firm called Linkabit in 1968. In a remarkably similar process as occurred with Hybritech in the biotechnology area, Linkabit merged with a rival named M/A-COM in 1980, leading to the rapid movement of several of the company's key employees and founders out of the company to form new start-ups. The most important of these start-ups became Quallcom, which emerged in the 1990s as an important company in developing a proprietary wireless telecommunications standard called CDMA, which in the early 2000s became a dominant technology for broadband wireless telecommunications. Simard documents the formation of dozens of wireless communications companies in San Diego, many of which are middleware type companies closely tied to technologies propagated by Quallcom. Using social network methods, Simard also demonstrates that a cohesive set of career affiliation ties links the founders of these companies, social ties which can be used to both share tacit information surrounding developments in wireless communications technology and reduce the career risk of working within a radically innovative start-up in the region.

The Formation of Middleware Software Hubs within CMEs: Sweden and Germany

Within LMEs national institutional frameworks are incentive compatible with the creation of radically innovative middleware software hubs. The development of radically innovative regional economies within CMEs faces a far more challenging problem. As “normal” institutions within CMEs are not incentive compatible with the construction of high-technology clusters, actors must impose patterns of coordination that circumvent normal patterns by which individuals orchestrate their economic activities. This suggests that technological leadership by a large network equipment company is not enough. An additional catalyst may be needed to form vibrant social networks linking experts within the technology outside the firm and then develop patterns of labor mobility within the network capable of sustaining radically innovative firms. Can large firms within CMEs serve as this catalyst?

Developments within Sweden suggest that they can. A good indicator of changes taking place in this country comes from patent specialization statistics developed by the German government as part of periodic reports of the country’s industrial competitiveness (BMBF 2001*a*, 2001*b*, 2006*a*, 2006*b*). Using revealed comparative advantage methodologies, the statistics produce an index revealing whether a given country patents more or less in a given bundle of patent classes compared to all other countries within the OECD. Within the index positive patent specialization figures indicate that a country has an above average patent intensity in a given class and negative numbers show less than average patenting. Figure 7.1 displays the results for patenting intensity in high-technology industry (what the Germans call *Spitzentechnologie*), a composite of patent classes in communications, information technology, and

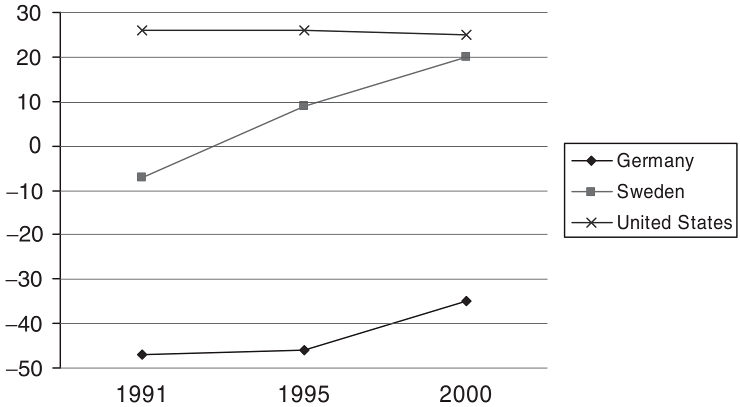

Figure 7.1. Comparative patent specialization of Germany, Sweden, and the United States in high-technology technologies, 1991–2000

Source: BMBF (2001*a*, 2001*b*, 2006*a*, 2006*b*.)

biotechnology, for Germany, Sweden, and the United States during the 1990s. As expected from the varieties of capitalism perspective, the United States has a higher than normal patent specialization in high-technology industries, while the Germans have a much lower than average patent intensity. The figures for Sweden, however, show a dramatic change from a below-average patent intensity in high-technology industry at the start of the decade to a level of patent specialization by 2000 that is close to the United States.

Sweden's dramatically increased performance in high-technology industry during the 1990s suggests that CMEs may be able to develop specializations within radically innovative industries. Given the small size of the country, it is likely that much of this change can be accounted for by the country's success in developing a cluster of wireless communication equipment manufacturers and middleware software start-ups in Stockholm. Ericsson's role in catalyzing the development of this cluster is now explored, along with a parallel discussion of why a comparable large telecommunications manufacturer in Germany, Siemens, was not able to precipitate a similar cluster of radically innovative firms in its local region of Munich.

The Surprising Performance of the Swedish Internet Software Sector

Recent developments in Sweden support an argument that technological hubs created by dominant firms can dramatically change "normal" institutional incentives within economies. Sweden has long been regarded as a "coordinated market economy" with patterns of market governance similar to those in Germany. Starting in the mid-1990s, however, parts of its economy have seen a dramatic transformation (see Glimsted and Zander 2003). Ericsson's leadership in third-generation wireless technologies has helped create a technology hub in the Stockholm area that has a technological intensity far more similar to Silicon Valley than normal patterns of industrial organization in Sweden (the following draws from Casper and Glimsted 2001; Casper and Whitley 2004).

To examine Ericsson's role in fostering patterns of economic coordination within the Stockholm region capable of sustaining radically innovative firms, we focus on two factors: (*a*) the influence of technology standards in fostering a switch from firm-specific to more generic, industry-specific technical skill-sets among software engineers and (*b*) initiatives taken by Ericsson to foster entrepreneurialism surrounding technologies it is sponsoring. From the perspective of human resource coordination, these factors have reduced the career risk of working in a radically innovative technology start-up, and through doing so allow competence-destroying firm strategies to become sustainable.

Ericsson, through the 1980s and early 1990s, in many ways resembled Siemens, Alcatel, and other European telecommunication equipment manufacturers. Operating as a quasi-monopoly equipment provider in a highly regulated domestic telecommunication market, it developed large systems integration capabilities needed to design early digital switching technologies designed primarily for voice traffic. As the only significant telecommunications equipment manufacturer in Sweden, it could attract the country's best engineering graduates, who were then offered stable, long-term careers in Ericsson. The company developed proprietary protocols and systems integration languages. The core of Ericsson's programming staff, for example, were experts in Ericsson's in-house systems integration language, Plex, a computer language used nowhere else. While the convergence of data-communication and voice-based digital communication technology has forced Ericsson to adopt new languages for its next generation telecommunications gear, several thousand employees have been retained for their expertise in Plex, which is still used to update legacy equipment.

During the late 1990s data-communication networking devices have begun to converge with traditional telecommunication switching equipment. The increased use of IP-based switching has forced firms like Ericsson to increasingly adopt connectivity standards developed for data-communication networks. An issue for such firms is how this influences internal product development. In designing switching equipment, base tower systems, and related capabilities for its Internet-compatible wireless equipment, a small group of system engineers within Ericsson developed a new systems integration language, called Erlang. As with Plex, Ericsson's initial strategy was to make this technology proprietary. However, unlike Plex, Erlang is a systems development language based on standardized object-oriented programming tools with the potential to help firms in a number of industries develop software to manage complex technological systems. Upset at Ericsson's move to keep Erlang proprietary, the chief developer of Erlang along with a group of systems programmers left Ericsson in 1999 to form an independent start-up software company (Glimstedt and Zander 2003).

Around the same time as this personnel crisis, Ericsson faced important strategic decisions regarding its sponsorship of wireless connectivity standards. Through its advocacy of the GSM wireless communication standard that became successful during the mid-1990s, Ericsson management learned that, in relatively open data-communication network architectures, network externalities play a crucial role in determining which network standards become dominant (see Glimstedt 2001). Ericsson was a major sponsor and developer of two important new web-based wireless connectivity standards—WAP and Bluetooth. The firm realized that if these standards were to succeed, dozens of other firms would have to work with these standards, creating unique applications software and middleware technology. Through creating marketplaces for various wireless applications, demand for Ericsson's end-to-end wireless systems technology would increase. Nurturing nascent wireless technology start-ups in the Stockholm area would promote Ericsson's favored technologies.

To help promote technology spillovers into the Stockholm economy, Ericsson made two strategic moves. First, it decided to make Erlang an "open source" development language, allowing other firms to use Erlang as a development tool. In this case, using open source development protocols ensures that enhancements to Erlang by third parties would flow back into Ericsson. More importantly, however, it helped create industry-specific rather than firm-specific skills among engineers involved in large-scale systems integration. Sponsorship of emerging wireless connectivity standards, such as Bluetooth and WAP or widely used mobile scripting languages like UML, produces a similar effect. Standardization of development tools, protocols, and connectivity standards dramatically increases the portability of skills across local firms working in wireless technology areas.

Second, Ericsson has changed its personnel policy toward engineers who leave to work in start-up firms. Formerly, it had strongly shunned engineers leaving long-term careers at Ericsson to work elsewhere, signaling that they would not be re-employed by Ericsson in the future. Through creating a corporate venture capital program, it now allows engineers leaving Ericsson to try their hand at technology entrepreneurialism. Given that most wireless start-ups within the Stockholm area are involved in the development of Ericsson-sponsored standards, and in many cases are using its core systems development language, local start-up ventures are working primarily to develop technologies compatible with Ericsson's next generation wireless technologies. If individual firms fail, their managers can now easily return to work within Ericsson, perhaps having developed new managerial skills or career perspectives through working in a start-up. If start-up firms are successful, Ericsson benefits through its sponsorship of key technologies and has close links with the management of the new companies.

The existence of industry-specific rather than firm-specific standards reduces the career risk for engineers leaving established large firms for start-ups. Industry-specific standards ensure that skill and knowledge investments made by programmers and engineers are portable. It allows managers of high-tech firms to successfully recruit highly skilled technical talent, knowing that competence destruction and accompanying hire-and-fire risks are high. This, combined with a more open human resource policy at Ericsson, helps explain the rapid emergence of numerous radically innovative firms. Within normally conservative Swedish labor markets, this employment insurance is a key catalyst for creating extremely active labor markets necessary to sustain competence destroying technology strategies.

To summarize, Ericsson's current leadership in third-generation wireless technologies has helped create a technology hub in the Stockholm area that has a technological intensity far more similar to Silicon Valley than normal patterns of industrial organization in Sweden. Ericsson has become the dominant provider of end-to-end wireless communication systems, and currently has about 40 percent of all orders for third-generation wireless equipment. Other major telecommunications equipment players, such as Nokia, have set up development centers in Stockholm, and Microsoft recently opened an R&D center for wireless software. Hundreds of software firms focussing primarily on wireless

Internet technologies have developed in the Stockholm area of Sweden. A recent survey showed that around 250 wireless firms are active in Sweden, most in technically intensive middleware technologies (see Glimstedt and Zander 2003).

The Poor Performance of German Middleware Software

In contrast to the Swedish case, the technological intensity of the German software industry has suffered from a lack of important "upstream" firms in the network layers of Internet-based telecommunications. While German firms are minor players in some areas, they have not become dominant forces in the creation of system architectures and related standards in core emerging network or connectivity markets. This point is best made through an overview of the activities of Siemens, long the country's dominant telecommunications equipment manufacturer, within the context of telecommunication network infrastructure markets (the following draws from Casper 2003*b*).

During the 1970s and 1980s Siemens was Germany's quasi-monopoly provider of telecommunication switches and a strong international player in centralized switching systems for voice traffic. Siemens emerged as an important player in the development of ISDN switching systems during the early 1980s. As ISDN was the dominant early digital telephone switching technology (i.e. one that could accommodate data and voice traffic), this investment could have given Siemens a strong position in the manufacturing of digital networking equipment. However, from the mid-1990s onward Siemens emerged as only a weak player in a number of high-capacity digital networking technologies, and has only recently, through purchasing several US-based companies, emerged as a competitor in Internet-based switching technologies.

The development of fixed network technology parallels wireless equipment as the other truly massive network equipment market within the Internet economy (during the 1999–2001 Internet boom Cisco's dominance of the router segment of this market transformed it into the firm with the world's highest market capitalization). During the 1990s, ever-increasing network traffic created widespread latency concerns over pure IP-based networks. This created demand by large corporations and governmental customers for telecommunication equipment providers to develop a range of high-capacity "overlay" networks that could provide higher-network capacity and reliability (see Dodd 1999). To compete successfully in these markets, established telecommunication equipment manufacturers such as Lucent, Nortel, Alcatel and others generally compete with Cisco and other providers of cheap IP-based routing equipment to provide more expensive but also more intelligent networking capacity to corporate and other large clients. This has led to the development of numerous networking technologies that attempt to provide rapidly increasing levels of bandwidth capability and reliability.

During the mid-to-late 1990s a high-end switching technology called ATM (asynchronous transfer mode) was widely heralded as the most important broadband networking technology. ATM switches repackage variable length IP data packets into fixed-length packets that are then sequentially channeled over fixed-network channels at very high bandwidth. The low latency provided by sequential transmission of packets allows the reliable channeling of high-quality video and other data-rich multimedia content. Combined with the development of a large market for leased network capacity (spearheaded at the time by WorldCom, GlobalCrossing, and others), it allowed large corporate clients to create geographically dispersed intranets with very high functionality that could simultaneously connect to often overcrowded public networks. North American firms became key providers of ATM technologies—above all Ascend, but also Fore Networks, Bay Networks, and Newbridge Networks. Large telecommunication switch providers quickly formed alliances with and eventually acquired each of these firms.

During the mid-1990s, Siemens decided to develop switches with ATM technologies as one of its core moves on the Internet. To do so, it developed an alliance with Newbridge Networks, a Canadian firm that for a time was a leading provider of high-end ATM switching equipment for very large corporate networks and governments. The alliance floundered. While corporate culture conflicts played a strong role (see Meissner and Naschold 1999), ongoing corporate restructuring within Newbridge has been a core problem (Saunders 1998). Weaknesses within its manufacturing division and an inability to compete in fast-growing markets for lower-end ATM equipment severely depressed Newbridge's share price (Greene 2000), leading to a management reorganization as well as widespread speculation during 1997 and 1998 that Siemens would acquire the firm. However, during late 1999, following Lucent's acquisition of Ascend, Alcatel, the last major telecoms giant without a strong presence in ATM markets, successfully negotiated to acquire Newbridge. While Alcatel has allowed Newbridge to continue work with Siemens in marketing some high-end products, the acquisition can only hurt Siemens long-term prospects in developing overlay technologies, particularly for corporate markets.

Siemens has also failed to emerge as an important player in the wireless equipment industry. Siemens was late to develop wireless technologies using GSM technologies, in part through adopting an early strategy to convince the German government to adopt rival standards which Siemens would have a better chance of controlling. The weakness of Siemens in the wireless area was so large in the late 1990s that wireless telecommunications consultancies such as the Yankee Group did not include Siemens in their semiannual ranking tables of firm performance in this area (Yankee Group 1999). While currently a strong player in the chipset market for handsets, the firm has failed to capture expanding markets for third-generation wireless switching systems dominated by Ericsson. Siemens eventually shifted its core wireless R&D center to a wireless technology hub in Aalborg, Denmark. No other German firm currently has a strong position in wireless infrastructure technologies; Bosch attempted to enter the handset market during the mid-1990s but failed.

Siemens has recently developed competencies in IP-driven network equipment markets. During the early 2000s, large infrastructure investments in network capacity have combined with the maturation of optical networking technologies to increase the reliability of so-called "dumb" networking technologies based solely on IP switching (see Gilder 2000). Siemens has become increasingly committed to adopting Internet-based standards as the core of its switching technologies. To do this, it spent $950 million to acquire three small US-based Internet equipment start-ups: Argon Networks, Castle Networks, and Redstone Communications, the activities of which were integrated into a newly expanded US R&D center in Burlington, Massachusetts (*The Economist* 1999).

These investments signal an increased internationalization of Siemens. The firm has increasingly decided to locate research competencies for important newly emerging technologies primarily in the United States. The success of this new strategy is undetermined, as critics note much higher investments in IP technologies by Siemens' core network switching rivals. Cisco Systems alone has acquired two dozen network switching start-ups during the late 1990s (Paulson 2001). However, the transfer of leading edge R&D activities in data-driven network equipment to the United States will surely minimize what were already weak technology spillovers around Siemens core R&D sites in Munich.

Overall, no German telecommunications equipment manufacturer has developed technological trajectories that could lead to local agglomerations of technology start-ups in core Internet infrastructure technologies. While Munich has become the most important technology hub in Germany, very little of this activity is in software or equipment-related networking technologies. During the height of the Internet boom from the late 1990s through 2001, no companies listed on the *Neuer Markti* were involved in the development of new network telecommunications technologies, and less systematic evidence from field research suggests that few if any private start-ups in these areas exist in Munich (see Casper 2003*b*). Largely due to its technological weaknesses in core data telecommunications technologies, Siemens has not been able to assume a similar role in Germany as other large telecommunication equipment players, and in particular Ericsson in the Stockholm area.

A study by Sternberg and Tamasy (1999) on the impact of Siemens on the development of Munich's industrial structure concludes that Siemens is primarily oriented toward the outsourcing of complex semiconductor components and related electrical parts. This is driven in part by the decentralization of Siemens into several major electronics groups, all of which depend on a variety of relatively complex components. This is viewed by Sternberg and Tamasy as a positive development, in that Siemens does not "make or break" firms in the Munich area. Elements of hierarchy often found in more vertical supplier networks, such as those often found in the automobile industry are removed. Creating a large demand for intermediate electronic components has increased the technological intensity of the Munich area. This phenomenon might create important technological communities in the electronics component industry, which though highly competitive, may have more incrementally innovative technological trajectories in which German firms may more easily develop competitive success.

The lack of technology drivers within Germany's telecommunications industry reinforces constraints created by normal institutional frameworks in Germany. Of particular importance, the absence of technology clustering within local regions restricts the development of active labor markets for engineers and developers within Germany. Idiosyncratic evidence from interviews with Munich software start-ups suggests that Siemens has failed to develop either technological spillovers or human resource policies that could precipitate more technologically intense clusters of software firms in Munich. While technological weaknesses dampened Siemens' capacity to play this role in the Munich area, Siemens has a reputation for encouraging long-term employment, generally hiring engineers early in their career, and developing their careers internally, which mutes the creation of active labor markets for high-profile scientists and engineers.

Overall, Siemens has failed to match Ericsson's success in becoming a dominant player in the creation of system architectures and related standards in core emerging network or connectivity markets. The *potential* for Siemens to strongly alter "normal" institutional incentives within Munich or other leading technology districts in Germany is low.

Conclusion

The success of the Stockholm technology cluster demonstrates that it is possible for large companies to play a dominant role within regional economies that can lead to the suppression of normal institutional framework conditions and the creation of alternative patterns of economic coordination within CMEs. Does this success of the Swedish middleware software industry invalidate the varieties of capitalism approach? The case does weaken strong forms of institutional analysis seeking to read off patterns of innovation within an economy from institutional architectures. It shows that national institutional incentives and constraints can be circumvented in some cases; there are degrees of freedom for actors in developing viable patterns of economic coordination not anticipated by the models of capitalism perspective. However, the case also illustrates that at least one of the major problems of economic coordination surrounding the Silicon Valley mode, developing deep and flexible labor markets, was a central issue surrounding the formation of this technology cluster. This finding legitimates the general approach to analyzing the sustainability of new technology firms emphasized by the varieties of capitalism theory.

8

Conclusion

Governments around the world are investing resources and designing policies aimed at promoting competitiveness in new economy industries such as biotechnology and software. This study has argued that the orientation of national institutional frameworks plays a strong role in explaining the success by which actors can sustain the Silicon Valley model of organizing radically innovative firms. While expectations drawn from the varieties of capitalism perspective are an important starting point, this study has also shown that public policy can be an important complement helping to explain country competitiveness. Moreover, regional heterogeneity in patterns of economic coordination exists in both LMEs and CMEs, suggesting that national institutional frameworks may not be the only reference point actors use to structure economic relationships. This concluding chapter summarizes these findings and discusses their implications for comparative institutional research.

Varieties of Capitalism and Country Competitiveness in Radically Innovative Industries

A core expectation of the varieties of capitalism perspective is that national institutional frameworks create trade-offs surrounding the types of commercial innovation strategies sustainable across particular economies. The first part of the study applied this approach to examining the organization and performance of radically innovative industries in two key European economies, Germany and the UK. Expectations from varieties of capitalism theory were drawn out surrounding the Silicon Valley model of financing, governing, and staffing radically innovative firms. This yielded the prediction that radically innovative firms within CMEs, such as Germany, would face substantial institutional obstacles that should stifle the development of sustainable agglomerations of radically innovative companies. LMEs such as the UK, by contrast, should have a comparative institutional advantage in radically innovative industries.

Public policy implications were also developed. National institutional frameworks have a strong impact on patterns of economic coordination within an economy and, due to historical path dependencies and interdependency across institutions, are difficult to change quickly. An implication of this argument is that public policy should be designed to "work through" or be incentive compatible with the dominant institutional logic of economic coordination within an economy. Governments within LMEs can, through the design of what Mowery and Nelson call sectoral support systems, craft sector-specific policies to complement broader institutional incentives within the economy. More exhaustive policy instruments are required for CMEs to encourage competitiveness in radically innovative industries. The goal of technology policy within CMEs must be to create needed sectoral support systems, but also, and more fundamentally to design either new national institutional frameworks or sector-specific institutional supports needed to develop patterns of financial and labor market coordination needed to sustain radically innovative firms. In sum, the VOC approach predicts that the type of public policy instruments used to stimulate new economy firms should differ across LMEs and CMEs and that, moreover, LMEs should be able to more easily design successful policies, while CME policies are more likely to fail.

Case studies of a well-known radically innovative industry, biotechnology, were developed to examine the impact of national institutional frameworks on the sustainability of the Silicon Valley model of organizing new technology firms. In addition to a benchmarking case focussed on the San Diego region of the United States, in-depth studies were completed for the largest European CME, Germany, and LME, the UK. For each case, evidence on the general success of the country in developing and sustaining radically innovative firms was presented. This was complemented by process-tracing research designed to investigate whether institutional frameworks or, at times, public policies adequately promoted forms of economic coordination within the economy needed to sustain each element of the Silicon Valley model: high-risk finance, high-powered governance incentives within firms, and flexible labor markets. Finally, each of the three empirical studies reviewed public policy toward the biotechnology sector and, in the German case, more wide-ranging government initiatives to orchestrate the development of radically innovative industries.

Do the findings on radically innovative industries within these countries support the varieties of capitalism approach? To a large extent they do, though with some important complications suggesting that the relationship between national institutional frameworks and innovative outcomes is complex. The most straightforward case was the US comparative study of the San Diego biotechnology cluster. This region has a large and growing biotechnology industry focussed predominantly on radically innovative therapeutic biotechnology companies. Patterns of economic coordination within the region strongly conform to the Silicon Valley model, helping to substantiate the claim that this model of organizing companies has successfully diffused from the San Francisco region to other parts of the country.

As expected, public policy toward biotechnology in the United States complements normal institutional incentives within the economy and is oriented toward the crafting of a sectoral support system. Public policy toward biotechnology in the United States focusses primarily on the commercialization of science. An important element of the success of the US economy in promoting science-based industry is the ability of universities and other nonmarket research intensive actors to play an active role in the so-called marketplace for ideas (Gans and Stern 2003). Though the strong financial resources of most US universities play an important role, US policy toward science has, through the Bayh–Dole framework, created a straightforward regulatory framework governing the stewardship of publicly funded intellectual property and, through the SBIR program, created an important mechanism whereby potential spin-off companies can obtain funding for commercialization research.

The findings on Germany also confirmed expectations surrounding CMEs. Beginning in the mid-1990s the German government launched an array of technology policies toward new economy industries, with biotechnology serving as the centerpiece of the new initiatives. These policies contained some elements consistent with the sectoral support system approach, particularly with regard to the commercialization of university science. Policy also attempted to circumvent long-standing problems facing new technology firms. A government system of venture capital subsidies aimed to strengthen the availability of high-risk finance to start-ups. To help promote the use of stock options as a viable performance incentive within firms, the German government also supported a change in finance law to simplify their use within firms. These activities are in line with the prediction that, within CMEs, public policies would need to circumvent or fundamentally change institutional frameworks within the economy to sustain the Silicon Valley model of industrial organization.

The empirical survey of German biotechnology found that the German policies, surprisingly, did stimulate the formation of hundreds of biotechnology companies focussed on radically innovative strategies. This finding shows that technology policies can, at least in the short run, catalyze new patterns of entrepreneurialism within a CME. However, the empirical survey also found that the performance of the German companies has been poor and, moreover, key drivers of this poor performance can be linked to the inability of the new public policies to create patterns of economic organization capable of supporting key elements of the Silicon Valley model. Despite the provision of several hundred million dollars in government venture capital subsidies to German biotechnology firms, a sustainable system of private venture capital funding has not emerged. Nor have government policies led to a sustainable system of stock market support for technology companies. The *Neuer Markt* was for a time Europe's leading technology-oriented stock market, but could not survive the Internet stock-related crash of 2001 and 2002 and closed in 2003. The limited ability of German firms to engage in IPO activity also impacts the viability of stock options as a high-powered performance tool. German new technology companies have rapidly implemented stock-option schemes, an important change in corporate practice. The effectiveness of this tool, however, has been limited by the low probability of companies reaching a successful IPO.

The continued existence of long-term employment norms within German industry has also impacted the viability of radically innovative technology strategies. German biotechnology companies have been weakened by extremely limited labor markets for mid-career scientists and managers. The generally unchanging structure of German labor markets creates barriers against "competency destroying" technology strategies. German technology start-ups cannot easily "hire-and-fire" personnel, in large part because labor markets for highly experienced technical staff and managers are limited due to the long-term employment equilibrium throughout the economy. Labor market rigidities create important limitations on the strategic orientation of German biotechnology firms, in that they cannot engage in projects in which necessary human resource competencies could shift quickly. They also limit the ability of German biotechnology firms to assemble skill-sets needed to innovate within the complex and, with regards to clinical development, highly regulated environment facing therapeutic discovery. In sum, key institutional elements of the "German model" have created important constraints on the ability of biotechnology firms to develop necessary financial and human resource competencies, helping to explain the poor performance of the German biotechnology industry.

The performance and industrial organization of the UK biotechnology industry also conformed to the predictions of the varieties of capitalism approach. The UK biotechnology industry is strongly oriented toward radically innovative strategies and, by most indicators, such as total employment, number of public companies, and number of marketed products, the UK industry leads Europe. Institutional frameworks surrounding finance, corporate governance, and labor market regulation within the UK strongly conform to the LME model. Biotechnology companies within the UK have, as a result, been able to adopt each of the three elements of the Silicon Valley model. The UK is home to Europe's most liquid capital markets which, after reforms enacted in the early 1990s, were able to support several dozen biotechnology initial public markets. The UK venture capital system has also performed well and was able to survive a severe crisis during the late 1990s caused by unexpected failures of several costly late-stage clinical trials within prominent UK firms. Company laws within the UK conduce toward the crafting of high-powered performance incentives within companies. Due to the success of UK companies in reaching viable exits via IPOs, these performance incentives have proved viable. Labor markets within the UK are highly flexible, buoyed in the life science area by the widespread restructuring and consequent dismissals of tens of thousands of scientists and managers within the pharmaceutical industry.

A problematic finding surrounding UK biotechnology, however, is that, while its industry leads Europe, the aggregate performance of its companies appears to lag far behind those within the United States. Thus, while patterns of economic coordination clearly support the Silicon Valley model of company organization and finance, institutional architectures alone do not predict competitive performance within biotechnology. The inferior performance of the UK biotechnology industry was linked, at least partially, to differences in the public policy context surrounding the commercialization of science. Universities within the UK have a difficult time playing an active role in the marketplace for ideas surrounding biotechnology and science-based industries. Several factors were found that weakened the performance of UK universities in commercialization processes. These include lack of adequate resources within university technology transfer offices created by the primarily public funding structure of UK universities, an anticommercialization bias often found in UK public policy toward science funding, and, on a more microscale, transaction cost barriers toward commercialization created by common organizational practices toward commercialization within UK universities. Public policy within the UK has, in recent years, strived to develop a more effective support system toward the commercialization of science. Through ensuring that nonmarket actors such as universities have the necessary resources and incentives to participate within commercialization processes, such policies could provide an important complement to broader national institutional incentives and constraint and have a significant impact on the competitive position of the country's biotechnology industry.

In sum, the findings from the United States, UK, and Germany indicate that the orientation of national institutional frameworks strongly impacts the viability of the Silicon Valley model of organizing and governing new technology firms. The United States and UK were shown to have a comparative institutional advantage in supporting biotechnology, a radically innovative industry. Institutions in Germany conduce toward more incremental innovation trajectories and, as a result, created important constraints to the creation of radically innovative competencies in biotechnology. Turning to public policy, the study was initially framed as a test as to whether government policies could essentially trump national institutional frameworks in fostering the emergence and sustainability of radically innovative new technology industries. While public policy does strongly impact the sustainability of radically innovative industries such as biotechnology, policy generally works as a complement rather than a substitute to national institutional frameworks.

The Problem of Institutional Reflexivity: Why So Many Radically Innovative Firms in Germany?

The poor performance of radically innovative biotechnology firms in Germany supports the expectations of the varieties of capitalism approach. An important issue for institutional theory, however, is understanding why so many firms were founded in Germany to begin with. About 80 percent of the approximately 400 German biotechnology firms founded during the late 1990s adopted radically innovative therapeutics research strategies. Their existence implies that their founders were decidedly not following the dictates of the theory of comparative institutional advantage. Their reflexivity to the types of institutional incentives and constraints identified as important by varieties of capitalism research is low.

The founders of most German biotechnology firms were internationally prominent university scientists. These scientists had a strong knowledge of international industry dynamics within the biotechnology industry, which are strongly linked to the commercialization of science into therapeutics discovery technologies. Given the availability of low-risk venture capital to start companies and the provision of free company incubation space within newly created technology parks, launching new companies was relatively simple and low-risk (see Asakawa and Lehrer 2004). The ‘high science’ background of most employees in these firms, coupled with the lack of experienced industry scientists, helps explain why these companies have moved into high-risk therapeutics centered research areas. It is likely that international industry dynamics also impacted the strategies of many German biotechnology firms, especially as many senior German scientists can be assumed to have colleagues in the United States and other countries that had previously launched companies.

Professors founding companies also had a ready supply of labor for their newly founded companies: junior scientists working within their academic laboratories One-third of scientists working for German biotechnology firms examined in Chapter 4 came directly from the firm’s founding academic laboratory, and when all previous jobs were taken into account, fully half of the German scientists were previously employed in the firm’s founding laboratory Only later, when more experienced personnel are needed (primarily in pharmaceutical development activities) do the constraints of being in German industrial labor markets become apparent. Markets for downstream assets, such as experienced industry scientists who can work on pharmaceutical development processes, have remained untapped by biotechnology entrepreneurs. As a result, German firms, once founded, have had a hard time recruiting experienced personnel commercial development capabilities. “Normal” German labor markets, that is relatively tight labor markets for mid-career scientists, which are the result of the German system of long-term employment in large companies, seem to be tied to this. This skill-set deficit, combined with financing shortfalls, helps explain the performing shortfalls of the German industry.

If institutional reflexivity is low, how should the relationship between institutions and the strategy and structure of actors be conceived? This discussion suggests that the founders of German biotechnology firms were responding to different institutional pressures than those emphasized by the varieties of capitalism approach. Incentives within the academic research system, an institutional environment largely ignored by research on innovation (though see Whitley 2003), have strongly influenced the trajectory of the German industry. The German academic research system is more hierarchical than the US or UK academic systems. German academic departments are staffed by a small number of senior chaired professors, each of whom is responsible for hiring several junior professors (*Lehrstuhle*) and for the hiring of graduate students and post-doctoral fellows. While no studies of career dynamics within the German research system exist (though see Knorr Cetina 1999; Whitley 2003), it is likely that senior German professors have more responsibility for orchestrating the development of careers for junior scientists employed in their laboratories. If so, then the opportunity to found biotechnology companies could provide a convenient opportunity to push junior scientists out of laboratories and into the commercial marketplace. The movement of hundreds of junior scientists into German biotechnology firms could be the result of an oversupply of scientists within German academia.

The German biotechnology case indicates that considerable myopia exists. Research linking macro-institutional frameworks to micro-level activity within the economy should avoid the temptation to read off economic outcomes from the characteristics of institutions. Founders responded to shorter-term incentives created by public policies and near-at-hand staffing opportunities to push academic scientists into companies. Only later was the normal pattern of institutional incentives and constraints surrounding German labor markets felt by German companies. As the first wave of German biotechnology companies have clearly struggled, an interesting topic for future research is whether the institutional myopia surrounding the first wave of entrepreneurs in Germany, and other countries, will continue, or whether actors will learn to respond more systemically to how institutions structure patterns of economic coordination within the economy.

Subsector Specialization as an Alternative Trajectory by Which CMEs Can Gain Competitiveness within New Technology Industries

Alternative trajectories exist by which CMEs can develop competitive positions within new economy industries. One potential trajectory, motivated by research on sectoral systems of innovation, argues that new technology industries such as biotechnology or software can be disaggregated into multiple segments which may vary in underlying technological and market characteristics. Enterprise software and platform biotechnologies, both large and important subsectors within their industries, were found to have more incrementally innovative trajectories far more similar to 'medium technology' industries such as machine tools than to radically innovative industries such as standard software or therapeutic discovery-based biotechnology. Varieties of capitalism theory predicts that Germany and other CMEs should have a comparative institutional advantage in such industries. This expectation was assessed with both descriptive statistics on subsector specialization across the subsectors of the software and biotechnology industries within the UK, Germany, and Sweden, and through a more qualitative case study of the German competitiveness in platform biotechnology and enterprise software. Both types of evidence broadly confirmed the subsector specialization argument, and through doing so created support for this alternative pathway by which CMEs have successfully competed within the new economy.

The comparative institutional advantage argument has important implications surrounding the sustainability of platform biotechnology and enterprise software within CMEs. German and other new technology firms embedded within CMEs can develop patterns of knowledge investment among employees that are difficult to sustain by firms depending on hire-and-fire to achieve flexibility. Turning to the LME case, a contradiction exists within the incentive structures most high-technology enterprises offer to employees. Top management expect skilled employees to commit to very intense working conditions needed to successfully win innovation races with competitors, but also reserve the right to hire-and-fire at will. This incentive conflict is reduced through offering very high-powered short-term performance incentives to employees (stock options, bonuses, and the like). While effective, hire-and-fire creates strong incentives for employees to invest in skills that can easily be transferred to other firms. Within LMEs the development of firm-specific skills is risky, in that they cannot be easily transferred to other firms if the current firm fails or the employee is laid off or fired.

Short of a fundamental recasting of national institutional frameworks toward an LME model, governments within CMEs cannot easily promote patterns of coordination within the economy needed to sustain radically innovative companies. Returning once more to the subsector specialization argument, however, governments may be able to promote the formation of successful new economy companies through emphasizing comparative institutional advantage within incrementally innovative segments of the new markets. The German government's policies of orchestrating resource flows into radically innovative firms during the late 1990s failed to create sustainable clusters of radically innovative companies. These policies did, however, create numerous platform biotechnology and enterprise software companies that have performed well.

An interesting topic for further analysis is which, if any, of the German policies were needed to support the subsector specialization within platform biotechnologies and enterprise software. It is likely that similar policies as those seen within LMEs, that is development of a sector support system supporting the commercialization of university of science, might have sufficed. Most platform biotechnology firms are founded on university science. Universities in Germany, the UK, and indeed most European countries face similar obstacles to the development and commercialization of intellectual property surrounding research. Policies aimed at providing resources and incentives that encourage nonmarket actors such as universities to participate in commercialization processes are important across most innovative sectors of the economy.

That being said, many of the more aggressive policies implemented within Germany may not have been necessary, particularly surrounding venture capital subsidies. Most platform biotechnology and enterprise software companies begin to generate revenue at an early point in their development. They can thus use retained earnings to finance incremental growth. Funding from VCs or, more importantly, IPOs is generally important when companies contemplate more substantial growth, typically either acquisitions or expansion into new marketing territories. Most platform biotechnology and enterprise software companies also typically use stock options as a high-powered incentive instrument to create commitment to collaborative organizational models. In these respects, availability of stock market financing is important. However, because incrementally innovative firms typically have earnings and a market proven business model, IPOs for these firms are typically far less risky than those for radically innovative biotechnology or software companies. This suggests that the more conservative mainline Frankfurt Stock Exchange within Germany, as well as other more conservative markets within CMEs, should be able to support such firms. In sum, aggressive public policies aiming to channel financial resources to new technology companies are not necessary to sustain companies whose financial and governance requirements are aligned with a country's comparative institutional advantage.

Can Large Firms Shape Innovative Characteristics within Regional Economies?

The descriptive statistics on subsector specialization did identify one troubling case for the varieties of capitalism approach. The Swedish software industry has more radically innovative firms than expected for a CME, particularly in a subsector of the industry with close technological linkages to the digital telecommunications industry called middleware software. From the mid-1990s onward Sweden developed a large cluster of radically innovative software and wireless telecommunications start-ups in the Stockholm area, many with close links to a dominant telecommunications equipment supplier Ericsson. The Stockholm software sector was used to explore a second trajectory by which CMEs could potentially compete within new technology industries. Could alternative patterns of economic coordination within regional economies develop in ways that supercede or circumvent normal institutional incentives and constraints within an economy?

Empirical analysis of the Stockholm software cluster suggests that many companies in this sector have successfully adopted radically innovative strategies and are performing well. Patterns of economic coordination emphasized by varieties of capitalism theory needed to make the Silicon Valley model of industrial organization sustainable were crucial within the Stockholm region. A dominant provider of wireless telecommunications technology, Ericsson, had taken important steps to reduce the career risk of moving from established and safe jobs to a start-up. This includes the ability, through its sponsoring of industry standards, to dramatically reduce the technological risk-facing local companies. The company also changed its human resource policies to facilitate moves by its engineers and managers to local wireless communication start-ups by offering to reemploy personnel if start-ups failed. The Swedish software case showed that, within a regional economy, local patterns of labor market coordination can tip from the normal pattern of long-term company employment and risk aversion common to CMEs toward working within new technology start-ups toward the flexible labor market equilibrium found within successful technology clusters within LMEs.

How portable are the mechanisms driving alternative forms of coordination within the Stockholm cluster to other regional economies within CMEs? Despite the failure of Siemens to create similar effects in Munich, other important telecommunications companies exist within CMEs, some of which, such as Nokia in Finland or DoCoMo in Japan, have leading market positions that could possibly promote similar technological spillovers within their local economies. It is also important to stress, however, that within CMEs large firm technological leadership must be complemented by internal human resource policies that accommodate the movement of valuable engineers and managers out of the company. Ericsson had the foresight to change long-entrenched employment policies to accommodate the movement of its engineers to start-ups. Ericsson's German telecommunications rival Siemens, for instance, does not appear to have changed its policies of primarily long-term employment. Given that flexible human resources policies are strongly at odds with the long-term employment norm within CMEs, it should not be assumed that other dominant firms within CMEs will so readily change path.

Variation in sectoral dynamics might also limit the ability of large companies to strongly shape the innovative characteristics of regional economies. Digital telecommunications is likely to be the industry most impacted by network externalities. Network externalities are low within the bioscience industries, for example, and largely unknown in other new technology industries, such as nanotechnology. If such technological spillovers across firms are more limited in other industries, then so too are the possibilities of dominant firms to directly lessen risks of low technological cumulativeness faced by local start-ups.

If companies can create alternative patterns of economic coordination, might governments do the same? The German biotechnology industry demonstrates the difficulty of using public policy to circumvent institutional frameworks on a national level. Regional policies may benefit from a greater ability to target key actors, such as large firms or, as seen in the biotechnology case, universities and leading scientists employed within them. However, in telecommunications and other industries where the importance of universities as the source of technology for companies is weaker, the sources of government influence may be limited. While governments have at times played important roles in standard setting, within the global telecommunications industry standard setting consortia have increasingly been dominated by companies (see e.g. Glimstedt 2001). The viability of policy instruments toward company technology strategy may be low.

Regional Heterogeneity within LMEs

Comparative institutional research has not systematically explored the issue of regional heterogeneity within national models. One finding discussed in the context of the San Diego biotechnology case is the surprisingly poor performance of biotechnology within many regions of the United States. National institutional explanations have difficulty explaining why there is so much spatial variation in the performance of technology clusters within the United States, particularly across regions with promising starting conditions for high-technology industry. The existence of regional heterogeneity in the success of US technology clusters, particularly across regions with seemingly appropriate endowments in university research, is an important problem facing varieties of capitalism theory.

Potential explanations for regional variation include differences in the ability of universities to develop effective technology transfer organizations, or the colocation of appropriate venture capital resources within a region (see, e.g. Florida and Kenney 1988). A third explanation for the divergence in performance across US technology clusters begins again with Saxenian's emphasis (1994) on regional social structures facilitating mobility. While the technology transfer explanation has been generally unexplored as a mechanism to promote patterns of economic coordination surrounding radically innovative firms, both the venture capital and labor market mobility explanations are consistent with varieties of capitalism theory. According to the logic of this argument, within LMEs there is a regional component to economic coordination that must develop in order for a cluster of radically innovative firms to emerge.

This book's study of social network formation within the San Diego biotechnology cluster provided support for the labor market mobility explanation. It also demonstrated that the failed acquisition of a key early firm within the region Hybritech, helped catalyze the founding of numerous early companies within the cluster as well as a 'backbone' of network links across these companies. While the colocation within San Diego of several world-class biomedical research centers and the existence of vibrant venture capital markets within California no doubt also contributed to the region's success in biotechnology, the importance of social networks formed primarily through shared corporate experiences culminating in the Hybritech acquisition points to the importance of the social network and mobility explanations.

From the perspective of public policy toward technology clusters, the primacy of mechanisms of social network formation located within market activities casts doubt on whether governments can successfully seed technology clusters. Fleming, King, and Juda (2006) have documented a similar company centered mechanism surrounding IBM as playing a key role in the formation of social networks linking inventors in Silicon Valley's semiconductor industry. This finding mirrors the earlier discussion of Ericsson's role in seeding Stockholm's technology cluster. The activities of companies, rather than governments, form a central mechanism in regional cluster formation. As governments around the world are investing heavily in both biomedical science and facilities to aid its commercialization, underlying the mechanisms leading to the formation of biotechnology clusters is an important area for future research.

The Portability of the Argument

Can the findings surrounding the four countries examined in this study be generalized to other countries? One well-known weakness of the varieties of capitalism approach is its emphasis on only two ideal-typical families of capitalism. Other comparative institutional studies have suggested that at least five distinct families of capitalism exist (Amable 2004), if not more (Whitley 1999). There is, of course, no doubt that meaningful variations in national institutional frameworks exist across other important economies such as France or Japan. Studies have shown that these two countries share some elements of the CME model (see Hancké 2002; Yamamura and Streeck 2003) and, as a result, have faced similar challenges in developing well-performing industries within new economy sectors (see Sako 2003; Trumbull 2004). However, the specificities of these cases do vary in important ways from the German or Sweden cases, and it would be incorrect to limit expectations of how institutions might structure innovative behavior to effects gleaned by ideal-typical LMEs or CMEs.

This weakness, however, is counterbalanced by the development within the varieties of capitalism approach of strong microfoundations surrounding the governance of innovative competencies. Entrepreneurs contemplating the formation of a firm located within a radically innovative industry such as therapeutic biotechnology face a similar constellation of technical and market risks no matter where in the world they are located.

While the Silicon Valley model of organizing such firms should not be assumed to be the only strategy of organizing radically innovative companies, from the 1990s onward the approach has been widely copied across the world and has become the basic template for developing technology start-ups. As a result, the problems identified surrounding the financing, organization of incentives, and staffing of these firms should be assumed to be common across new technology industries.

Moreover, there is strong empirical support for the claim that national institutional frameworks structure patterns of economic coordination within an economy and, through doing so, have a fundamental influence on the viability of each aspect of the Silicon Valley model. While regional variation in patterns of economic coordination surrounding high-technology industries does exist, understanding mechanisms driving regional heterogeneity is an important ongoing research topic. That being said, such cases are most usefully framed as departures from "normal" patterns by which national institutional frameworks structure behavior in the economy. As a starting point for study, perspectives linking institutions to the sustainability of particular innovation strategies are justified.

Finally, how portable are the study's findings surrounding public policy? Most generally, policy must work through, or be designed to be incentive compatible with a country's national institutional frameworks. Perhaps the most important empirical conclusion of this study is that comparative institutional advantage within the new economy exists for both liberal market and coordinated economies. In this respect, findings surrounding the German experience become important in framing additional comparative research. Is it possible for governments to recognize and nurture industries for which their economy has a comparative institutional advantage? Policy must be flexible enough to account for unanticipated drivers of entrepreneurial activity and, particularly when dealing with new industries and actors in an economy, an institutional myopia when it comes to thinking about longer-term competency development. Policies aimed at reducing such myopia and increasing the reflexivity of firms to their institutional environment could hasten the process by which firms develop competitive success within the new economy.

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