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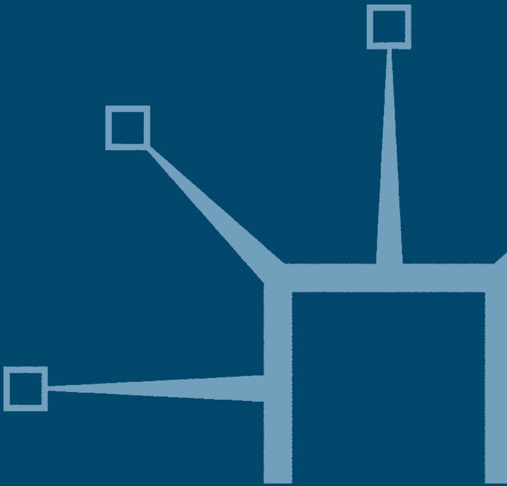
# Global and Local Knowledge

## Glocal Transatlantic Public–Private Partnerships for Research and Technological Development

Elias G. Carayannis and Jeffrey M. Alexander



# Global and Local Knowledge

*Also by Elias G. Carayannis*

THE STRATEGIC MANAGEMENT OF TECHNOLOGICAL LEARNING

IDEA MAKERS AND IDEA BROKERS IN HIGH-TECHNOLOGY ENTREPRENEURSHIP (*with Todd Juneau*)

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GLOCAL KNOWLEDGE: Transatlantic Public–Private Partnerships for Research and Technology Development (*with Jeffrey Alexander*)

MODE 3: Knowledge Creation, Diffusion and use in Innovation Networks and Knowledge Clusters (*with David Campbell*)

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*To Dr Jekyl and Mr Hyde, for reasons they know well…*

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# Preface

Knowledge does matter: but the question is when, how, and why. Moreover, with the advancement of economies and societies, knowledge matters even more and in ways that are not always predictable or even controllable (for example see the concepts of strategic knowledge serendipity and knowledge arbitrage in Carayannis *et al.*, 2003).

This book has been a journey of insight and discovery in the emerging global knowledge "village." Perspectives from and about different parts of the world and diverse human, socio-economic, technological and cultural contexts are presented and interwoven to produce an emerging new worldview on how specialized knowledge that is embedded in a particular socio-technical context can serve as the unit of reference for stocks and flows of a hybrid, public/private, tacit/codified, tangible/virtual good that represents the building block of the knowledge economy, society and polity. GloCal (global/local) networks (see Carayannis *et al.*, 2005), coupling together different national innovation systems and trans-nationally linking heterogeneous networks of knowledge producers, knowledge carriers and knowledge users, are thus becoming crucial components of the global, real and virtual knowledge architectures and infrastructures.

Two major purposes of this book are:

- To add to the theories and concepts of knowledge further inputs, such as suggesting a linkage of systems theory and the understanding of knowledge, emphasizing multi-level systems of knowledge and innovation, summarized also under the term of "Mode 3."
- To leverage this diversified and conceptually pluralized understanding to support practical and application-oriented decision-making and policy-making with regard to the optimization of knowledge creation, diffusion and use systems as well as the leveraging of knowledge for other purposes and objectives that bear directly on economic performance, technological advancement and civic development.

Knowledge-based decision-making and policy-making has significant implications and ramifications for the management of knowledge within and across industry (global multinational corporations as well as local entrepreneurial technology ventures), universities, and government research laboratories, as well as for public and international affairs pertaining to knowledge and innovation policy in the context of the knowledge economy and society. Furthermore, the architecture of multi-level systems of knowledge and innovation appears essential for understanding the current dynamics of knowledge, where national (supranational) systems of innovation continuously are being challenged by a co-evolution with the global innovation system. Consequently, national innovation systems increasingly become globally embedded. In the book, this conceptual aligning of bridging, on the one hand, systems theory and knowledge and, on the other hand, encouraging the conceptual use of multi-level systems of knowledge and innovation, is being summarized and offered for discussion under the particular term of "Mode 3."

With regard to knowledge-referring decision-making, the interplay of knowledge and innovation management of non-governmental organizational actors, i.e. firms and universities, and the knowledge and innovation policies of the public, governmental organizational actors, must be regarded as crucial. The designing of optimized patterns of knowledge interaction between non-governmental and governmental actors can be supported with the conceptual understanding of multi-level systems of innovation.

Research networks, tying together, linking and coupling different (heterogeneous) groups of knowledge producers and knowledge users, become crucial for the whole process of knowledge production (knowledge creation). Research networks can unfold across a spectrum of different rationales, following the logic of a diversified typology of linkages: university/business, basic research/applied research and experimental development, national/global (sub-national/national/supra-national), knowledge producers/knowledge users. Innovation clusters, in addition, are based crucially on research networks in science and technology.

Two important knowledge-oriented policy means of public governmental actors are: allocation, reallocation, of public funds for knowledge, and support – also "communicative investment" – for the development and enhancement of research networks, linking together, ultimately globally, different knowledge producers and knowledge users. Public knowledge support is not limited to a resource-based approach, i.e. expenditure for knowledge. In fact, this would be a constrained and misleading perception of public knowledge capabilities.

To develop new concepts to guide policy, this book addresses some of the fundamental concepts of knowledge, innovation, economic growth, and collaboration:

- How does knowledge relate to R&D, S&T and innovation?
- What are the mechanisms and dynamics of knowledge creation, production, use and diffusion?
- What are measurements of knowledge production (e.g. bibliometric indicators)?
- What is the impact of knowledge (R&D, S&T and innovation) on economic performance?
- How are networking and innovation networks defined and delineated (e.g. the scope, scale and types of local/regional, national and supranational interactions)?
- What new policies are needed to manage and govern in the knowledge-based economy and society?
- How do university–industry (business)–government interactions and policies affect the national and global capacity for R&D and innovation?

The book also explores some key concepts necessary for understanding the nature of strategic research partnerships in a knowledge-based economy:

- National systems of knowledge, R&D, S&T, and innovation.
- Knowledge (R&D, S&T, and innovation) as an "engine" for economic growth.
- Proper knowledge-oriented policy interaction between government, university, and business.
- Knowledge networks and alliances: e.g. private–public partnerships for knowledge, S&T as public or private goods.
- Local/regional, national, supranational, and global innovation systems.

The goal of this book is to delineate a framework to understand dynamically complex knowledge systems, moving towards a "mode 3" architecture of innovation networks and clusters.

ELIAS G. CARAYANNIS
JEFFREY M. ALEXANDER

# Introduction

The human species has survived, evolved, and prospered driven by its natural instinct of *curiosity* and natural competence to *learn and adapt*. Knowledge, and especially scientific and technological knowledge, which is the focus of this book, is the child of the happy merger of curiosity and learning spiced with happy accidents of serendipity and arbitrage.

Modern societies and economies, being knowledge-based and becoming knowledge-driven, thrive or perish according to the degree, scope, and intensity of availability, awareness, accessibility, and affordability of strategically sustaining or disruptive knowledge and its by-products.

*Global and Local Knowledge* is a qualitative and quantitative study of when, how, and why such knowledge is best created, diffused, and used, in particular in the form of transnational public–private partnerships for research and technology development, with an additional focus on EU–US collaborations of this nature. Moreover, an implicit focus of this book is the nature, dynamics, and structure of the processes of knowledge creation, diffusion, and use that manifest themselves effectively in the form of *innovation networks* and *knowledge clusters*, and thus the implications of participating in *transnational public–private partnerships for research and technology development partnerships* (*TPPPRTDs*) as well as the trade-offs and opportunity costs of participation or abstention that are essential elements of technology policy- and strategy-making. In this context, the concepts of strategic knowledge serendipity and strategic knowledge arbitrage (Carayannis and Juneau, *Idea Makers and Idea Brokers* (2003)) are revisited as intrinsic to the TPPPRTDs.

# 1

# Introduction and General Concepts

Economics since Adam Smith identifies three chief productive factors in any economy: land, labor and capital. The shift in the West from an agrarian economy to one based on manufacturing was marked by the shift from land as the most important factor to physical capital – factories, machinery, and resources which composed these assets – and the financial capital to acquire those assets. The rise of a "post-capitalist" society as described by Drucker suggests that other assets are approaching ascendancy as contributors to economic productivity (Drucker, 1980). The manufacturing-based economy has given way to a "knowledge-based" economy.

In an era of globalized, highly mobile financial capital, multinational corporations can essentially "arbitrage" across national borders to find the best organizations to integrate into their mode of production. The increased velocity of commerce (especially through electronic commerce) and competition demands multifaceted expertise from a firm. Only through the judicious and experienced application of knowledge can firms hope to outperform their counterparts and achieve sustained competitive advantage (Arthur, 1996).

In post-capitalist economics, wealth flows not to those who control financial capital, but to those who can acquire and direct intellectual capital. The term "intellectual capital" refers to intellectual assets (i.e. skilled workers, scientific knowledge, and business information) which create knowledge into the future through their utilization. Intellectual capital has been defined by Klein and Prusak (1994) as "intellectual material that has been formalized, captured and leveraged to produce a higher-value asset."

The post-capitalist knowledge-based economy operates with dynamics which differ radically from those assumed by neoclassical economics.

Unlike other forms of capital, intellectual capital is not only unevenly distributed, but it tends to grow without physical limits. A firm which captures and exercises unique knowledge capabilities will tend to attract more expert employees, thus exhibiting "increasing returns to scale." According to Arthur, this dynamic leads to a new form of economics – knowledge economics – that is very different from traditional, process-oriented economics. The rules of this new paradigm "call for different management techniques, strategies, and codes of government regulation." The task of management becomes "a series of quests for the next technological winner" (Arthur, 1996).

The core activity of firms in increasing-returns markets is research: the generation of new knowledge which leads to products with competitive commercial value. The strategic goal of the firm is to establish a stream of innovations, each capitalizing on the success of its predecessor. Intellectual capital is thus the primary source of wealth creation, since it represents the generation of new knowledge within the firm to establish and maintain technological leadership. The critical issue for national and corporate technology policy and strategy is how best to allocate resources among all of the potential opportunities in research and technological development to achieve the maximum benefit to private returns and national needs. This implies that research needs to be "directed" to some extent, even at its most basic level.

Understanding the role of intellectual capital and its components in contributing to national competitiveness requires an examination into the nature of knowledge and how it is created. The following section discusses the nature of the "building blocks" of knowledge-based competitiveness: creativity and innovation.

## I Creativity, innovation, and competitiveness

### A Creativity

Starting at the individual level, creativity may be defined as the capacity to "think outside the box" – to think laterally, to perceive, conceive, and construct ideas, models, and constructs that exceed or supersede established limits and ways of thinking and perceiving. Creativity is related to the capacity to imagine, since it requires the creator to perceive future potentials that are not obvious based on current conditions. From a cognitive perspective, creativity is the ability to perceive new connections among objects and concepts – in effect, reordering reality by using a novel framework for organizing perceptions.

In the business context, creativity now is championed by certain authors as the critical element enabling change in organizations. Kao (1996, xvii) defines creativity as:

> the entire process by which ideas are generated, developed and transformed into value. It encompasses what people commonly mean by innovation and entrepreneurship. In our lexicon, it connotes both the art of giving birth to new ideas and the discipline of shaping and developing those ideas to the stage of realized value.

Kao views creativity as the "result of interplay among the person, the task, and the organizational context". Drazin *et al*. (1999) agree with this assertion. They conclude that creativity is both an individual and group level process. Complex, creative projects found within large organizations require the engagement of many individuals, rather than just a few. It is often difficult to assign credit to any one individual in a creative effort (Sutton and Hargadon, cited in Drazin *et al*., 1999). Creativity, in this view, is an iterative process whereby individuals develop ideas, interact with the group, work out issues in solitude, and then return to the group to further modify and enhance their ideas.

## B Innovation

Innovation is a word derived from the Latin, meaning to introduce something new to the existing realm and order of things or to change the yield of resources. Innovation is seen as the panacea for competing successfully in today's global marketplace, but in much of the literature the concept is a vague one. Managers are told they must promote innovation, but they are not given the specifics of how this is to be accomplished. In many cases, authors often cite one or two examples of companies that are profiting from "innovation," and the reader is left to grapple with the mechanics of extrapolating useful information that is transferable to his or her own situation. If creativity can be seen as a process and a product or event, the use of the term innovation in terms of creativity seems to muddy the waters. If one consults the business literature, "innovation" and "creativity" appear to be used interchangeably.

In an extensive review of popular and academic business literature, we found that the information provided ranged from the esoteric notion of promoting an innovative organizational climate to concrete steps in creative problem-solving. Given the target audience, some of the information provided is aimed at practical applications. What seems to be lacking is a general innovation model which links the inputs of innovation to both outputs and outcomes, and which identifies the levels of innovation available to managers. This model can only be constructed if we develop its theoretical foundations – the theory of innovation. Other literature explores the variations on innovation by process, industry, and results.

Nelson and Winter (1977) introduced some of the fundamental problems in constructing an integrated theory about the nature of innovation. In their view, a "useful" theory of innovation would have a few specific features:

> By a theory we mean a reasonably coherent intellectual framework which integrates existing knowledge, and enables predictions to go beyond the particulars of what actually has been observed. (Nelson and Winter, 1977, p. 36).

Developing a theory of innovation based on the existing body of literature in innovation management is further complicated by the need to synthesize the results of prior research. As noted by Kuhn (1970):

> a new theory, however special its range of application, is seldom or never just an increment to what is already known. Its assimilation requires the reconstruction of prior theory and prior fact. (Kuhn, 1970, p. 7)

Theory-building must identify "that class of facts … shown to be particularly revealing of the nature of things" (Kuhn, 1970, p. 25), and must "be wide enough to encompass and link the relevant variables and their effects, and strong enough to give guidance as to what would happen if some of these variables changed" (Nelson and Winter, 1977). Consequently, the development of theories on the management of innovation must integrate concepts from both research on management, and a language for describing the nature of innovation itself, keeping in mind that innovation may proceed differently in different environmental settings.

Recent work to extend the body of theory on the management of innovation focuses on the role of knowledge in extending and evolving the capabilities of a firm to generate and/or implement innovations in technology and business processes. This new basis for a comprehensive theory of the management of innovation examines how firms generate, acquire and apply new knowledge, especially in relation to the research process.

A second aspect of the study of innovation examines various types of innovation, categorized by both the technical differences among innovations and their different effects. A typology of innovation is a necessary part of research on the management of innovation. Variations in the nature of different innovations will affect the design of mechanisms which facilitate specific innovations for strategic purposes.

One of the most fundamental distinctions among types of innovation is presented by Utterback and Abernathy (1975): the difference between product and process innovation. Utterback and Abernathy explicitly relate the significance of each type of innovation with both the stage in the development of the technology in question and the firm's "chosen basis of competition." In this view, competitive strategy is interrelated with technology development. In the early stages of technology development, a firm will focus on those aspects of innovation which best meet the needs of the customer (so-called "performance-maximizing" innovations), followed by a period when the product is developed into a limited number of "dominant designs," emphasizing a strategy based on differentiation. As the technology matures, the locus of innovation shifts away from product development towards refinement of the production process, emphasizing a low-cost strategy.

Utterback and Abernathy's approach provides the foundation for an evolutionary typology of innovation. In this typology, innovations are classified according to their impact on their underlying technologies. Four types of innovation are commonly cited in the literature on innovation management.

At the lowest level of impact are incremental innovations. These innovations are described as those which extend a technology along its existing "technological trajectory" (Dosi, 1982). A technology trajectory is the set of potential trade-offs among technological variables which are considered relevant within a particular technological paradigm. Therefore, incremental innovation is analogous to the work described by Kuhn (1970) as "normal science"; it improves on an existing configuration of technologies without fundamentally altering that configuration.

At a somewhat higher level of impact are generational innovations. As described in Henderson and Clark (1990), these innovations involve improvements to the subsystems encompassed in an existing technological system. A related concept developed by Henderson and Clark is the architectural innovation. In this case, the links between existing subsystems are reorganized to produce new capabilities in the technological system. Both generational and architectural innovations may appear to be technically simple, but they often challenge the ability of incumbent firms to adapt to technological change, causing substantial organizational disruption (Gatignon *et al.*, 2000).

Radical innovations are those which involve a complete re-conceptualization of the problem that a technology is supposed to solve. They break from the prevailing technological paradigm and integrate new technologies into a new system – occasionally by merging the technologies of two separate systems (Sahal, 1985). Significantly, radical innovations often have their origins outside the traditional technical domains of an industry – for example the addition of jet propulsion to aircraft. Therefore, radical innovations flow from trans-disciplinary research and development.

Two other aspects of technological innovation are relevant to this book.

The first is the increasing tendency of firms to derive competitive advantage from the combination and synthesis of multiple technologies. Kodama (1992) refers to this phenomenon as "technology fusion." His analysis of Japanese firms identifies three strategies of firms which gain competitive advantage through technology fusion: demand articulation (using customers' needs to guide the firm's technological developments); intelligence-gathering (ensuring that the company's employees are active participants in identifying and processing new technical information from other sources); and collaborative research and development. Technology fusion particular leads a firm to explore and incorporate technologies which are beyond the core technologies of the firm's industry.

The second aspect is the increasing degree of complexity in technological innovation. Many authors have documented the increasing importance of complex products in the global economy. "Complex" products are those where no single person can comprehend all of the knowledge necessary to design and build that product. Again, the trend towards increasing technological complexity leads to the increasing importance of multidisciplinary development teams which incorporate experts with disparate scientific and technical expertise.

Innovation may be also generally categorized as product, process, or administrative (Tidd, 2001). Others classify innovation by regional influences (Evangelista *et al.*, 2001). Still others view innovation as product-process-radical-technological (Cooper, 1998). Another view of classifying types characterizes innovation by decision systems (Rogers, 1995). This method relies on the principle that adoption of innovation may be influenced by both individuals and entire social systems. There is also a distinction between sustaining and disruptive innovations (Christensen, 1997). The dichotomy between continuous and discontinuous innovation is especially significant:

> Discontinuities are often described as technological breakthroughs that help companies rewrite industry rules or create entirely new industries. Rarely have distinctions been made within the concept of "discontinuity," not to mention how to identify these radical innovations. For the corporate strategist, a big question remains: how to actually structure opportunity identification so it becomes a rational process-one that yields breakthroughs reliably (versus waiting for opportunities to arise serendipitously). (Kaplan, 1999)

Chesbrough and Teece (1996) attack the problem of definition from a different viewpoint. They state that there are two types of innovation. Autonomous innovations are those that can be pursued independently from other innovations. They use the example of a new turbocharger to increase horsepower in an engine, which can be developed without the complete redesign of the engine or the rest of the car. Systemic innovations, on the other hand, are those which must be accomplished along with related complementary innovations. Redesigning a workflow process in a factory would be an example of a systemic innovation, because it requires changes in supplier management, personnel, and information technology.

We propose an approach to classifying and subdividing the concepts of innovation along four fundamental dimensions:

(i) The process of innovation (the way in which the innovation is developed, diffused, and adopted);
(ii) The content of innovation (the specific technical or social nature of the innovation itself);
(iii) The context of innovation (the environment in which the innovation emerges, and the effect of that environment on the innovation);
(iv) The impact of innovation (the social and technological change which results from the completion of the innovation process).

## C The relationship between creativity and innovation

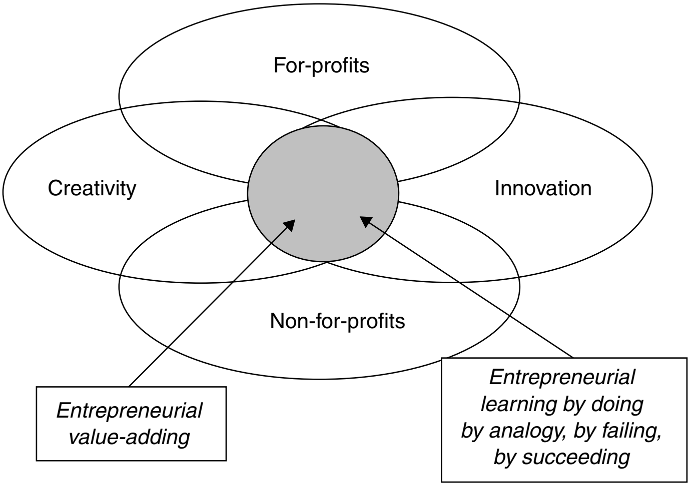
In much of the foregoing discussion, a recurring theme about innovation is that of uncertainty, leading to the conclusion that an effective model of innovation must include a multidimensional approach (uncertainty is defined as unknown unknowns whereas risk is defined as known knowns). One model posited as an aide to understanding is the Multidimensional Model of Innovation (MMI) (Cooper, 1998). This model attempts to define the understanding of innovation by establishing three-dimensional boundaries. The planes are defined as product–process, incremental–radical, and administrative–technical. The product–process boundary concerns itself with the end product and its relationship to the methods employed by firms to produce and distribute the product. Incremental–radical defines the degree of relative strategic change that accompanies the diffusion of an innovation. This is a measure of the disturbance or disequilibrium in the market. Technological–administrative boundaries refer to the relationship of innovation change to the firm's operational core. The use of technological refers to the influences on basic firm output while the administrative boundary would include innovations affecting associated factors of policy, resources, and social aspects of the firm.

Government or market success or failure is determined by how they take advantage of the four major elements that shape the setting for creativity, innovation and competitiveness in the globalized world: (1) the coordination and synergy in the relationship between governments, enterprises, research laboratories and other specialized bodies, universities and support agencies for small- and medium-sized enterprises (SMEs); (2) the power of information and communication technology; (3) the efficiency that managerial and organizational systems can bring to production and commerce; and (4) the international agreements, rules and regulations. All four elements of this framework will impact on creativity and innovation at the micro-level (firm level) as well as on innovation and competitiveness at the macro-level (industry, national, global).

## D Competitiveness

Competitiveness is the capacity of people, organizations, and nations to achieve superior outputs and especially outcomes, and in particular, to add value, while using the same or lower amounts of inputs.

Moreover, entrepreneurial value-adding and entrepreneurial learning by doing, learning by analogy, and learning by failing, does not belong



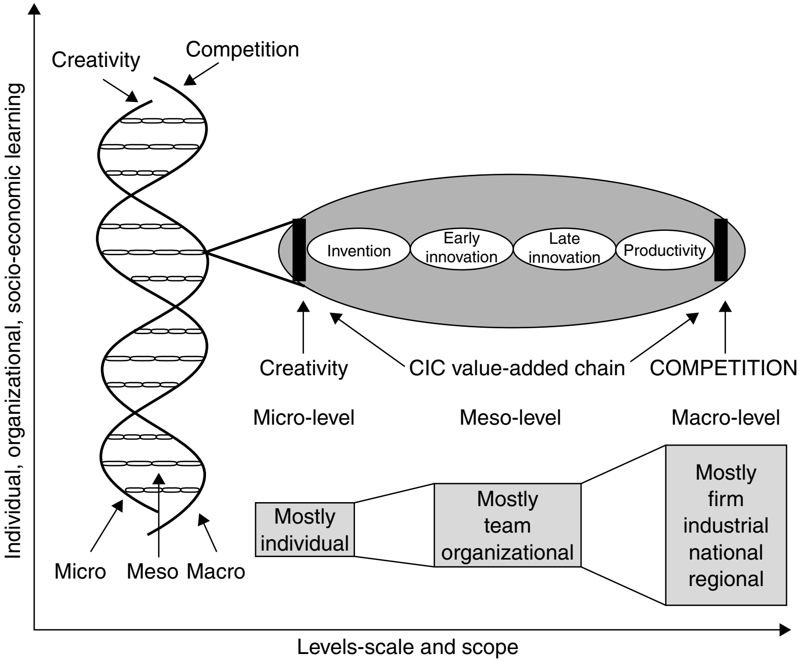
*Source*: Carayannis and Gonzalez (2004).

*Figure 1.1* Value-adding and learning topology

to the realm of for-profit entities only, but also in the domain of not-for-profit entities (Carayannis and Gonzalez, 2004). This is shown in Figure 1.1 with the overlapping circles connecting creativity and innovation activities across for-profits and not-for-profits.

The standard for judging whether these results are "superior" can encompass both prior capabilities of a particular organization or nation and a comparison with other organizations or nations. The critical assumption of competitiveness, then, is that it is accomplished through a process of organizational improvement, where the institutions in an economy leverage people, knowledge and technologies to rearrange relationships and enable higher states of production.

Creativity is the result of inspiration and cognition, the liberation of talent in a nurturing and even provocative context and it is mostly an intensely private and individualistic process – it operates at the micro (individual) level (Carayannis and Gonzalez, 2004). Innovation is a team effort and takes place at the meso (group/organizational) level, as it needs to combine the blessings of creativity with the fruits of invention and the propitiousness of the market conditions – timing, selection, and sequencing are important as well as "divine providence," obsession and clairvoyance. Competitiveness is the edifice resting on the pillars of



*Source*: Carayannis and Gonzalez (2004).

*Figure 1.2* Creativity, innovation, and competitiveness spiral and value chain

creativity, invention, and innovation and it materializes at the macro (industry/market/national/regional) level (see Figure 1.2).

We are inspired by the Nobel-prize-winning discovery of the double helix as nature's fundamental scaffold and evolutionary process to elucidate and articulate the nature and dynamics of the interrelationship between and among creativity, innovation and competitiveness and their evolutionary pathways. We attempt to do that by means of the Creativity, Innovation, and Competitiveness Double Helix (CIC Helix) (Figure 1.2) in which one strand represents the flow and record of creativity and the other that of competitiveness.

As discussed in this book, strategic research partnerships involving government, university, and industry participants can serve as a focusing device, as well as a facilitation mechanism, to ensure that innovations can be generated by society with more efficiency and effectiveness. Similarly, the December 2004 report of the US Council on

Competitiveness, *Innovate America*, proposes that government, academic, and industry groups need to coordinate their activities closely to "optimize society for innovation" (Council on Competitiveness, 2004). While this mode of research and technology development may appear to be a relatively recent organizational innovation, it is in fact the culmination of the evolution in science policy in the US and elsewhere since the end of World War II.

## II Key perspectives on science policy for government–university–industry (GUI) partnerships

Vannevar Bush's essay to President Truman, titled "Science: The Endless Frontier," represents one of the earliest statements of an explicit rationale for government involvement in the advance of science and technology. In his treatise, Dr. Bush argued that science could bring direct benefit to national societies. More importantly, Dr. Bush established a governance framework, now interpreted as a social compact between scientists and politicians. In this framework, scientists are left to pursue their own paths of inquiry, and their collective research will lead inexorably to the discovery of socially relevant knowledge and inventions. In this sense, Dr. Bush's essay is a restatement of Adam Smith's "invisible hand" of economics, where the will of individual actors in a free market will lead through competition to maximum efficiency and returns to investment.

There are two key points of the Bush doctrine on science policy which have come into dispute over the past two decades.

First, Bush's view of scientific progress assumes that researchers, in their pursuit of scientific truth, will naturally produce socially useful knowledge as a byproduct. His report noted several valuable inventions which were produced by wartime research, including the mass production of penicillin and artificial rubber. The governance framework is based on the proposition that scientific progress will lead naturally to useful ends.

Second, the Bush essay implies a model of innovation where basic research is conducted by scientists, and that research generates knowledge which is applied downstream by engineers to create new products and services. In essence, this is a reflection of the "linear model of innovation," where basic research is the "input" in a pipeline that leads to industrial innovations at the end. One fallacious corollary to this view is that if the volume of input is increased (i.e. increasing the amount of research funded), then the outputs will also increase accordingly.

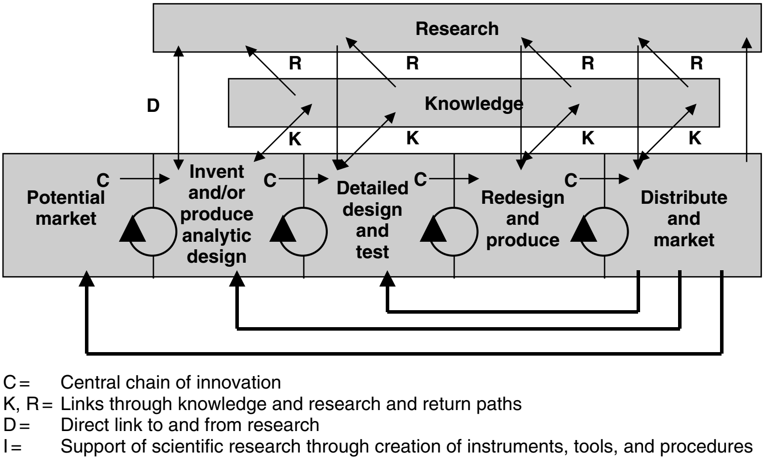
Therefore, it would follow that increased government funding of research will lead to at least some increase in the social benefits derived from science.

Neither of these assumptions is valid any longer, if they ever were. During World War II, the research cited by Bush was directed towards national needs by the government and the War Department. It is not always reasonable to assume that research will produce the most valuable knowledge, from the viewpoint of human society, if researchers are left to their own pursuits of inquiry. Similarly, it is possible to create useful innovation without significant government support of basic research, perhaps by leveraging scientific knowledge produced elsewhere.

The late Donald Stokes (1997) devised a new analytical perspective on the nature of research which expanded upon the traditional linear model of basic versus applied research. Instead of looking at fundamental science as purely "basic," he noted that some fundamental research into the nature of the universe was truly "pure research," motivated strictly by the quest to understand natural phenomena. In contrast, some "basic" research is still motivated by the desire to use knowledge for a useful purpose. By the same token, "applied" research, or research which is not "scientific" but is rather based on pure empiricism or experimentation, can also be motivated by the simple quest to observe nature versus the desire to create useful results. Each of these domains (basic science, applied science, basic empiricism, applied empiricism) form the four quadrant's of Stokes's matrix.

Within this matrix, Stokes places Niels Bohr in the pure research quadrant: in concentrating on basic research, Bohr displayed little interest in any practical application of his model of the atom. He simply sought fundamental knowledge. Thomas Edison, by contrast, is placed in the pure applied research quadrant, suggesting that he cared little about the theory of electrons as long as he could get a light bulb to glow brightly for some usable length of time. Stokes's model also has a quadrant for Louis Pasteur, a man driven not only by the desire to understand the whys and hows of disease transmission, but also by a wish to protect people from milk-borne tuberculosis.

According to Stokes, Pasteur's quadrant is a type of activity heretofore unrepresented in the science policy literature – a concept now called "directed basic research." Certain forms of "basic" research could have greater potential social and economic value than others.



C = Central chain of innovation
K, R = Links through knowledge and research and return paths
D = Direct link to and from research
I = Support of scientific research through creation of instruments, tools, and procedures

*Source*: Kline and Rosenberg (1986).

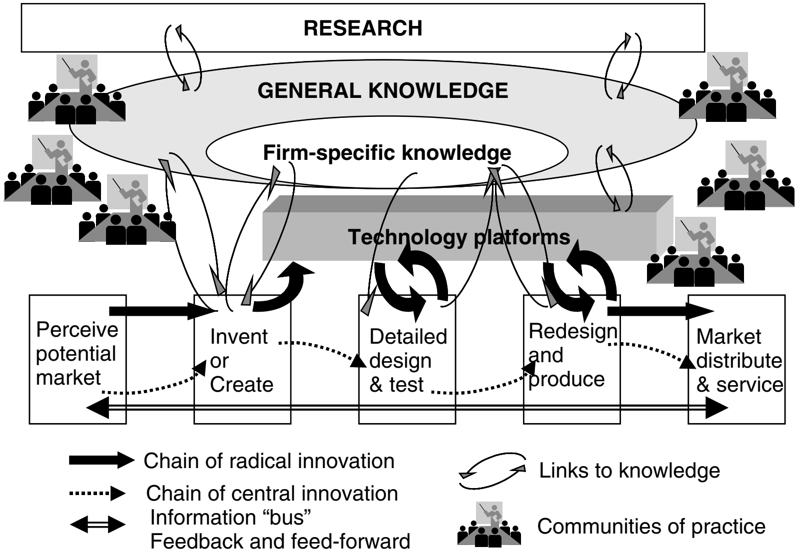
*Figure 1.3* The chain-linked model of innovation

## A Open innovation systems

The second potential fallacy of the linear model of innovation is that it ignores the possibility that inefficiencies in the innovation process itself ("turbulence" in the innovation "pipeline") can reduce innovation outputs.

To capture this idea, Kline and Rosenberg introduced the idea of a "chain-linked model of innovation," capturing feedback loops among the various steps in the process of commercial innovation, and in particular the fact that research and knowledge interacts with the innovation process at every stage (see Figure 1.3).

The "chain-linked" model of innovation has been expanded by Myers and Rosenbloom (1996) to account for the contribution of three key organizational capabilities that are involved in the "Total Process" of innovation: firm-specific knowledge, communities of practice, and technology platforms (p. 215). Of particular interest is the relationship between "research," "general knowledge," and "firm-specific knowledge." In the Total Process model, the external research community adds to the stock of general knowledge, while the internal research organization of a firm, along with other technical staff, builds up "firm-specific" knowledge which is not generally accessible



*Source*: Myers and Rosenbloom (1996).

*Figure 1.4* The "Total Process" model of innovation

to external organizations. A critical link in the chain of knowledge is composed of "communities of practice" – groups of experts both inside and outside of the firm who "communicate and apply new knowledge" (p. 215).

One implication of the "Total Process" model is that the area of practice known as "knowledge management" has direct relevance to the management of technology and innovation. If access to knowledge is a critical influence on the innovation process, then the management of knowledge is one lever by which managers can influence the pace and direction of innovation (see Nonaka and Takeuchi, 1995; Carayannis and Alexander, 1998).

## B Innovation networks and knowledge communities

Collaborative, team-based research is now a prevalent mode for conducting fundamental scientific research in many fields. Major scientific advances are no longer the result of the efforts of individual researchers, but instead involve multiple investigators. Moreover, collaboration in scientific research is often both transorganizational and transnational in nature: that is, collaborations frequently involve researchers based within different organizational entities and located in different countries (Georghiou, 1998; US National Science Foundation, 2002). As stated succinctly by John Ziman, "the organizational units of modern science are not individuals, but groups" (Ziman, 1994, p. 227).

At the same time, technology development is dependent to a greater degree on scientific knowledge than in the past (Rosenberg, 1983). Industrial inventions in the early twentieth century were often the result of experimentation by individuals with relatively little formal training in science. Current practices in industrial R&D emphasize the use of multidisciplinary project teams (Leonard and Sensiper, 1998), outsourcing to contract research organizations (Howells, 1999), research partnerships with other firms (Hagedoorn *et al.* 2000), collaboration with universities (Business–Higher Education Forum, 2001), and other forms of innovation involving external partners (Chesbrough, 2003). Industrial innovation can be modeled as a process which involves significant exchanges of information within a firm, and between a firm and the broader industrial and scientific knowledge base (Myers and Rosenbloom, 1996).

Public–private research collaborations are one mechanism by which firms can access or create critical knowledge for use in industrial innovation. In the United States and Europe, public sector organizations (primarily university and government research institutions) are significant sources of new fundamental knowledge, and also a locus for conducting basic scientific and technological research (Fusfeld, 1986; Rosenberg and Nelson, 1996; Godin and Gingras, 2000). The extent to which a firm can facilitate the development and flow of specialized, relevant knowledge from public research organizations into their own innovation activities can have a significant impact on both corporate and industrial technology development (see, for example, McMillan *et al.*, 2000; Hicks *et al.* 2001; Cohen *et al.*, 2002).

The rise in both the instances and the promotion of public–private research collaboration stems from some fundamental changes in the nature of national innovation systems in industrialized countries. The public sector, and particularly the academic community, has long been viewed as the primary performer of basic scientific research (Fusfeld, 1986; Mansfield, 1991). As industrial technology has evolved over time, basic scientific research has become much more relevant to innovation in corporations. Whereas industrial technology in the early twentieth century was often developed independently of the understanding of its underlying scientific principles, technology development in modern industry is dependent on an understanding of science (Freeman, 1982; Rosenberg, 1983; McMillan *et al.*, 2000).

At the same time, economic and competitive pressures on private firms have led many corporations to reduce their investment on internal basic research. Instead, universities and other public sector research organizations are expected to compensate by making their basic research activities more relevant to industry, supporting public policy goals for enhancing national economic competitiveness (Cohen and Noll, 1995; Bozeman, 2000). In effect, public–private research collaborations are focusing on a new type of scientific inquiry aimed at commercially relevant topics. This type of research corresponds to Pasteur's quadrant, and is also referred to as "basic technological research" to distinguish it from pure science (Rosenberg, 1990; Pavitt, 1991, Branscomb, 1993). In this sense, the interaction between science and technology becomes especially relevant to industrial technology development. Scientific discovery creates a "map" for guiding the search for new technological innovations (Fleming and Sorenson, 2000). Transdisciplinary research collaboration on fundamental but industrially relevant science enhances the cognitive scope of firms to consider new paths of innovation (Howells, 1995; Coombs and Hull, 1998).

This new concept of public–private cooperation in science and technology places new expectations on the public sector as well, changing the nature of academic research. The new social contract between the university and the larger society is being negotiated in much more specific terms than the old one. The former contract, based on the linear model of innovation, presumed the existence of only long-term contributions of academic knowledge to the economy. Now both long- and short-term contributions are seen as possible, based on examples of firm formation and contract research in fields such as biotechnology and computer science. A new model of innovation is required to capture multiple reciprocal linkages at different stages of the capitalization of knowledge (Etzkowitz and Leydesdorff, 1997, p. 1).

The recognition of this new imperative for cross-boundary research collaboration provides the motivation for the study of government–university–industry strategic partnerships (Betz, 1997; Carayannis and Alexander, 1999; Etzkowitz and Leydesdorff, 2000; Murray, 2003). A number of national governments and transnational organizations have established programs to facilitate the formation of such partnerships, based on the belief that this form of collaboration enhances the efficiency and effectiveness of national innovation systems (Carayannis, Alexander and Ioannidis, 2000). Unfortunately, other than case studies on specific and fairly limited programs for funding such partnerships (primarily in the United States, the European Union, and Japan), there is a clear absence of systematic studies of public–private research collaboration (Peters *et al.*, 1998).

## C Transnational research collaboration: building knowledge bridges

In additional to transorganizational and intersectoral collaboration, transnational research collaboration is deserving of further investigation.

Anecdotal and statistical evidence shows moreover that collaboration in scientific research is increasingly transnational in nature. That is, the groups of researchers who are involved in scientific progress often span one or more nations in origin, location, and/or sponsorship. Georghiou (1998) provides data on the rise of global research cooperation at the personal (researcher), organizational, and national levels. At the researcher level, he provides rough figures on the rise in international co-authorship of scientific articles, particularly among industrialized nations. Technologies which reduce travel expenses and enable remote collaboration contribute towards the rise in such collaboration, as does the dispersion of scientific expertise among a wider range of nations. More recently, the increasing use of the Internet for academic and research communication also provides a new mechanism for scientists to identify potential collaborators and to initiate new joint research projects (Stead and Harrington, 2000).

The motives for firms to engage in transnational research partnerships are subject to increased study. Collaboration in basic scientific research is, as noted earlier, now more commonly transnational than not (Katz and Martin, 1997; Chompalov and Shrum, 1999; Melin, 2000; Newman, 2000). Differences among national innovation systems provide one key rationale for combining the institutional capabilities of multiple countries in new scientific research (Nelson and Rosenberg, 1993; Mowery, 1996; Whitley, 2003). These differences tend to contribute to differentiation in the specialization of nations in their knowledge, expertise, and industrial competitiveness (Brusoni and Geuna, 2001). Firms can access these different pools of expertise through transnational public–private research collaborations.

Indicators of the internationalization of research collaboration and industrial R&D all point towards a "globalization" of technological innovation (Georghiou, 1998; Mowery, 1998; Arundel and Geuna, 2001;

Guellec and de la Potterie, 2001; Dougherty *et al.*, 2003; Rycroft, 2003). While the phenomenon of globalization is a substantial topic of study in innovation management, the development of transnational relationships within the practice of technological innovation merits further study.

More recent research on inter-firm research collaborations has focused on the use of these alliances to manage transfers of knowledge between firms (Mowery *et al.*, 1996; Cummings and Teng, 2003). In this conceptualization, networks of alliances among firms are a mechanism for constituting a common knowledge base that the alliance participants can then integrate with their firm-specific knowledge to develop proprietary technologies. For this reason, research collaborations among firms are predominantly mechanisms for conducting pre-competitive research, rather than product development (Quintas and Guy, 1995).

In this view, networks of research collaborations are a new organizational form, drawing on combinative and complementary knowledge sources to enable firms to achieve new synergies in the exploitation of technical knowledge. Collaboration is therefore an engine of knowledge creation (Inkpen, 1996; Kogut, 1998). This view of research collaborations also adds a new dimension to the issue of technology sourcing raised in the literature on technology strategy. Rather than focusing only on the acquisition of technology, firm strategies include different approaches to knowledge sourcing, based on how a firm manages its participation in alliances (Bierly and Chakrabarti, 1996).

The knowledge-based approach to the analysis of research collaboration adds a new dimension to the question of how firms balance internal research activities with linkages to external research partners. Internal R&D capabilities are a necessary complement to the use of research collaborations for generating and acquiring knowledge. Cohen and Levinthal (1990) point out that firms need internal research to build and maintain sufficient "absorptive capacity" to be able to understand and apply externally sourced knowledge in a meaningful fashion. This view of the relationship between internal and external research is reinforced by other studies on the degree to which firms need to develop a common level of research and technological capability to benefit from participation in collaborations (Lane and Lubatkin, 1998; Mowery *et al.*, 1998; Cusmano, 2000).

Taking a dynamic view of knowledge and the firm, networks of research collaborations serve another important strategic purpose for companies. Participation in such networks becomes a conduit for a firm to learn new things – to not only acquire knowledge from its partners, but to attain a deeper understanding of how to apply that knowledge. Therefore, networks of collaborations become a tool for both inter- and intraorganizational learning (Carayannis, 2001). A definition of learning might be that on entity learns if, through its processing of information, the range of its potential behaviors is increased. Learning through alliances becomes one way that firms can develop new capabilities in a dynamic sense, which in turn can support sustained competitive advantage (Powell *et al.*, 1996; Powell, 1998).

Participation in a broad set of research collaborations involves a firm in a new, transorganizational entity, described by some as an "innovation network" (Freeman, 1991; Harris *et al.*, 2000; Schibany and Polt, 2001) or an "innovation community" (Lynn *et al.*, 1996; Sawhney and Prandelli, 2000). Firms become embedded in a new set of relationships based on the execution of distributed innovation – innovation involving multiple organizations acting in different capacities as part of the innovation process. To take full advantage of this participation, firms must not only focus on the technical learning that comes from the transorganizational entity, but also on learning how to collaborate more effectively to maximize the benefits derived from participation in research collaborations (Doz, 1996; Millar *et al.*, 1997; Simonin, 1997; Khanna *et al.*, 1998; Soh and Roberts, 2003).

Innovation networks differ somewhat from innovation communities in the literature on the management of innovation. An innovation network is a set of coalitions, both internal to an organization or with other organizations, which enable a firm to exploit new sources of innovation, to combine capabilities in innovation, and to diffuse innovations more rapidly (Harris *et al.*, 2000). Kogut (1998) has investigated the concept that a transorganizational network is, in and of itself, a new form and source of knowledge. This would imply that the participation of a firm in a network involving other organizational units is a tool for the generation and management of new knowledge. One way of putting this is the definition proposed by Millar *et al.* (1997) of transorganizational innovation:

> Transorganizational innovation (also referred to as networked innovation) involves bringing together knowledge from a range of disciplinary and geographically disparate sources. Networked innovation therefore depends on the management of knowledge sharing, technology transfer, and learning. (p. 399)

An innovation community, introduced primarily by Lynn *et al.* (1996), involves transorganizational innovation as a process combining both different sources of innovation and the integration of those sources with innovation users. The role of the innovation community concept in the management of innovation is to discuss how organizations interact to develop both processes and technologies which facilitate the diffusion of a technological innovation.

In the context of this book, both innovation networks and innovation communities are important to the study of transnational public–private research collaborations. From one perspective, these collaborations involve both sources of scientific knowledge (public research organizations) and the entities which use that knowledge in technological innovation (primarily private sector firms). From another perspective, these collaborations are an important mechanism for embedding firms in an innovation network, which they can then utilize to acquire and leverage knowledge through processes of organizational learning (Carayannis, 2001).

Combining the perspective of the strategic management of technology with the importance of organizational learning within and about research collaboration, effective participation in communities or networks of innovation becomes an issue of the strategic management of technological learning (Carayannis, 1994; 1996; 2000). Sustained competitive advantage from distributed modes of research and innovation is supported not only by technological learning, but learning-how-to-learn about technology and innovation. Enduring and successful involvement in research collaborations constitutes a process of socialization, so that the firm becomes embedded in its network of research relationships with multiple partners in knowledge generation, dissemination and use.

Multinational corporations are a particular type of actor within the concept of knowledge networks. Since multinational corporations (MNCs) are themselves geographically dispersed organizations, they function in some respects as a network of organizational units. The components of an MNC in a particular country may have some degree of operational autonomy from the other parts of the MNC. Given this fact, the management of innovation within MNCs is a problem of facilitating the transfer of knowledge and technology across both organizational and national borders (Persaud *et al.*, 2001; Zander, 2002; Cummings and Teng, 2003).

An important characteristic of MNCs is their institutional and structural capability to access sources of knowledge and innovation located in different nations. As noted earlier, Rycroft (2003) and others have discussed the increasing dispersion of scientific and technological capabilities across nations, as measured by various indicators. One implication of this dispersion in capabilities is that the technological competitiveness of firms can be enhanced by accessing a greater range of geographically distributed sources of scientific and technological knowledge. This is one motivation for the increased internationalization of corporate research and development, both in the establishment of overseas R&D facilities by MNCs and their more extensive linkages to foreign corporate partners and public research organizations.

The growing linkage between firms and public research organizations is a trend present in both the United States and the European Union. Due to the international character of industrial R&D, it is not surprising then that firms in the European Union are partnering with US public sector research facilities, and that US firms are doing the same with public institutions in the European Union. However, these kinds of partnerships pose interesting questions for existing theory on the role of MNCs in global innovation networks.

An explicit goal of the R&D Framework Programmes of the European Union is the promotion of research collaborations, including both private–private and public–private collaborations, as a means of enhancing technological competitiveness across Europe. There is evidence that the European Union is making progress towards this goal. The same is true of certain research funding programs in the US Federal Government, such as the Advanced Technology Program managed by the Department of Commerce (Ruegg, 1998). Therefore, one might expect that increased access to domestic public research institutions by foreign corporations would be one mechanism for enhancing the capabilities of those firms in technological innovation.

Another aspect of this issue is the ability of MNCs to act as aggregators of global knowledge in key areas of industrial technology. Due to their transnational scope, MNCs appear very well structure to acquire and combine knowledge from diverse sources, especially those sources which are less international in their geographic structure (such as government laboratories and university research centers). Therefore, MNCs may themselves reflect the globalization of scientific research in the nature of their own technological innovation processes (OECD, 1999a).

To provide a context for the research and studies encapsulated in this book, the next section reviews some of the salient concepts developed in the extant literature on innovation and organizational strategy. These concepts explain the reasons why government–university–industry collaboration occurs, and provides a theoretical framework for forming the propositions about these partnerships and which will be explored in later chapters.

## III Literature on strategy, innovation, and collaboration

This book addresses the relationship between transnational, public–private collaboration in basic research and the strategic management of technology and innovation within and across firms. The analysis of this topic draws on theoretical approaches from four relevant domains of literature.

The first domain is the recent and emerging set of literature on a knowledge-based theory of the firm. This theory is applied to new conceptions about the purposes of firms, their formation, and the sources of sustainable competitive advantage. Particular attention is paid to the development of the concept of the firm as a tool for generating, accumulating, organizing and applying knowledge.

The second domain is the theory on the management of technology and innovation. This literature set concerns how organizations (in particular, firms) can direct, allocate, and control the development of technologies, both internally and externally, to create a competitive advantage in the market and to achieve higher levels of sustained economic performance. The literature reviewed here focuses on the relationship between knowledge and technological innovation, and on the strategic management of technology as a capability which is central to firm competitive advantage.

The third domain is the literature on public–private partnerships in research and development. This domain has three relevant components. First, it examines the changes in the role of public organizations in performing basic scientific research, focusing on new expectations placed on public sector research related to economic development. Second, this literature focuses specifically on how basic research relates to industrial innovation in firms. Third, a part of this literature explores the dynamics of public–private research collaborations by analyzing both the justifications for public–private research collaborations and strategies for improving the effectiveness of such collaborations.

The fourth set of literature addresses the transnational nature of scientific research as it relates to corporate research and development. This set of literature examines both the global and collaborative nature of (primarily academic) science, and also the transnational aspects of innovation and technology in the private sector.

This section reviews key works in all four domains of literature, and synthesizes these works to develop the theoretical and methodological approach to the study of transnational public–private research collaboration.

## A The knowledge-based view of the firm

Strategy has been described as a firm's realized position in a competitive market (Porter, 1980; Mintzberg, 1987). Since the market is assumed to be competitive, a particular firm's strategy can be analyzed relative to other firms in the market. Therefore, models of strategic management are theoretical constructs which aim to provide first, an explanation as to how firms arrive at a particular position relative to their competitors; and second, a framework presenting how firms can formulate a particular approach that can lead to a superior competitive position.

Strategic models are related to the concept of a "theory of the firm." According to Holmstrom and Tirole (1989), a theory of the firm is an attempt to explain why firms exist (the *raison d'être* of organizations), and what determines the scale and scope of a firm. A theory of the firm, therefore, provides the parameters that can be used to understand how and why firms differ. Any model of strategic management exists in the context of a particular theory of the firm, since the economic justification for the existence of the firm necessarily affects how the firm behaves in its pursuit of a superior position in a competitive market. The consideration of corporate strategy as it relates to knowledge and research collaborations requires an overview of the evolution in thinking about strategy and competitive advantage.

The dominant view of strategy is represented by Porter (1980; 1985; 1990). Porter's model of strategic management is a fusion of the economics of industrial organization and the Harvard approach to strategy (Bain, 1968; Porter, 1980). The ability to sustain superior economic performance is based in the ability to exercise market power, according to this branch of industrial organization. Bain's original conception of this theory posits that market power derives primarily from industry structure, through the use of monopolies and/or collusion. Porter tempers this view with some principles from the Chicago school of I/O economics (e.g. Stigler, 1968), which notes that the threat of new entrants and the costs of managing collusion make traditional anti-competitive activity less effective. Instead, a firm gains competitive advantage by first selecting an attractive industry or market in which to compete; and second identifying one strategy among various generic options (Porter, 1985) which enables that firm to achieve very clear differentiation (based on cost leadership or another isolating factor) in the marketplace. This strategy is combined with optimized operational efficiency to deliver superior value to customers relative to competing firms. The firm carves a unique position in the competitive marketplace which, when properly exploited, grants the firm dominance over its competitors.

Given this assumption, Porter has created what he terms a framework, rather than a model, of competitive industry analysis that a firm can use to measure its position relative to competitors in that environment (Porter, 1985; Argyris and McGahan, 2002). The key parameters analyzed are the degree of rivalry with competing firms; relationships with suppliers of needed inputs; the presence or absence of potential new entrants or potential substitutes; the barriers to entry that limit the potential for new firms to enter the industry or market; and the resulting negotiating leverage of customers. Porter's approach assumes that all rents are created by establishing temporary monopolies over a segment of the market (Teece, 1984). While these monopolies are formed by superior strategy and execution, the mechanism of achieving sustained economic performance is still similar to that envisioned by Bain.

Based on this framework, the key feature of Porter's school of thought in strategic management is that its analysis focuses on the external environment in which a firm operates, and the degree to which the firm's strategy is an appropriate "fit" to that market environment. Porter's more recent work also looks at the internal fit of a firm's strategy – whether that strategy is aligned with the actual activities and operations of the corporation (Porter, 1996). This work also addresses the dangers posed by trade-offs – how an inability to focus on a single differentiating strategy can result in operational inefficiencies which reduce the value of the firm.

One alternative to Porter's approach, known as the "resource-based view" (RBV), instead looks inward to the firm to analyze how the unique capabilities inherent in a firm provide sustained competitive advantage (Wernerfelt, 1984; Barney, 1991). The resource-based view is closely associated with the work of Penrose (1959). The RBV model differs from Porter's I/O model in that it looks first at the internal resources of the firm, and proposes that strategy involves the accumulation and exploitation of relatively unique, hard-to-copy assets which are arranged to enable distinct corporate competences (Barney, 1991). The company with the greatest competitive advantage is the one which can maximize the unique economic returns from its resources, and can appropriate the value of those resources better than its competitors. Economic rents, therefore, are derived from a combination of Ricardian rents (the possession of a set of unique and exclusive resources, such as land or patents) and "quasi-rents" derived from the temporary optimal configuration of scarce resources (such as human capital).

Mahoney and Pandian (1992) discuss how the RBV does not contradict the Porter I/O model of strategic management so much as it complements that model. While Porter's model focuses on differentiation within the market as a barrier to entry or a barrier to imitation, the RBV proposes that the unique configuration of internal strategic resources provides a similar barrier to entry. These strategic resources are the basis for determining which among various potential strategies is the best to maximize both operational efficiency and customer value. The barriers to imitation specified in the RBV are analogous to the "isolating mechanisms" described in the I/O literature. Where the RBV literature differs from the I/O literature is in the assertion that it is what the firm decides to do with its resources (its "conduct"), rather than the industry environment (or "structure"), that most enables sustained superior economic performance.

The scope of the RBV model focuses on the resources and capabilities internal to the firm, and the degree to which those resources and capabilities contribute to competitive advantage. Some of the parameters that must be assessed by the firm include identifying and understanding its internal resources and capabilities, selecting those capabilities that constitute core competences (Prahalad and Hamel, 1990), and realizing the mechanisms and extent to which the returns from strategic resources can be appropriated by the firm. In this sense, the firm earns economic rents not by establishing a monopoly over a segment of the market, but by monopolizing a particular set of firm-specific resources that result in superior operational efficiency or higher quality and performance for the customer.

Another alternative to Porter is the relatively recent application of game theory economics to strategy. Game theory is described as "the analysis of rational behavior in situations involving interdependence of outcomes (when my payoff depends on what you do)" (Camerer, 1991,

p. 137). In games, "rational" is always interpreted in relation to the perceptions of the people involved: "even how they believe other people perceive it, how they believe other people believe the game is perceived, and so on" (Brandenburger and Nalebuff, 1996, p. 52). The game theoretic approach analyzes competitive decision-making under various environmental conditions to better understand how companies should interact with other organizations (players) in the market. One assumption of this approach is that competition is inevitable, from existing rivals and potential entrants, so that barriers to entry cannot be sustained. Instead, firm strategy should be based on calculated interaction with those rivals to achieve the optimal long-term outcome. Applying game theory to strategy requires a firm to understand the position of others in the market as well as its own position.

Teece, Pisano and Shuen (1997) point out the limitations of these three streams of research: competitive forces, the resource-based view, and strategic conflict (game theory). The competitive forces literature assumes that firms have the market power to prevent the entrance of rivals, when in fact competition is difficult to suppress. The resource-based view of the firm is static, ignoring the process by which core competences are built or lost. The game theory literature is criticized for focusing excessively on strategy as a series of moves and countermoves among industry rivals, and not focusing inward on how firms develop their own competitive capabilities. The authors counter these limitations by proposing a framework based on "dynamic capabilities," which adopts many of the principles of the resource-based view but introduces concepts relating to the ability of a firm to build new capabilities and competences, through the conversion of knowledge from internal and external sources into organizational learning (see also Winter, 2002).

The dynamic capabilities approach proposed by Teece *et al*. is complemented by recent efforts to create a new "theory of the firm" based around the concept of knowledge. The knowledge-based theory of the firm posits that firms exist primarily as a means for the collection, assimilation, and synthesis of knowledge. Following the concepts introduced by Polanyi (1964), many writers categorize knowledge into two types: tacit and explicit. Tacit knowledge is gained through "learning by doing"; it is knowledge which is internalized through practice. This knowledge is not easily depicted in words, diagrams, or other forms of communication, and may in fact not be verbalizable at all. In contrast, explicit knowledge is knowledge which can be identified, codified, and isolated more easily. In one conventional view, these two forms of knowledge are distinct and exclusive (see, for example, Nonaka and Takeuchi, 1995).

A new view of knowledge proposed by Tsoukas (1996) holds that "tacit and explicit knowledge are mutually constituted … the two are inseparably related." From this perspective, the artificial representation of knowledge in explicit form distorts that knowledge. It ignores the tacit component of knowledge, consisting of intangible elements such as expertise, judgment, and intuition which are necessary for the proper application of the explicit component. More importantly, tacit knowledge is necessary for understanding the dynamics of knowledge creation.

The primary resources for knowledge are the expertise and skills of the firm's employees – what is commonly termed "individual knowledge." If, as Tsoukas states, the firm is a "distributed system of knowledge," then firms can exploit individual knowledge only when transformed into organizational knowledge. While explicit representation of knowledge may be easily appropriable, the significant tacit component embedded in organizational knowledge makes transfer difficult. Some tacit knowledge can be transferred across and between organizations through the movement of individual employees. However, since organizational knowledge is the aggregation of individual knowledge, in most cases a single employee will not possess all the tacit knowledge needed to reconstruct the core competence of a firm.

One consequence of the knowledge-based theory of the firm is that boundaries of the firm are established at the point where tacit knowledge can be transferred through internal organizational processes (Kogut and Zander, 1992; Grant, 1996; Spender, 1996). As noted above, organizational knowledge supports only a limited set of core technological competences. This means that a knowledge-based view of the firm requires the recognition of the role of collaboration in enabling firms to assemble the proper mix of knowledge to achieve sustained competitive advantage.

## B Knowledge basis of technological innovation

The existing literature assumes that there are certain aspects of technological innovation which are common across all technologies. One such assumption is that a generalized model of the process of innovation exists. The prevailing conceptualization of such a model has changed over time. One significant change is the shift from a linear view of innovation to a non-linear one. As described by Kline and

Rosenberg (1986), in the linear model "one does research, research then leads to development, development to production, and production to marketing" (p. 285). The authors note several flaws in this conceptualization, especially focusing on the role of science and knowledge in the innovation process: "we must recognize not only that innovation draws on science, but also that the demands of innovation often force the creation of science" (p. 287). Thus, the relationship between scientific research and technological innovation is not a linear one, but rather a feedback loop, where at different times one is driving the other.

Coombs and Hull (1998) point out two aspects of the innovation management literature which are influenced by ideas embodied in knowledge management. First, the stream of literature which applies the concepts of evolutionary economics to technological change focuses on organizational routines, practices, and capabilities, which themselves are the product of shared organizational knowledge and skills (Nelson and Winter, 1982; Kogut and Zander, 1992). This literature emphasizes the role of "path-dependence" on technological innovation – that the future direction of technology is constrained in large part by the stock of knowledge accumulated in the past. Second, knowledge management considers knowledge to be a factor of production within the firm, often termed "intellectual capital." As a result, the generation and diffusion of knowledge within the firm contributes to the core competences of that firm, in what Leonard-Barton (1995) calls the "total system of knowledge management."

If one purpose of the organization of individuals in firms is to generate, acquire, and apply knowledge, then research and development serves two key roles to support that purpose.

First, internal research can generate new knowledge – particularly scientific and technical knowledge – which can then be disseminated throughout the firm. This is the traditional view of the importance of R&D in technological innovation, and one reason why indicators such as R&D spending are used as a proxy to indicate the level of innovation in firms. Note that R&D is not the only function that contributes to knowledge generation. Processes of "learning by doing" create knowledge throughout a firm, not just in the research laboratory. However, the R&D function is one area where knowledge generation is the primary focus of activity.

Second, as noted earlier, Cohen and Levinthal (1989; 1990), discuss how research and development increases the firm's capacity to acquire and process knowledge from external sources. In their terminology, research and development expands the “absorptive capacity” of the firm, facilitating learning from external sources of knowledge.

The knowledge-based view of technological innovation helps to explain some key features of modern industrial research and development. For example, from a knowledge perspective, R&D outsourcing is a logical strategy for acquiring knowledge from external sources rather than attempting to internalize those sources through mergers (Pisano, 1990). Also, as discussed below, this approach helps to explain why strategic technical alliances play a major role in industries characterized by rapid innovation and substantial scientific knowledge.

Innovation is related to knowledge through processes of individual and organizational learning. Through learning processes, newly generated or newly acquired knowledge is applied to the operational functions of the firm. As noted by Jelinek (1979), two types of learning are relevant to organizational innovation: administrative learning (the development of new organizational routines) and technical learning (the application of knowledge to the development and use of technologies). Acquiring and utilizing knowledge about new modes of organization to facilitate innovation plays a role in technological advancement, as does learning about the technologies of the firm.

Another key facet of learning is the interaction between scientific knowledge and technology development. Evolutionary economists characterize the function of identifying and developing new technological solutions as a “search” process (Howells, 1995; Fleming and Sorenson, 2000). In this search process, a firm tends to investigate primarily those technologies which are most familiar to it, generally through past usage. Scientific knowledge can help to expand the range of potential technological solutions that the firm investigates. As stated by Fleming and Sorenson (2000):

> Inventors search for more useful combinations of interdependent technologies by recombining and reconfiguring these technological components … By providing some understanding of how these technological components interact, science transforms the process of invention from a relatively blind search process to a more directed identification of useful new combinations. (p. 4)

Using another analogy, science provides a “map” for guiding industrial technology development. In particular, scientific knowledge from domains outside the traditional scope of a firm may help that firm to break out of traditional technological paradigms (Dosi, 1982) and facilitate the development of more radical innovations. Increasing degrees of integration among disparate areas of science and technology lead to a more "rugged" landscape of potential solutions. While such "rugged" search environments are more difficult to analyze and maneuver, they also present greater opportunities for the development of useful inventions.

Utilizing fundamental concepts about the nature of technological innovation, firms can begin to develop the knowledge and practices needed to manage technology and innovation to support sustained competitive advantage. Technology management is the set of policies and practices that leverage technologies to build, maintain, and enhance the competitive advantage of the firm on the basis of proprietary knowledge and know-how. The US National Research Council in 1987 defined Management of Technology (MOT) as linking "engineering, science, and management disciplines to plan, develop, and implement technological capabilities to shape and accomplish the strategic and operational objectives of an organization" (National Research Council, 1987). While technology management techniques are themselves important to firm competitiveness, they are most effective when they complement the overall strategic posture adopted by the firm. The strategic management of technology tries to "build advantage on the basis of technology," or "bring the potential opportunities that technology creates to bear on the formulation of corporate strategy" (Morone, 1989).

Coombs and Hull (1998) note the interrelationships between the study of knowledge management and the management of innovation. In particular, their analysis points out the implications of viewing knowledge as a factor of production, meaning that knowledge is believed to be a resource which firms use to change their internal capabilities. In the context of the management of innovation, this means that firms can utilize knowledge to change both their ability to manage the development and implementation of new technologies, and the organizational routines used to leverage advances in technology. One implication of their view is that the effective management of innovation is at least in part a function of the firm's ability to manage access to and benefits from various sources of knowledge, including internal sources (such as corporate research laboratories) and external sources (such as public research organizations).

A number of authors have explored the conceptual issues involved in integrating considerations of technology with corporate strategy (Butler, 1988; Ford, 1988; Coombs, 1994; Rothwell, 1994). One important aspect of integrating technology and strategy is the determination of the "core technologies" that are of greatest significance to the firm (Chiesa *et al.*, 1999). The concept of core technologies is analogous to the concept of more generalized "core competences". The problem of the core technologies concept is that firms face significant uncertainty when attempting to determine which technologies will be most important for future corporate performance. Consequently, a number of authors have recommended that firms develop a portfolio of technology competences, based in part on the "real options" approach to capital investments (Dixit and Pindyck, 1995). The utilization of strategic technology options to guide investment in core technologies enables firms to retain flexibility in the face of uncertainty about the future (Mitchell and Hamilton, 1988; Carayannis and Gover, 1997).

The "core technologies" concept, combined with the options approach to R&D investments, has two important implications for public–private research collaboration. First, the idea of "core technologies" explicitly recognizes that firms are unlikely to be able to acquire expertise in all of the technologies necessary for future sustained competitive advantage. There will almost always be cases where firms will need to access sources of "complementary" technologies to supplement those core technologies (Teece, 1986; 1992). Second, as a means of mediating the riskiness of investments in new technologies, firms can moderate the level of investment in each technology through the use of joint ventures or other partnerships.

The importance of external linkages in corporate technology strategy is supported by further analytical and empirical studies in strategic technology management. The process of managing technology encompasses the acquisition of new technologies and new technical knowledge as well as its exploitation. Conceptions of corporate technology strategy discuss two modes of acquiring technology – internal development, generally through corporate research and development activities, and external sourcing from other organizations. Sample external modes of technology acquisition include joint ventures, contracting out for R&D, and licensing of technologies from other parties (Ford, 1988, p. 90). A number of theoretical treatments of technology strategy address the factors that lead a company to source technologies from external sources rather than relying solely on internal development (see, for example, Pisano, 1990; and Howells, 1999). In two separate surveys of strategic technology management in global corporations, Roberts (1995 and 2001) notes that while central corporate research remained the most significant location for acquiring new knowledge (through research) and technology (through development), external sources such as suppliers, customers and especially universities were ranked as among the top sources of technological know-how.

In summary, the strategic management of technology includes the clear recognition that collaboration is a key mechanism in the management of innovation.

## C Research collaboration

Since the early 1980s, a growing number of researchers in corporate strategy and innovation management have tracked and analyzed the increase in interorganizational collaborative activity. Early work in this field focused on collaborations such as joint ventures (see, for example, Harrigan, 1985). As the 1980s progressed, the variety and complexity of such collaborations also increased. The current phenomenon of public–private research collaborations can be analyzed in the context of the overall literature on research collaborations.

Beginning in the 1980s, the traditional view of strategy as a means by which individual firms compete against each other was challenged by various theories about cooperation among rival firms. The term "collective strategy" was coined by Astley and Fombrun (1983) to recognize the need to develop corporate strategies which take into account the complex interdependencies among firms and other actors in the economic environment (Mintzberg *et al.*, 1998, p. 255). At approximately the same time, the public debate over national economic competitiveness began to address the use of inter-firm collaborations to facilitate technological innovation. This discussion focused primarily on the implications of cooperative research and research joint ventures for antitrust policy (see, for example, Ordover and Willig, 1985; White, 1985).

The topic of inter-firm technology alliances became the focus of more intensive study during the 1990s, emphasizing the strategic nature of such collaborations more than their legal or economic aspects (see Hagedoorn and Schakenraad, 1990; Hagedoorn and Schakenraad, 1992; Hagedoorn *et al.*, 2000). Early works in this field of research developed typologies of strategic technology alliances based on analyses of their motivations, management, and results. The research based on the Cooperative Agreements and Technology Indicators database at the University of Maastricht mapped "networks" of firms linked by multiple strategic alliances. The mapping of alliance networks implied that firms were becoming very sophisticated in developing their own "alliance strategies," and that competition in high technology industries was taking on the character of rivalry among networks of firms, rather than individual firms (Gomes-Casseres, 1994).

With this understanding of inter-firm research collaboration as a background, public–private research collaboration can be viewed as a special case within the theory of research collaborations as networks of learning (Carayannis and Alexander, 1999). Several authors note that "cross-boundary" research collaborations, where dissimilar organizations' cooperation on joint research projects, represent a new mode of technological innovation. In fact, these public–private partnerships are themselves a new organizational form for managing innovation (Nooteboom, 1999; Leydesdorff, 2000; Fritsch and Lukas, 2001; Kaufmann and Todtling, 2001). Cross-boundary research collaborations also hold special significance as a mode for organizing transdisciplinary research, especially in areas which are relevant to both applied (industrial) research and fundamental understandings of natural phenomena (Chompalov *et al.*, 2002).

## IV Measuring innovation: a continuing challenge to calculate competitiveness

How should innovation be measured, if indeed it can be measured? Research and Development (R&D) is generally the initial measurement tool utilized (Evangelista *et al.*, 2001) but R&D itself may be measured based on different attributes. For example, for R&D/Intellectual Property Rights (IPR) measurement, the number of patents is generally the measurement axiom. However, other attributes are frequently measured also, such as research funding budgets, number of researchers, number of significant inventions, number of new products, amount of published research, etc. (Tidd, 2001). Still, other attributes are linked in a more subtle way, such as increased productivity and growth or lower costs (Nelson and Winter, 1982). Another classification of measurable characteristics is the social impact of innovation. Examples would include the ability to measure the user benefits, lower consumer prices, user time savings, and other social enablers (Mansfield *et al.*, 1977).

A typology of measurable characteristics may help to bring together the disparate measurables. The main categorization is between "hard" and "soft" measurables. Hard measurables are those characteristics that may be directly linked to the innovation process. For example, the number of patents issued is a direct outcome of the process of research and generally is not influenced by outside factors. Productivity improvements, on the other hand, may be the direct result of an innovation but the link is less clear due to other influential characteristics – productivity increases could be influenced by the mere fact of managerial-increased interest surrounding the implementation of a productivity

*Table 1.1* Comparison of variables for measuring innovation

| **Hard measurables** | | **Soft measurables** | |
|---|---|---|---|
| **Characteristic** | **Measure** | **Characteristic** | **Measure** |
| R&D | • Patents<br>• R&D budget<br>• New products<br>• R&D staff<br>• Publications<br>• R&D incentives<br>• New features<br>• Inventions | Impact | • Productivity<br>• Growth<br>• Lower costs<br>• Flexibility<br>• Supply/Demand<br>• Firm size<br>• Market influence |
| | • New markets<br>• Product extensions<br>• Conferences<br>• CRADAs<br>• Partnerships | Social | • User benefits<br>• Lower prices<br>• Social enablers<br>• Time savers |

innovation. This is not to assume that the innovation was not the primary influence of productivity gains but rather the measurement process may not be sufficiently rigorous to differentiate the various influences.

Research and development has a direct effect on output. In the manufacturing field, it is seen that applied research and development funding was a more powerful explanation of differences in productivity growth across manufacturing industries than total R&D funding by the entire industry. This would indicate that R&D expenditures are a direct measure of firm productivity. Firm productivity is greater than the norm, as expressed by industry norms.

Patents are increasingly used as indicators of the output of invention activities. The number of patents granted to a given firm or country may reflect its technological dynamism. The drawback of patents as indicators, however, is that many innovations do not correspond to a patented invention. Many patents correspond to an invention with a near-zero technological and economic value, and many patents never lead to innovation. We do not have any statistics telling us what the “success rate” is but, with an assumption that all countries are experiencing the same pattern, the indicator still gives a good picture of where the countries relatively stand.

Another interesting output indicator is the number of scientific publications. Again there is a huge difference between the countries, but for the EU as a whole there is progress. To be able to value the published scientific articles (quality), one can examine how many times a certain publication has been cited.

# 2

# The Research and Technology Development Public–Private Partnership Ecosystem in the United States: Theory and Evidence from Selected Examples

Studies of research-oriented collaborations between public sector organizations (primarily universities and governments) and firms take on a special significance. Several aspects of modern innovation systems reflect the importance of this subject.

The scale of public–private research partnership activity has increased over time. A number of studies illustrate the growing interdependence of public science and industrial technologies (Meyer-Krahmer and Schmoch, 1998; McMillan *et al.*, 2000; Hicks *et al.*, 2001; Kaufmann and Todtling, 2001). Informal collaboration across sectors has a long history, as evidenced again primarily by co-authorship of scientific papers. Even in Japan, co-authorship studies reveal a rich pattern of industry–university collaboration, where no such cooperation was thought to have occurred (Hicks, 1993; Pechter and Kakinuma, 1999).

Another significant trend is the increase in formal cross-sectoral cooperation, where researchers in a group are drawn from a mixture of government, private industry, and/or academic and other non-profit institutions. As with global cooperation, there have been a number of government-sponsored programs in multiple countries which foster collective government–university–industry (GUI) research collaboration (OECD, 1998). At the level of national policy, governments are being encouraged to facilitate public–private research collaborations to improve the efficiency and effectiveness of "national innovation systems" (OECD, 1999b, p. 66). Empirical studies of public–private research collaborations are still needed to inform decisions on whether these policies are justified.

Moreover, the extent of cross-sectoral collaboration is having a strong impact on corporate research and development activities. In significant sectors of high-technology development, such as biotechnology and information technology, Hicks *et al*. (2001) found that US patents are increasingly citing scientific publications and journal articles as "prior art," demonstrating a growing linkage between academic or basic research and the production of new technologies. Kaufmann and Todtling (2001) argue furthermore that "boundary-crossing" in research collaboration, where firms cooperate on research with non-firm organizations, "improves the capability of firms to introduce more advanced innovations." The analysis by Fleming and Sorenson (2000) shows that the integration of scientific knowledge from academic research into industrial patents produces innovations with more lasting impact than those developed without referencing such literature.

Cross-sectoral collaboration in research and technology development is important because research and development and therefore innovation are needed for industry to remain competitive. This is more important because of the fast rate of technological change and the need for firms to be at the forefront in the use of the latest technology. Firms also need to continuously improve their competitive position so that they can attract educated and qualified people (Arthur, 1996) to add value to the firm's business. As discussed earlier, the company may not be able to "produce" all that it needs to be competitive in-house and may need to purchase some of these from outside the firm. Usually, universities and smaller or start-up firms are the places where large corporations can fill this gap. In addition, firms in the knowledge economy need to develop good relationships with government to positively influence many aspects of the business, with government and industry being "intelligent stewards" rather than adversaries.

Apart from industry that needs to cooperate for competitive advantage purposes, universities also need to reach out to industry and government. First, university research projects with commercial value need people from industry because they understand what real problems exist. Second, the projects require real-time operating data, process models, and technical supports that are only available from commercial operations. Third, universities need industry to help in the implementation of new technology to generate economic benefits. Finally, universities need access to experienced scientists and experts and advanced testing facilities, which are only available in firms.

As discussed above, government needs to participate in the GUI interaction because it needs to provide incentives, regulations, and enforcement. In addition governments enter the scene as entrepreneurs directly and/or indirectly, not only supplying the resources to the other actors or regulating their relations with each other, but as an instigator of organizational innovations and structural adjustments that increasingly form the basis of innovation systems. The partners are both participants and observers: they act in the "double hermeneutics" that Giddens (1976) originally specified as typical of the social scientist (Leydesdorff, 2000).

This chapter reviews some cases of GUI collaboration within the United States. Several studies into technology policy in the United States have identified the advantages of such cross-sectoral collaboration (US House of Representatives Committee on Science, 1998), including:

- Sharing of risk and cost for long-term research;
- Access to complementary capabilities;
- Access to specialized skills;
- Access to new suppliers and markets;
- Access to state-of-the-art facilities.

US agencies are becoming direct participants in R&D collaboration by forming partnerships between agency research facilities and external research organizations. This increase in collaboration calls for new mechanisms for R&D management which take into account the dynamics of working with extramural research organizations as partners rather than grantees or contractors. There are several examples of such collaborations, as discussed in the following sections.

GUI collaboration in the United States was forged during the crisis of competitiveness of the 1980s, when the increase in imports from Japan threatened to undercut many "critical" US industries. One of the key industries under attack was the semiconductor sector, which was viewed as an important resource for national security as well as economic growth.

During the late 1980s and early 1990s, US Federal R&D agencies began increasing the promotion of collaborative research through their programs. Many of the newer, more innovative R&D programs (such as the Advanced Technology Program administered by NIST or the NSF Engineering Research Centers program) either limit proposals to those developed by consortia, joint ventures, and other collaborative groups;

or give collaborative proposals higher priority than those of single investigators and organizations. According to Dr. Thomas Moss, Executive Director of the Government–University–Industry Research Roundtable at the National Academy of Science, agencies:

> want to see the best minds engaged in their work, and want to harness best facilities. This means collaborative projects often look better than single site endeavors … In many cases funders also believe that collaboration builds in more stakeholding and commitment to the overall goals of the project. (Interview by the authors, April 1998)

Also, these programs tend to require that the recipients of funding share the costs of the project with the government, allowing the agency to leverage its R&D funds to a greater degree than if it covered its costs on its own.

Agencies are also increasing their level of research collaboration by participating directly in collaborative efforts with industry and universities. Since the passage of the Bayh-Dole Act of 1980, which launched government efforts to encourage partnering between government or university laboratories and industry, many agencies have placed special priority on developing programs in technology transfer and cooperative research. Some agencies, such as the Department of Energy and NASA, now use the number of collaborative arrangements formed with industry each year as a metric for overall agency performance.

## I GUI collaboration in the United States semiconductor industry

As a pioneering effort in industrial research collaboration, SEMATECH has been analyzed by a wide range of organizations in an attempt to determine its benefits and potential drawbacks. A number of studies (cf. Irwin and Klenow, 1996; Bridwell and Richard, 1998; and Macher *et al.*, 1998) seem to give a positive overall assessment of SEMATECH's impact on the industry, with some notable exceptions. While it is now widely accepted that there are specific conditions where industrial research collaborations such as SEMATECH have beneficial effects, it is still difficult to identify any ways by which SEMATECH may have supported the renewal of the US semiconductor industry.

SEMATECH was incorporated on August 7, 1987, by fourteen high-tech companies representing 85 percent of the national capacity for semiconductor manufacturing. The SEMATECH facility in Austin, Texas was formally opened in November of 1988. DARPA was selected by Congress as the executive agency to manage the appropriated funds earmarked for SEMATECH.

A significant aspect of SEMATECH in the revival of the US semiconductor industry is its role as a coordinating and focusing organization for the formation and management of government–university–industry (GUI) collaboration in semiconductor research. SEMATECH's extramural research program and its activities in conjunction with the Semiconductor Industry Association (SIA) and the Semiconductor Research Corporation (SRC) have extended the influence of SEMATECH in setting research directions in various research institutions. These include:

- SEMATECH Centers of Excellence at major universities throughout the United States and SRC participation in the Engineering Research Centers Program of the National Science Foundation;
- The Extreme Ultraviolet Lithography (EUV) cooperative research and development agreement (CRADA) between a group of SEMATECH members and the US Department of Energy;
- SEMATECH's support for the Focus Center Research Program of the Microelectronics Advanced Research Corporation.

## A Semiconductor industry research at the NSF ERC program

As with the national laboratories, SEMATECH has extensive links to research universities. Since 1988, SEMATECH has funded "Centers of Excellence" around the United States, each combining the resources of multiple universities and, in some cases, Sandia National Laboratory. Each center focuses on a specific area of semiconductor manufacturing processes or technology, such as X-ray lithography, metrology, and multi-level metal interconnect. The funding for such centers has been modest, approximately $1 million each, with some centers funding research in as many as six universities.

A more recent form of partnership between SEMATECH and universities is coordinated through the Semiconductor Research Corporation (SRC) and the Engineering Research Centers program of the National Science Foundation. The ERC program was developed based on a 1983 study by the National Academy of Engineering, initiated at the request of the NSF director at that time, which recommended the establishment of a new cooperative program with the following two goals:

(i) to improve engineering research so that US engineers will be better prepared to contribute to engineering practice; and
(ii) to assist US industry in becoming more competitive in world markets.

Establishment of the ERC program was motivated by the perception that significant engineering advances were occurring through the integration of new developments across traditional disciplinary boundaries (similar to what Kodama (1992) calls "technology fusion"), and that engineering education in universities no longer prepared students properly for the way in which engineering research was conducted in industry. This required that the centers established by the programs share the following objectives:

- Provide continual interaction of academic researchers, students, and faculty with their peers, namely, the engineers and scientists in industry, to ensure that the research programs in the centers remain relevant to the needs of the engineering practitioner and that they facilitate and promote the flow of knowledge between the academic and industrial sectors;
- Emphasize the synthesis of engineering knowledge; that is, the research programs should seek to integrate different disciplines in order to bring together the requisite knowledge, methodologies, and tools to solve problems important to engineering practitioners; and
- Contribute to the increased effectiveness of all levels of engineering education.

The ERC Program is managed out of NSF's Engineering Education and Centers (EEC) Division of the Directorate for Engineering. The ERC Program issues solicitations for the establishment of ERCs, each with a specific technological focus, such as Data Storage Systems or Telecommunications Research. Universities submit proposals to host an ERC; these proposals are peer-reviewed by technical researchers and executives from academia and industry. Each ERC is funded by the NSF for eleven years. There are twenty-six ERCs now in this program. Over the course of the eleven years, each center is expected to generate funding from sources outside the NSF, so that the center is self-sufficient by the end of the grant period. To illustrate, in the fiscal year 1994, the twenty-one centers then in the ERC program received \$51.7 million from the ERC Program Office, \$53.7 million from industry in cash, in-kind donations, and associated grants and contracts, and \$73.5 million from university, non-profit, and other US Federal government sources.

Each ERC forms several consortia involving university faculty and staff, students, and multiple industrial firms (and on occasion government research facilities as well) to pursue specific research projects under the ERC's focus area. One to this structure, projects tend to focus on more fundamental research of broad interest to industry, rather than on development of specific product technologies for individual firms. The academic and industrial researchers exchange knowledge regarding the needs of industry in the research area, relevant developments across engineering disciplines, and the processes of academic and industrial research. The performance metrics used by the ERC Program to evaluate individual centers include the numbers of partnerships formed, patents filed and awarded, licenses granted to industry, and undergraduate and graduate degrees granted to students involved in ERC projects.

ERCs are selected to focus resources on complex engineered systems which are several generations ahead of current technology, and which will have significant economic impact. Semiconductor technology is one area of focus for the program. One of the earliest centers established under the program dealt with semiconductor research: the Center for Advanced Electronics Materials Processing at North Carolina State University (NCSU), launched in 1988. Two other centers were established later: the Center for Low Cost Electronic Packaging at the Georgia Institute of Technology, and the Center for Compound Semiconductor Microelectronics at NCSU. Another center is operated under a joint agreement between the ERC program and the SRC – the Center for Environmentally Benign Semiconductor Manufacturing at the University of Arizona.

The joint SRC–NSF center represents a particularly interesting case in GUI collaboration. This center operates under the joint supervision of the NSF's Engineering Directorate and the Semiconductor Research Corporation, with funding from both bodies. The research is conducted jointly among five universities: the University of Arizona, Stanford University, the University of California at Berkeley, Cornell University, and the Massachusetts Institute of Technology. While the ERC program itself has a long track record of funding and managing the development of successful university–industry research centers, the program's management approach has been modified in the case of this center to accommodate the mode of collaboration favored by the SRC. Drawing on its own experience in coordinating industry-focused academic research, the SRC has assigned "mentors" from its member semiconductor companies to provide important guidance at the project level to the NSF–SRC center. According to one center participant, these mentors typically track progress on research projects on a monthly basis or more frequently, via teleconference if necessary. The SRC believes that this particular management tool provides a better guarantee that the results of the ERC research will suit the needs of industry. Participants in this ERC report that they do have more frequent and substantive interaction with industry partners on a continuing basis, and that the mentors also facilitate access to other researchers and managers from the center's corporate partners, enabling more open dialogue on industry needs and priorities.

## B The EUV CRADA

In 1997 a consortium of semiconductor companies led by Intel was formed to support EUV lithography research. Called EUV LLC, this consortium's founding members also include AMD and Motorola. Intel hired Charles Gwyn, Sandia's SEMATECH Program Manager, to help manage this effort. EUV LLC signed a Cooperative R&D Agreement (CRADA) with three Department of Energy national laboratories (Sandia, Lawrence Berkeley, and Lawrence Livermore). The CRADA funds research into methods for using extreme ultraviolet (EUV) lithography as the basis for the next generation of semiconductor manufacturing processes.

The project is intended to have the following results (Borrus, 1998):

(i) Ensure that the technical specifications – i.e., the crucial product standards – for the next generation of lithography tools are set in the United States by the choices of US equipment producers and their customers (chip-makers).
(ii) Create a significant US player in next-generation lithography tools while adding market competitors to the current duopoly that controls supply of lithography tools.
(iii) Provide first access for US chip-makers to next generation equipment.
(iv) Reinforce and amplify the US skill- and supplier-base in leading-edge semiconductor production tools and technologies.
(v) Perhaps even create access to the Japanese market by encouraging Japanese chip-making firms to adopt the American-sponsored technology standards.

The EUV CRADA received criticism from members of the US Congress due to the participation of foreign semiconductor equipment manufacturers, such as the Dutch stepper firm ASML Inc. and the Japanese firm Nikon (Borrus, 1998). Also, the Institute for Defense Analyses (IDA), a US Defense Department think tank, pointed out in a report that the members of EUV LLC have extensive technology alliances with foreign firms, and that there is a strong possibility that developments from the CRADA will be transferred to those overseas firms, eroding any military advantage to the United States from its next-generation lithography technology. Despite objections from the Congress, the Department of Energy in February 1999 agreed to allow a Dutch semiconductor equipment supplier, ASML, to participate in the effort through a joint agreement with EUV LLC, subject to certain conditions about technology access and transfer. The Department of Energy emphasized that the benefits of participation by ASML outweighed the risks of overseas "leakage" of US technology, as it provides a liaison between the EUV–DOE collaborative effort and a comparable EUV project in Europe. The European project is partly funded by the European Commission, and is led by ASML with the Carl Zeiss Group and Oxford Instruments Plc. The EU government is pitching in 10 million Euro ($8.7 million) to help fund the project, which will operate within an Esprit program, called the Extreme UV Concept Lithography Development System (EUCLIDES).

The policy debate over the formation and terms of the EUV CRADA highlights the problem that globalization of research presents in the formation and management of GUI consortia. Increasingly, such consortia are forming the infrastructure for developing international systems of innovation, in some cases superceding the priorities of domestic institutions. Due to the international diffusion of technological capabilities, policies which limit consortia to purely domestic players may be short-sighted, limiting access to needed resources to help domestic industry.

The EUV case also illustrates some of the potential risks involved if government participants are cast in the role of selecting "winners" and "losers" in technology. The EUV lithography process is now in competition with a new X-ray lithography method (called Scalpel) from Lucent Technologies' Bell Labs to be the preferred next-generation lithography system approved by International SEMATECH. So far, there are indications that both technologies will be approved. However, it is possible that EUV will not prove feasible as a solution to next-generation manufacturing challenges in semiconductors, leaving the Department of Energy open to criticism for picking the "wrong" technology.

## C MARCO: the Focus Center Research Program

The Microelectronics Advanced Research Corporation (MARCO) is a not-for-profit research management organization which is a wholly owned subsidiary of the Semiconductor Research Corporation (SRC). The SRC is a research management consortium that was established in 1982 as the university research arm of the Semiconductor Industry

Association (SIA). MARCO has its own management personnel but uses existing support and infrastructure services provided by the SRC.

In late 1995, Dr. James Glaze, then Vice-President of Technology for the Semiconductor Industry Association, approached the SIA Chair, Craig Barrett (President and Chief Operating Officer of Intel Corporation) with the idea of pooling industry and government funding to support very advanced university-based research in semiconductor design and manufacturing. According to Dr. Glaze, he and others felt increasing concern that too much of the industry's research was focused on short-term, incremental innovations aimed at very well-defined technical challenges, so that long-term but extremely significant technical issues were not addressed. This trend had been accelerated by recent reductions in US government funding for university research in electronics. A formal proposal was made to the SIA in January 1996, and after extensive discussions among industry, universities, and the government, implementation of the MARCO initiative began in late 1998.

MARCO is chartered with the establishment and management of a new, university-based Focus Center Research Program (FCRP). The FCRP is a new initiative to support pre-competitive, cooperative, long-range, applied microelectronics research at US universities. This initiative receives 50 percent of its funding from the Semiconductor Industry Association (SIA), 25 percent from SEMI/SEMATECH (representing US-based semiconductor manufacturing equipment suppliers), and 25 percent from the Defense Advanced Research Projects Agency (DARPA) of the US Department of Defense. There are over thirty US companies participating in the FCRP. A Governing Council, consisting of representatives from the three participating organizations, provides oversight of the FCRP. Funding is targeted to be approximately US$10 million per year for a fully operational center. If the concept proves to be successful, up to six centers will be funded ultimately. At this point in time, a pilot program will establish two centers for a trial period of two years. The technology areas for the two pilot centers will be "Design" and "Interconnect."

The FCRP sponsors developed a joint proposal solicitation to universities. Proposals were submitted to DARPA, and reviewed by industry and government evaluation teams. Industry and DARPA program managers produced a combined recommendation of winners, which was accepted by industry members and the DARPA Source Selection Authority. The two lead universities for the pilot centers were the University of California at Berkeley for the design/test focus center, and the Georgia

Institute of Technology for the interconnect focus center. Each lead university works with a team of affiliated universities in their technology focus areas (see Table 2.1).

MARCO is intended to complement, not overlap, with research carried out at SEMATECH, in SRC-funded university research, and in other joint research projects of the semiconductor industry. Unlike SEMATECH, an industry consortium with only corporate members, or the SRC, which funds centers in individual universities, the FCRP will support "virtual (or distributed) centers" that span multiple universities with participation from broad constituencies of firms, as well as contributions from government researchers. This will tap the best expertise across many institutions in order to build the greatest overall capability in a particular technology area. Due to this distinctive structure, the FCRP can tackle technical challenges which are very different from those addressed by the other consortia in the semiconductor industry. The research topics of the FCRP must conform to the following parameters:

- Emphasis on the elimination of barriers via more revolutionary approaches, paradigm shifts and the creation of multiple options;
- Longer range (beyond eight years to commercialization) research;
- Broader, less granular objectives;
- Fewer industrial business practices applied; and
- Heavy emphasis on research efforts with faculty, post-doctorates, visiting scientists as well as students (MARCO, 1998a).

*Table 2.1* Universities participating in the FCRP

| **Focus center** | **Lead university** | **Affiliated universities** |
|---|---|---|
| Design & test | UC Berkeley | Stanford University, MIT, Carnegie-Mellon University, Princeton University, University of Michigan, UCLA, UC Santa Barbara, UC San Diego, UC Santa Cruz |
| Interconnect | Georgia Institute of Technology | Stanford, MIT, State University of New York Albany, Rensellaer Polytechnic Institute, Cornell University |

*Source*: MARCO.

The FCRP thus addresses technology focus outlined in the National Technology Roadmap for Semiconductors (NTRS) but not addressed by previously existing industry resources. As such, the centers:

- Concentrate attention and resources on those areas of microelectronics research that must be addressed to maintain the historic productivity growth curve of the industry;
- Strengthen the university research infrastructure and expand its capabilities in silicon-related research;
- Achieve critical mass through relatively large blocks of funding together with the active participation of industrial visiting scientists; and
- Provide an optimal balance of creative freedom and targeted objectives.

The transfer of knowledge from the FCRPs to the semiconductor industry builds on the years of experience in the industry in managing consortia such as SEMATECH and the Microelectronics and Computer Technology Corporation (MCC).

First, rather than depending on only one institution to manage research in a given technology area, the FCRP will create "communities of innovation" linking researchers at multiple universities, all of whom can contribute to progress.

Second, the research will be long-range, an area best carried out by academic researchers, but still linked directly to industry imperatives by setting priorities through the NTRS.

Third, industry and government (DARPA) support can lead to direct interaction between the university researchers and the end-users of the knowledge generated under the FCRP, contributing to a common understanding of user concerns and disseminating new knowledge more widely. Also, DARPA program managers contribute their experience in long-range research management, balancing the more short-term focus of industry members (MARCO, 1998b).

MARCO is not a "partnership" as found in other areas of university–industry interaction. In this initiative, the substantial bulk of research is conducted by academic researchers in the university setting. Industry participants function primarily to provide direction and oversight of the research, evaluate the usefulness of the results for industry, and commercialize any technologies developed in the laboratory. All intellectual property issues are negotiated directly between member companies and each university in the consortium, rather than conducting negotiations through MARCO. Although this makes transfer technology somewhat more complex, as each firm is likely to license technologies from multiple universities, it facilitated the partnership by removing the need to harmonize the very diverse IP and licensing policies used by each institution. Also, the bulk of technology transfers between the university centers and companies are expected to take place through informal channels, primarily industry researchers who are sent on assignment to work at the focus centers by their companies.

## II United States agency efforts to promote collaborations

Several agencies have specific programs and initiatives which are intended to promote collaborative research among government, universities and industry. Some examples are presented below.

**National Institute for Standards and Technology.** A number of NIST programs specifically support collaborative research. The ATP program gives preference to those proposals presented by consortia of firms, joint ventures, or teams of firms and universities. The Manufacturing Extension Partnership program uses combinations of academic and industrial sources of technical assistance to support US firms. The NIST laboratories themselves have extensive CRADA arrangements with hundreds of US firms, and also act as managers for research consortia in a number of areas.

**Department of Energy.** The Department of Energy has some programs focused specifically on aided collaborative efforts. The Industries of the Future program, managed by the Office of Industrial Technologies, facilitates industry consortia (often including producers, suppliers, and users in specific industry sectors) in the development of technology roadmaps for reducing energy consumption and waste generation. Also, the DOE laboratories managed by external contractors are encouraged to sign CRADAs with industry, such as the extensive CRADA linking various national laboratories and a consortium of semiconductor firms for research on extreme ultraviolet manufacturing processes.

**NSF.** The Engineering Research Centers program funds university-based centers supported in part by industry, where universities solicit participation and funding from firms to conduct multidisciplinary research on engineering topics and assist in the development of engineering curricula.

### A NIST

The mission of NIST is "to promote US economic growth by working with industry to develop and apply technology, measurements, and standards." Primary R&D products of the agency include new measurement standards, basic industrial technologies, and research papers on fundamental discoveries in industrial technologies and manufacturing.

NIST has four major programs: the Advanced Technology Program; the Manufacturing Extension Partnership; the Malcolm Baldrige National Quality Award Program; and the NIST laboratory program. The distribution of funding among these programs is largely determined by the Congress in response to the President's budget request, rather than by NIST itself. Since these programs operate relatively independently of each other, the leadership of each program is expected to produce their respective budget requests, with feedback from the Program Office of the Office of the Director of NIST.

Overall strategic direction for NIST, and especially for the intramural laboratory research program, is set by the Office of the Director. The Director also actively solicits direct input from industry as to NIST's past performance and future priorities. The primary mechanism for this input is the Visiting Committee on Advanced Technology, an advisory committee composed of fifteen members from industry, with some representation from labor and academia. Members are appointed by the Director of NIST, and each can serve up to two consecutive three-year terms. The Visiting Committee meets quarterly to review NIST budgets, programs, and policies, and conducts less frequent in-depth reviews of issues such as NIST strategic planning.

There is a clear division between intramural and extramural research programs at NIST, with the laboratory programs accounting for all the intramural research funding and the ATP and MEP accounting for 97 percent of extramural research funding. These programs are each managed by separate organizations, with ATP and MEP managed through their respective program offices and the laboratories program managed by the eight individual laboratories.

Each of the NIST laboratories (technical laboratories and the Technical Services program, which manages standards, reference materials and measurements, and technology partnerships) reports directly to the Director of NIST. Each laboratory sets its own priorities, with input from industry. Industry feedback is gathered through special conferences on potential priority research areas, comments from the Visiting Committee on Advanced Technology, and laboratory assessment boards organized and managed by the National Research Council.

The laboratories use six criteria in judging priority projects:

(i) The magnitude and immediacy of industrial need;
(ii) The degree of correspondence between a particular industrial need and NIST's mission to develop infrastructural technologies;
(iii) The opportunity for NIST participation to make a major difference;
(iv) The nature and size of the anticipated impact resulting from NIST's participation;
(v) NIST's capability to respond in a timely fashion with a high quality solution; and
(vi) The nature of opportunities afforded by recent advances in science and technology.

Each laboratory also uses short- to medium-term measures of the impact of its work, using quantitative measures of interaction with industry as well as solicited feedback. These measures help to determine which priority efforts are worth continuing and which should be abandoned. Finally, the NIST Program Office conducts periodic long-term assessments of the economic impact of laboratory programs.

The major extramural R&D program at NIST over the past twenty years has been the Advanced Technology Program (ATP). Strategic planning for the ATP is directed mostly at developing the focused program competition topics. Focus areas are chosen using the following criteria:

- Potential for US economic benefit;
- Strength of the technical ideas;
- Evidence of strong industry commitment; and
- The opportunity for ATP funds to make a significant difference.

Proposed focus areas are studied by ATP staff, and are also the subject of industry-oriented conferences held by NIST to explore the research opportunities in these areas. Focus areas which score well in the above criteria become official focused programs in future award competitions.

ATP has also been the focus of several NIST-sponsored and independent evaluations. These have resulted in refinements to the program operation, and also in changes to the legislation governing the ATP.

During a program competition, full proposals are accepted from eligible applicants. These are then screened for completeness and classified into their technical areas. Each proposal undergoes a technical review by researchers in that area, who are chosen mostly from Federal government but who may include outside consultants. Proposals which pass the technical review also undergo a business review to ensure that the technology commercialization plan is feasible. Proposals are evaluated on the following criteria:

- Scientific and technical merit;
- The potential broad-based economic benefits;
- Plans for eventual commercialization of the research;
- The experience and qualifications of the proposer; and
- Evidence of the proposer's level of commitment to the project, and clarity and appropriateness of the proposer's management plan.

Proposals judged to be of high merit are identified as competition semi-finalists. These proposals then undergo an oral review before a blue-ribbon panel of judges, presented by a team from the proposing organization. Judges includes senior technical executives from business, renowned academic experts, and government officials. The panel may also elect to perform a site visit to see the environment where the proposed project will take place. The semi-final review results in a rank ordering of proposals, based on their merits and the desire to create a balanced package of projects. The ATP office then signs a cooperative agreement for cost-shared funding with the proposers. The office can also help an awardee obtain additional support from other Federal grant programs.

NIST has four primary mechanisms for conducting and promoting collaborative research:

- Through the ATP, NIST gives preference to joint ventures or government–university–industry consortia which apply for funding;
- In the laboratory program, laboratory researchers can conduct research on behalf of industry through a Work For Others agreement, and companies can apply to use NIST facilities for their own research purposes;
- NIST has used CRADAs to conduct joint research projects with industry since 1988. It now has over 200 active research partners;
- NIST laboratories also sponsor special research consortia, based on the demand from industry, which coordinate work in specific technical areas. These consortia are usually structured as CRADAs, where NIST manages consortia meetings, coordinates research efforts, and supports information dissemination to consortia members. The members must pay a fee to participate. Examples of such consortia are the Enhanced Machine Controller program, the North American Integrated Services Digital Network Users' Forum, and the Ultrasonic Program to Improve Flow Measurement.

### *National Institute of Standards and Technology Advanced Technology Program*

The objective of the Advanced Technology Program (ATP) is to provide cost-shared support for industrial R&D which will speed commercialization of key enabling technologies with broad economic impact. Congress intended that the ATP focus on assistance to industry. However, universities, non-profits, and Federal laboratories (excluding NIST) may participate as subcontractors and joint venture participants.

ATP strongly encourages applications from joint ventures, and especially from consortia which also include universities and government laboratories. The key objectives of the program are contained in the Omnibus Trade and Competitiveness Act of 1988, as amended by the American Technology Preeminence Act of 1991. Interpretation of the statutory objectives is the responsibility of the ATP Program Office.

The ATP Office organizes a Source Evaluation Board (SEB) of Federal scientists and engineers in the field of the competition, supplemented by consultants from other sectors (mostly independent business consultants). The identities of the members of the SEB are not revealed. ATP Office maintains records of experts in the various fields; other experts are identified through recommendations. After an SEB member signs a non-disclosure agreement, the member can review proposals at his/her location or at the NIST campus. If a proposal reaches semi-finalist stage, the proposers can send a team to make an oral briefing to the SEB. Approximately 15 percent of proposals reach this stage. SEB members offer type-written evaluations of the technical and business aspects of the proposal. The SEB offers scores, rankings, and recommendations to the Selecting Officer.

US subsidiaries of foreign corporations may participate if they meet all ATP eligibility criteria, with the following additions:

- Participation is deemed “in the economic interest of the United States”;
- The country of the foreign parent firm allows US-owned companies similar opportunities to participate in national programs comparable to the ATP;
- The country of the foreign parent firm allows US firms local investment opportunities comparable to those offered to their own firms;
- The country of the foreign parent firm provides US-owned companies protection of intellectual property rights.

## B National Science Foundation

The NSF is managed by a staff under the NSF Director, but strategic oversight is provided by the National Science Board (NSB). The NSB is composed of twenty-four appointed individuals who are viewed as leading researchers and educators from academia, industry, and other organizations.

Traditionally, long-range planning at the NSF was strictly a bottom-up procedure. Research divisions assessed the best areas of research opportunities in their fields of responsibility, and proposed research programs to the NSF top management and staff. These were then packaged into a set of proposals for consideration by the NSB at an annual meeting.

The current planning process has three steps involving NSF staff, external advisory committees (one for each research division), and the NSB. First, mid-level executives in the NSF staff create a draft strategic plan following the requirements set forth by the Director. This is then passed among the advisory committees and the NSB for comments and rewrites. Then, each advisory committee takes relevant sections of the draft and processes them towards a final version. These different final drafts are reviewed and modified by a task force within the NSB, which added various dimensions which were added to the final plan. All units of the NSF then demonstrate how their particular activities further one or more of the missions of the NSF in the language presented by the plan.

Stakeholders outside the NSF are involved primarily through the advisory committees and the National Science Board. The plan is given an official review by the OMB, the NSTC, and the GAO to certify compliance with the Government Performance and Results Act.

The NSF funds R&D and educational activities through grants, contracts, and cooperative agreements to more than 2,000 colleges, universities, and other research organizations. It receives about 53,000 requests for funding each year, and makes 20,000 awards. The vast majority of funds are distributed via grants, as opposed to contracts or cooperative agreements. This includes funding under the SBIR program.

In general, the NSF now uses two basic criteria for evaluating each proposal. The first is the “intellectual merit” of the proposed activity, including contribution to the field, originality and creativity, feasibility, and clarity. The second criterion is the “broader impacts” of the activity, including contribution to teaching, learning and scholarship;

impact on underrepresented groups; extension to research infrastructure and facilities; and diffusion of the results to society. The program manager to whom the researcher submitted the proposal makes an award recommendation, which is then reviewed for approval by the manager's division director. The proposal is then forwarded to the Division of Grants and Agreements for review of financial information and similar technical details. A grants officer then orders the transfer of the award money to the researcher's institution.

Principal investigators are required to file annual reports and a final report recording their progress towards stated project objectives, and any products from their research. If, at any time, the grants officer believes that the research project team is not conforming to its agreed-upon grant conditions or following the accepted procedures (including the possibility of scientific misconduct), the officer can notify the PIs and give them an opportunity to correct the situation. If the PIs fail to take appropriate action, the grant can be suspended or terminated. Cooperative agreements are monitored by a grants officer as well, and follow the same guidelines as research grants except that the NSF grants officer has more freedom to terminate the agreement if he or she deems it necessary to protect the interests of the NSF.

The NSF has several programs which fund research by collaborative teams or consortia. These programs include:

- Grant Opportunities for Academic Liaison with Industry (GOALI). A grant program which exclusively funds university-based research or education projects which include significant involvement by private firms;
- NSF Science and Technology Centers. This program was established in 1987 to create academic-based research centers which encourage knowledge transfer to industry and development of innovative educational opportunities. There are currently twenty-four centers, managed locally but with oversight by the Office of Science and Technology Infrastructure. Each center receives an annual budget averaging approximately $2.6 million, supplemented by contributions from industry. Centers are scheduled for a renewal competition after four years and a final phase-out after eleven years;
- Engineering Research Centers. A program which funds, through cooperative agreements, centers at universities which conduct research and education in engineering with industrial members.

### *National Science Foundation Engineering Research Centers*

The ERC program is intended to create long-term collaborations between industry and university, create new industry-relevant knowledge spanning traditional disciplines, and develop new leaders in engineering who are prepared for team-based, cross-disciplinary work environments. The program funds centers which are based in universities, but which are expected to extend their research and educational activities to embrace private companies. A central focus of the program is to encourage collaboration between industry and university.

Eligibility criteria for the ERC program are published in the program announcement. The ERC program office ensures that proposers meet those criteria. Pre-proposals are evaluated by technical experts from academia, while proposals are reviewed by top industry R&D executives and senior university researchers. The identities of reviewers are generally not publicized. Pre-proposals are all reviewed by technical panels and rated by a general panel which meets at the NSF. Proposals are also rated by the review board during a meeting at the NSF. Most reviews are completed on paper.

Criteria for the awards of the collaborations are established by the ERC program office, with some input from outside groups such as the National Academy of Engineering. Evaluation criteria are published in the program announcement. Pre-proposals and proposals are rated as “highly recommended,” “recommended,” and “not recommended” by reviewers. There is a ninety-day window between the Notice of Intent and the pre-proposal deadline. The finalists invited to submit proposals are notified approximately sixty days after the pre-proposal deadline.

For this program, funding decisions are made within a month of the end of the review process. Unsuccessful proposers receive feedback which they can use to improve later proposals. Many institutions must propose two or three times before they are accepted. For the total cost of each collaboration, the NSF’s award covers 50 to 66 percent per year, with the balance covered by industry participants. The amount covered each year declines toward the end of the ten-year grant period so that industry will take on more of the support. ERC program directors each monitor two to three centers for progress. ERC operators develop their own performance indicators and submit annual reports to the ERC program office, which reviews the reports and may conduct follow-up reviews. The ERC program as a whole is reviewed periodically.

Foreign firms may become members of ERCs as long as their parent countries allow comparable access to similar programs. Each ERC director can decide to allow a foreign firm to join, but the firms on the center's Industry Advisory Board can veto that decision. Foreign firms cannot vote on matters pertaining to the operation of centers, but they can speak at advisory meetings.

## C Department of Energy

The mission of the Department of Energy is "to foster a secure and reliable energy system that is environmentally and economically sustainable, to be a responsible steward of the Nation's nuclear weapons, to clean up our own facilities, and to support continued United States leadership in science and technology."

Civilian R&D funding is allocated across several programs under the Department of Energy, notably the Office of Energy Research; the Office of Nuclear Energy, Science and Technology; the Science and Technology Development programs for Environmental Management; and programs in Energy Efficiency and Renewable Energy and Fossil Energy. Overall budgets and policies for the energy programs are decided by the Secretary of Energy. These strategic decisions are stated in the annual DOE Strategic Plan (which is mandated by the Government Performance and Results Act of 1993). These strategic decisions are reviewed by a number of external groups, such as the Energy Advisory Board which meets to provide input to the Secretary of Energy on Department-wide policy. The DOE Strategic Plan is also reviewed by the Office of Management and Budget in the White House and the US General Accounting Office within the US Congress.

In 1997, the DOE launched an initiative to develop strategic technology roadmaps to guide research and development in several areas. Strategic corporate roadmaps were developed for the Department's fossil fuels program and the efficient and renewable energy programs. One of the key enabling technology roadmap efforts is the development of sophisticated computer modeling capabilities. These roadmaps are reviewed by representatives from industry, academia, science and technology organizations (such as the National Academy of Sciences), and consumer groups. These roadmaps will provide specific R&D objectives, phases of targeted development, and deadlines which will be used to guide the individual R&D programs.

R&D programs in the Department of Energy are guided by program managers who are responsible for specific technology areas, mission components, or scientific disciplines. Most actual agency R&D is conducted by extramural performers, which include the DOE National Laboratories. Different energy program areas make different uses of intramural or extramural performers depending on their nature. For example, the Office of Energy Research, which supports basic research in scientific disciplines related to energy, provides a combination of direct grants to universities, contracts and cooperative agreements with companies, and funding for research programs in the extramural National Laboratories. In most cases, whether for grants or contracts, the DOE program managers are required to solicit competitive bids or proposals from extramural performers as the basis for assigning R&D projects.

The majority of extramural research is conducted by the National Laboratories or other facilities which are managed under long-term contracts by corporations, universities, or non-profit organizations on behalf of the DOE. These laboratories must apply to specific DOE program offices for the funding of specific research projects.

For projects at a National Laboratory, the principal investigator for a research team submits a proposal to a program office at DOE headquarters in response to an RFP issued by that office. In general, the office will issue a special RFP open only to proposals from a DOE National Laboratory or a similar DOE-funded FFRDC. The DOE program office then selects which teams at which facilities will conduct the research, based on a merit evaluation. This evaluation may or may not use external peer review, depending on the nature and topic of the research competition.

When a laboratory receives approval for a project, the specifications for the research are added as an addendum to the standing management and operating contract between DOE and the laboratory contractor. In general, these addenda are drawn up on an annual basis through negotiations between each laboratory and its local DOE Field Office. The DOE program office then assigns a program manager to oversee technical progress on the particular research project, while the Field Office is charged with ensuring that the project is conducted in accordance to DOE regulations on financial management, environmental guidelines, safety and health regulations, and other general operating requirements set by DOE.

Since the passage of the Bayh–Dole Act and Stevenson–Wydler Act in 1980, which set in motion the recent push for technology transfer, the Department of Energy has increased its emphasis on collaborative research. Both the extramural National Laboratories and the DOE itself use the number of CRADAs signed, licensing revenues raised, and other measures of collaboration with industry as measures of performance. Also, the DOE has initiated several partnership programs which use networks of CRADAs to coordinate cooperative development of specific technologies with industry; examples include the Superconducting Technology Partnership and the Thin-Film PV Partnership for photovoltaics. Collaboration among multiple laboratories and firms, as well as universities, is now emerging. The first such collaboration was the Extreme Ultraviolet partnership between a "virtual national laboratory" composed of personnel from Sandia National Laboratory, Los Alamos National Laboratory, Lawrence Livermore National Laboratory, and several semiconductor manufacturing firms led by Intel and AMD.

### *Office of Utility Technologies Photovoltaic Program*

The objective of the Photovoltaic Program (PV) is to develop photovoltaics into a significant part of the domestic economy, as an industry and as an energy source. The program targets developers and manufacturers of photovoltaic technology and potential users in the utility industry or other sectors.

Technology development is conducted primarily through contracts with the DOE extramural laboratories, focusing on the National Renewable Energy Laboratory (NREL) and Sandia National Laboratory (SNL), and subcontracts with industry and universities. The laboratories also use Cooperative Research and Development Agreements with industry for some projects. Firms and universities in specific projects are generally required to collaborate with other organizations, particularly the users of PV technology, as part of their contract terms.

The Photovoltaics Office in the Office of Utility Technologies sets the overall strategy and policy of the PV program, after extensive consultations with representatives from PV producers, researchers, and energy users. The objectives are set forth in a five-year program strategic plan. Each year's objectives are also used to determine the responsibilities and research areas for NREL and SNL, which are then implemented as addenda to the management contracts between the laboratories' operating contractors and the DOE.

Most contract and CRADA opportunities are announced through open requests for proposals directed at industry, and advertised in the

Commerce Business Daily and in publications of NREL and SNL. In particular, NREL produces a quarterly newsletter titled "PV Working with Industry" which lists RFPs which are expected to be issued in the future, based on the annual Operating Plan for the PV program.

Most proposals submitted to NREL are evaluated by internal staff scientists and researchers with relevant experience from other national laboratories, and occasionally by outside experts. The proposals may be evaluated by each reviewer separately, with written comments, or (if convenient) during a panel discussion among reviewers. Since most RFPs result in a low number of proposals, and only a few awards are made per competition, the reviewers simply state their recommendations as to which proposals should be accepted. If the RFP topic is outside the expertise of NREL or the issuing office, external evaluators may be used. The evaluators are generally retired researchers from industry or academia or former industry executives. Their identity is not revealed to the public. Since outside reviewers must have expertise in photovoltaics, they are usually identified through networking with the PV research community.

The exact project selection criteria are developed by the PV staff at the issuing laboratory (NREL or SNL), after which they are reviewed and approved by the DOE PV program staff. All evaluation criteria are published in the RFP, along with a general description of the evaluation process (such as whether external reviewers will be used). The list of recommended awardees is developed within one day of the receipt of all reviews and evaluations. Generally, the list of recommended awardees corresponds to the recommendations of reviewers.

Almost all projects, including those awarded to universities, are funded on a cost-shared basis. The average share covered by DOE ranges from 60 to 90 percent, with the higher share used in the case of university research. After an award is made, the contractor meets with a technical monitoring team assigned to the project from NREL/SNL to discuss program objectives and to draw up a project management plan. The management plan includes details on project objectives and interim deliverables, including periodic progress reports and sample technologies. Technologies submitted as deliverables are tested for performance by NREL/SNL. The monitoring team also uses teleconferencing and site visits to check project progress on a regular basis.

Some contracts have been awarded to foreign research institutes, but not foreign universities or firms. There are no clear regulations on the participation of foreign organizations. These projects are designed to use foreign organizations, such as projects to conduct test installations of PV technology in overseas locations. In a number of cases, technology development contracts have been issued to US subsidiaries of foreign corporations (such as Siemens Solar, which is a subsidiary of Siemens).

# 3

# The Research and Technology Development Public–Private Partnership Ecosystem in the European Union: Theory and Evidence from Selected Examples

The European Union, as part of the evolution of the EU as a political organization, has integrated collaborative programs and funding into its support of research and technology development. The European Union's relationship with its member states requires that it focus its funding on collaboration, funding cross-national partnerships which are beyond the scope (or political will) of national governments. Even within national governments, however, collaboration is now a major focus of innovation policy. In particular, there is the perception that the "mental gap" between the public and private sectors in research collaboration is greater in Europe than in the United States or Japan.

This situation suggests that there are two primary dimensions to research and technology development collaboration within the European Union. In the dimension of publicly-funded research, EU policy on collaborations in science and technology have aimed at advancing political goals (set forth in, among other documents, the Single European Act), as well as strengthening the European economy by (for example) promoting and supporting strategic industries. In the dimension of corporate research, firms have leveraged funding from the EU and other sources to improve competitive advantage by forming strategic alliances with other firms, and by finding and working with the best research talent across the member nations of the EU. This finding is supported by research evaluating the effects of collaborative research programs supported formally or informally by the EU (Georghiou, 1999).

There are three primary modes of support for public–private collaborative research in the European Union, primarily at the EU level but also at the national level:

- Industrial cooperation with public funded R&D institutions, primarily for non-industrial research;
- Public funding of industrial research. This covers up to 50 percent of costs and focuses mostly on cooperative efforts;
- Public orders and contracts.

## I European Union R&D overview

The EU approach to the support of public–private collaborative research tends to be more explicit, clearly defined, and targeted than similar policies found in the United States. Some relatively early EU programs focused on collaboration, such as the ESPRIT initiative, recognized that collaborative research is useful particularly in the pre-competitive domain of research and in interdisciplinary fields of science and technology (Georghiou, 2001). Thus, there is more consistent promotion of public–private collaborative research across the projects funded by the EU Framework Programme. Even at the national level, statements of central government policy stress the need for public–private research collaboration (see, for example, the UK White Paper on Competitiveness published in 1999).

A substantial amount of basic research is however carried out at a European level, in the framework of the activities of several intergovernmental organizations, but also those of the European Union.

Historically the first scientific cooperation initiatives in Europe were indeed launched in the area of basic research with the setting up of CERN (European Centre for Nuclear Research) in the field of high-energy physics in the 1950s, the European Southern Observatory or ESO (astronomy) in the 1960s, and the European Molecular Biology Organisation and European Molecular Biology Laboratory (EMBO and EMBL, molecular biology), all of which are organizations that continue to play a very important role in basic research in Europe today.

Following the Communication on “Europe and basic research” and the conclusions of the Competitiveness Council on March 11, 2004, the

Commission has consulted widely on principles and appropriate mechanisms for funding basic research, taking account of different national practices, including those of the new Member States. In particular, the Commission and the EUROHORCs (EU Research Organisations Heads of Research Councils) set up a joint working group in order to develop recommendations for the operational parameters of a European basic research scheme, drawing from experience at national and European level.

On the basis of this work of consultation and analysis, it appears that the basic principles of the mechanism are the following:

(i) "Investigator-driven research": the research supported should be truly "investigator-driven" and "bottom-up," with proposals selected on the criterion of scientific excellence;

(ii) Adequate means: the level of funding accorded to the scheme would need to be appropriate and sufficient to address the specific needs of basic research in Europe. The individual grants should be of a significant size so as to attract the best scientists and teams from the whole of Europe, including bright young researchers and excellent emerging teams, and give them high international visibility;

(iii) Efficiency: lean management procedures should be the rule, with minimal administrative requirements for applicants. The grant allocation should be flexible and light, and designed according to best practice as identified at national level and elsewhere, while being compatible with the EU financial management and legal framework;

(iv) Autonomy: the mechanism should be implemented and managed in an autonomous structure, to assure, in an optimal way, the particular features of the scheme and reflect its independence from the strategic orientations of other parts of the Framework Programme. At the same time, its funding decisions should be taken with a true European perspective, independently of research funding at national level and without any regard to "juste retour";

(v) Transparency: the mechanism should guarantee transparency in its operations, in particular regarding the management process, peer review and awards made;

(vi) Accountability: the mechanism should be accompanied by an appropriate reporting regime to ensure accountability in both scientific and financial aspects.

Based on the principles set out above, a number of precise operational parameters for implementation of the basic research support mechanism can be identified:

(i) Structure and administration: A high quality administrative structure has been set up, guided by a "Governing Council" comprising representatives of the scientific community in Europe at the highest level.
(ii) Scientific scope: A key advantage of operating at European scale is that a more competitive approach to research funding can be taken. This allows the available resources to be adapted to needs and to respond to new opportunities arising for scientific and technological progress within and across disciplines.
(iii) Evaluation and peer review: Peer review is at the core of EU research funding, as the basic mechanism used for the evaluation of proposals. The "bottom-up" nature of the basic research funding mechanism and the broad application to science across all fields suggest the need for a relatively large pool of experts, which could be established for a period of time, possibly extending over a whole framework programme period.
(iv) Characteristics of the grant: The grant allocated to individual research teams must be attractive for the researchers in size and conditions and ensure a high level of flexibility in the implementation of the projects. The best approach for the application procedure is a simplified cost-based model in which researchers specify the needs for their projects according to the full economic cost of research in relation to the institution at which it takes place.
(v) Evaluation of the funding mechanism: In the same way as any EU action, but in particular because the structure and approach is relatively new, the implementation of the basic research mechanism must be reviewed and evaluated at appropriate intervals both to measure its achievements and to adjust and improve procedures on the basis of experience.

The principles and requirements for an operational framework for implementation set out above provide indications of the type of mechanism which will be needed for the support of basic research within the EU context and for the purposes of the European Research Area.

## A Key features of basic research in the EU

In Europe, most basic research is carried out in universities. It is financed partly through their basic grants and partly from outside sources, most of them governmental but some of them private.

Even if this type of research is the traditional field of activity of universities, it is not confined only to universities. In many European countries, the part played today by the major national research organizations is considerable, and a large part of their activities are precisely in the field of basic research. This is the case, for example, with the CNRS in France, the CSIC in Spain, the CNR in Italy, the Max Planck Institute in Germany, etc. In these types of organization, basic research is most frequently funded by fixed grants allocated annually to various laboratories or institutes, or in the framework of multi-annual, sometimes thematic programmes. In some cases, however, projects are funded through outside sources, private or even public in the form of "competitive" funding at European or national level.

In several European countries, there are actually agencies which fund research, more especially basic research, in universities but also in research organizations: the Research Councils in the United Kingdom, the Deutsche Forschungsgemeinschaft in Germany, the Vetenkapsradet in Sweden, the NWO in the Netherlands, the FNRS in Belgium, etc. These operate largely by giving grants for projects carried out by individual teams similar to those seen in the United States.

In Europe, the private sector is relatively inactive in the field of basic research. Few companies have strong research capabilities in this field, and their activities generally tend to focus on applied research and development activities. Moreover, the funding of research through foundations is still limited.

Unlike in the United States, where the private sector has always defended the idea of the need for sizeable public funding of basic research, European industry has for a long time advocated giving priority to public funding for applied research, in particular for research carried out by companies themselves. Today, the importance of basic research for economic competitiveness is starting to be recognized more and more in Europe, including by organizations which represent the business world, such as the European Round Table of Industrialists.

In the field of research, and basic research in particular, Europe has undeniable strengths: the quality of the European training system; the very high standard of a large number of university teams; the existence of centers of excellence in practically all fields; the strength of the traditions of basic research which often exist in the countries acceding to the Union. But it also has a number of weaknesses.

In this regard, the first thing which should be mentioned is the lack of sufficient competition at the European level, since teams and researchers are largely exposed only to competition within their own countries. By exposing researchers, teams and institutions in different countries to the ideas and dynamism of their greatest counterparts elsewhere in Europe, the establishment of genuine competition on a continental scale would undoubtedly stimulate the creativity and excellence of basic research in Europe.

The fact that Europe is split into a number of different countries, trivial but with several major consequences, also has an impact in other respects:

- The lack of cooperation and coordination of activities due to the compartmentalization of national programs and support systems.
- The lack in some cases of a critical mass of projects due to the small number and limited size of centers of excellence.

In terms of results, Europe in overall terms offers a less attractive environment for researchers: researchers from third countries but also European researchers, which Europe trains in number and at a high level, but who often choose to pursue their career in the United States.

In Europe, most basic research is carried out and funded at national level. One of the reasons for this is that it is largely performed by universities, thus in the framework of the national education systems.

For a long time, the predominant feeling among the Member States has also been that this type of research by definition falls within the sphere of national competence and that, in view of the objectives of EU research policy, the European Union should confine itself to supporting applied research and technological development. Here too, the perception has changed over the years due to an awareness of the realities about the knowledge-based economy and an understanding of the importance of advances in scientific knowledge and research, including basic research, for achieving the economic and social goals of the Union.

The research activities carried out within the networks and projects of the European Science Foundation (ESF), a non-specialized organization set up in the 1970s, also often concern quite basic research topics. This is also the case with activities conducted under the Union's Research Framework Programme, which includes a certain amount of basic research in the form of specific activities or certain aspects of the research activities of major programmes.

## B Basic research in the Framework Programme

Basic research activities can be found in the following parts of the Sixth Framework Programme:

- "Marie Curie" actions to support the training, mobility and careers of researchers; these activities are open to all scientific fields, including theoretical research (theoretical physics, cosmology, mathematics);
- Support for access to research infrastructures and their exploitation (particle accelerators, astronomical observatories, etc.);
- To some extent at regional level in cases where, and subject to the limits within which, the regions, which generally tend to focus their efforts on technological development and innovation, provide funding for universities and the research activities which they carry out;
- The NEST activity to provide specific support for research "at the frontiers of knowledge" (€215 million), which is open to proposals for "visionary" research, throughout the field of science and technology, with the emphasis on interdisciplinary research;
- To some extent, the "thematic priorities," with work in particular in the field of nanosciences and the physics of materials; some research on molecular biology and the basic mechanisms of genetics and genomics; the FET (future and emerging technologies) action to support new scientific and technological disciplines relating to the information technologies.

Taken as a whole, however, the support provided by the Framework Programme for basic research seems limited. The resources explicitly devoted to it are not very great, and the general perspective of the programmes is still very much dominated by knowledge application objectives. Above all, the range of research support modes remains limited, without there being, more especially, a support system for individual teams of a significant size. In total, the Framework Programme does, however, seem to provide an appropriate basis for action on a greater scale, to be conducted with additional resources.

Along with its assets, Europe, as has been shown, suffers from a number of weaknesses as far as basic research is concerned. These are largely due to the compartmentalized nature of the national research systems, and above all the lack of sufficient competition between researchers, teams and individual projects at a European level. Since these weaknesses vary in nature, they will not be overcome and the challenges associated with overcoming them will not be met unless resources, approaches and instruments are combined. There is no single formula which will allow all of the problems to be solved at the same time.

There seems to be a need to introduce a European level support mechanism for individual teams' research projects, modeled on the "individual grants" given by the NSF. In this respect, it should be noted that all research projects supported by the Union are evaluated by means of a procedure involving panels of independent experts based on the principle of "peer review," with rules and operating conditions very similar to those applied, for example, by the NSF. A support scheme for individual teams operates on a limited scale within the framework of the Marie Curie actions (Marie Curie Excellence Grants). Outside of the Union framework, there is the European Young Investigator (EURYI) scheme set up by the EUROHORCs Association, which has a comparable budget.

During the discussion on basic research and on a European Research Council, such a support mechanism was repeatedly put forward as a major and desirable innovation. It seems quite natural in the context of the European Research Area. Such a mechanism would in fact make it possible to combat the effects produced by the compartmentalized nature of the national systems. By stimulating competition and encouraging innovation as well as experimentation in ideas and new approaches, including interdisciplinary ones, it would stimulate creativity, excellence and innovation by exploiting a form of European added value other than that produced by cooperation and networking: the added value which comes from competition at EU level.

The principle of stimulating through competition is currently exploited in the Framework Programme, though only at the level of projects and networks. Indeed, it should not be forgotten that proposals for projects and networks submitted in response to calls for proposals are presented and evaluated in a competitive context and only the best ones are adopted, within the limits of available resources.

Support mechanisms in keeping with the particular type of basic research concerned should be defined, in particular with recourse to topics and work programmes that are more open and less binding than in the case of targeted research. The importance of this mechanism is not in principle limited to basic research. In the case of applied research too, support for individual teams' projects could and must be envisaged. In fact, in the United States, most of the funding given by the NIH, where many of the activities carried out are applied research, is awarded in the form of "individual grants."

Given that, according to the scientific community itself, it is difficult to establish strict, universal criteria for distinguishing between basic research and applied research, such a mechanism would therefore actually benefit from being applied throughout the scientific and technological field.

To be able to implement this new activity and achieve a sufficient impact without endangering other activities which support research at European and national levels, a significant volume of fresh funding should be provided for in the Union's research budget. Converging on this point with the recommendations of the "Mayor Group," the Commission plans to propose making the introduction of such a mechanism, as well as increased support for basic research, one of the main themes of the Union's future action in the field of research.

## II National activities to support basic research

At the same time, as a supplement to the Framework Programme, various nations have undertaken their own initiatives to promote basic research and revise the way that such research is supported and conducted:

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| Austria | 2001. Several initiatives to attract foreign ICT experts have been adopted. |
| | 2002. Research bonus for research expenditures was raised from 3% to 5%. Different research promotion funds. |
| Belgium | 2002. Reduction of personal tax on scientific researchers' income. |
| | 2003. As of Oct 2003, employers (universities, high schools and national scientific research funds) will be exempted from depositing half of the payroll tax relating to the incomes of researchers. |
| Czech Republic | 2003. Approval of the National Research Plan providing for the concentration of available human resources and funding on the priority areas of research. |
| Denmark | 2001. A number of research centers have been set up. Establishment of a Ministry of Science, Technology and Innovation. |
| | 2002. Introduction of a green card to make it easier for businesses to obtain work permits for foreign nationals. Tax credit scheme to enhance collaboration between businesses and public-sector research institutions. Strengthening the university managements. |
| | 2003. Action Plan for enhanced interaction between public sector research and education institutions. |

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| France | 2002. Four research and technological innovation network have been set up specifically for the life sciences.<br>2003. Finance Act allows R&D investment to be exempted from the basis of assessment for trade income tax. |
| Germany | 2001. Work is done to attract foreign IT specialists. Several initiatives to promote research.<br>2002. Different initiatives to enhance the education sector. Programs to foster research cooperation.<br>2004. Measures to ease the economic use of inventions. Venture capital initiatives for high-tech start-ups. Initiative with the social partners "Partner for Innovation." Master plan "Information society Germany 2006" envisaged.<br>2005. Extension of venture capital funds; initiatives to foster public–private partnership, promotion of spin-offs from universities and extension of top university research. |
| Greece | 2001. Establishment of a special secretariat for the knowledge-based society.<br>2002. A law to giving R&D expenditures favorable tax treatment (50% R&D tax credit). |
| Ireland | 2001. Industrial Designs Act – protection of industrial designs.<br>2003. Science Foundation Ireland (SFI) announced substantial research investment in three new centers for science, engineering and technology. |
| Italy | 2001. Fund for Basic Research to finance the strengthening of public and joint public–private research facilities. Initiatives to create centers of research excellence at universities and graduate schools.<br>2002. Universities more attention to labor market regards supply of courses.<br>2003. "Plan for Digital Innovation of Firms" – strengthen innovation, foster technology transfer from public research centers to firms, etc. Different initiatives to enhance basic research. National portal set up to provide updated and online information both to researchers wishing to work temporarily in Italy and for Italians wishing to work in other countries' research centers. |
| Luxembourg | 2002. Initiatives to enhance public research – project: "University of Luxembourg," meant to complete and to rationalize the embryos of existing superior education and research structures. |

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| | 2003. Portal for innovation and research was launched. Offers optimum services to companies and research centers concerning innovation, R&D and the creation of innovative business companies. |
| Netherlands | 2001. Trying to activate and intensify the exploitation of knowledge within universities. Setting up of ECV Knowledge Centre – to build a bridge between working and learning.<br>2002. A "training impulse subsidy scheme" was launched to support innovative initiatives from within the private sector. "Technostarters" scheme – aims to improve the orientation of knowledge institutes towards knowledge transfer and exploitation by encouraging them to offer technostarters a good infrastructure and support. |
| Portugal | 2001. Integrated Innovation Support Program (PROINOV). Initiatives to strengthening business investments in R&D.<br>2002. Public support through tax incentives. Deduction rates have been increased. New programs have been set up to support business enterprise R&D.<br>2003. The IDEIA Program (Business Applied Research and Development) is addressed to applied research projects, and involves partnerships between firms and institutions of the National Scientific and Technological System, aiming at the creation of new products, services or processes. |
| Spain | 2001. Extension of tax incentives to promote R&D and innovation. Special aid programs to fund technical research. Initiatives to increase the number of researchers.<br>2002. Corporate income tax reform improves tax incentives to R&D and innovation by broadening the range of deductible expenses.<br>2003. Tax deductions for research, development and technological innovation activities. |
| Sweden | 2001. Establishment of a new organization for research funding. Promoting links between universities and business sector. All universities and university colleges shall be given the opportunity to set up holding companies. Initiatives to restructure research institutes so they become fewer, larger and more competitive internationally.<br>2002. Initiated a project with representatives from the business sector, social partners and universities. Aims to formulate an aggressive strategy for a coherent innovation |

policy. Primary objective is to transform new knowledge from universities into enterprise and growth.

UK 2001. More autonomy to universities. Considering proposals for R&D tax incentives for larger firms.

2002. R&D tax credit for large companies introduced.

## A United Kingdom

The Department of Trade and Industry has been funding collaboration schemes for industrial innovation through three major programs: LINK, advanced technology and general industry programs. LINK is a program for pre-competitive research between industry, academia, and multiple government departments. Under general industrial collaborative projects, DTI supports research and technology organizations that specifically encourage small- and medium-sized enterprises to participate.

The six research councils, such as the Engineering and Physical Sciences Research Council (EPSRC) and the Medical Research Council (MRC), have established nine interdisciplinary programs through large grants to academic research centers of strategic research to provide postgraduate training. These strategic research centers are tied to industry-supported technology.

- CARBON TRUST;
- LINK;
- Harnessing Genomics;
- SMART Awards;
- Biotechnology Exploitation Platform Challenge;
- Vivamer (spinoff from University of Cambridge);
- Faraday Partnerships.

## B France

France faces challenges comparable to those in the United States from recent trends in industrial research and development. Those challenges are more serious, since the increased focus on short-term research still has not resulted in significant improvement in the competitiveness of most French high-technology firms. Unlike the situation in the United States, France does not have the same degree of institutional flexibility to change the nature of academic and government research. France does not have a powerful university R&D system. Instead, special higher education institutions, known as the *grands écoles*, produce the technical and business elite who become government ministry administrators and corporate executives. It is the ministries which control nearly all government-funded scientific and engineering research through their control of the Conseil nationale de la recherche scientifique (CNRS), which is the institution that funds most fundamental research in France.

### *MEDEA*

The Microelectronics Development for European Applications (MEDEA) initiative, based in Paris, was launched on July 1, 1996 as a collaborative project under the EUREKA program. The initiative is a "microelectronics programme for integration into selected application systems. It will focus strongly on the needs of the electronics systems industry being both industry-driven and market oriented" which "aims to achieve highly competitive results" (EUREKA, 1998). MEDEA picks up from where its EUREKA predecessor JESSI (Joint Sub-micron Semiconductor Initiative) left off. While JESSI focused on process technology development, MEDEA is directed more towards applications rather than process technology and design automation. Also, "with JESSI, Europe managed to become independent as far as its chip requirements were concerned. With MEDEA, Europe wants to go further, making even finer chips and bigger silicon wafers to cut costs per chip" (Michelson, 1996).

Funding for MEDEA projects is split between the EU Commission, the Member States, and the firms. The decision-making authority is generally held by the Member States. 12 percent of funding is received from the Commission, as compared to the 17 percent that the Commission financed for JESSI. In addition, the firms are required to contribute 50 percent of funding themselves, with the rest coming from the firms' national government. At the national level, the contribution towards funding from the participating member states is led by Germany (32 percent) with France following at a close second (29 percent). The Netherlands (19 percent), Italy (10 percent), Belgium (4 percent) and Austria (2 percent) provide the balance of funds (EUREKA, 1998). France clearly leads the Member States with the most person-hours for five out of six of the MEDEA disciplines and ranks second in the sixth discipline (automotive). Combining these two factors (the level of contribution from the Member States and the forecasted person-hours per country), one sees that the French investment in these projects is leading to more work for employees per monetary unit than in the other participating countries. This shows a strong commitment by both the French Government and the participating firms to the objectives of the MEDEA program.

The three main French firms participating in the MEDEA program are Alcatel-Alstrom-Recherche, Bull S.A., and SGS-Thomson Microelectronics. All three of these companies are large firms. In addition to these three firms, which are involved with a number of the MEDEA projects, other French companies are also involved with specific MEDEA projects. For example, Societé l'Air Liquide, Gressi, Incam and Recif are involved with SGS-Thomson in the project to establish pilot production lines for making ICs on 300-mm diameter wafers.

Six strategic objectives that were formulated in the definition and establishment of MEDEA:

- To develop core competencies for IC [integrated circuit] makers and users;
- Provide IC technologies and systems for the Information Society as the general public became more dependent on computers and datacoms;
- Reduce dependencies on non-European supply in some critical areas;
- Provide platforms for horizontal and vertical cooperation;
- Use market opportunities and gain global market share; and
- Exploit the leverage effect of microelectronics on employment.

MEDEA's focus is in six main technological areas. Half of these disciplines are applications-oriented while the other half are geared more towards basic technology. The three applications-based technologies are in the areas of multimedia, communications and automotive/traffic systems. The more basic technologies are in the areas of design techniques and libraries, CMOS technology, and manufacturing technologies. There are a total of forty-five MEDEA projects covering these six main technical sectors (EUREKA, 1998).

The MEDEA structure ensures that governmental decision-making on research priorities supports the needs of industry, cementing the link between the two through its cost-sharing requirements. Also, the moderate subsidy from the European Commission leverages that investment across national borders, encouraging further collaborative research. By involving multiple firms, universities and research institutions in MEDEA, the program can facilitate the wide diffusion of new innovations.

## C Germany

Research initiative levels have dropped throughout Germany, mainly due to the Federal Government's efforts to raise the prior East German research policies to that of the West. This change has taken much funding and manpower away from existing R&D programs. Still, Germany has a long tradition of encouraging collaborative research and development, with nearly every major R&D program involving cooperative efforts to some extent.

### *The Fraunhofer Gesellschaft*

The leading organization focused on applied research in Germany is the Fraunhofer Gesellschaft (FhG) and its forty-seven worldwide institutes. Founded in 1949, FhG conducts applied research for industry on a contract basis, using the facilities and personnel of regional polytechnics or universities (Burton and Hansen, 1993). By forging a stronger bond between academia and business, FhG aims to speed the commercial application of new technologies. Unlike other organizations, such as Max Planck Gesellschaft, which concentrate on basic or "blue sky" research, FhG is only concerned with developing technologies that will have immediate results in the global marketplace. FhG also differs from other research bodies in that its results are not immediately available to the public. Rather, given that it is the contracting agency that is paying for the research, it is up to them whether or not the information is kept secret.

The institutes receive all of their financial support from industry and the German government, with both paying equal shares. The involvement of the government and taxpayer money means that obtaining a contract for research is not as simple as calling the nearest FhG institute and requesting their services. To begin with, all contracts must be worth at least DM100,000 in order to receive government support. Furthermore, the exact level of funding is dependent upon the technical and economic risks of the proposal. Finally, the projects must be perceived as potentially profitable. One of the primary benefits of this system over other arrangements is that SMEs have just as much of an opportunity to secure funding for R&D projects as large, capital-rich, companies.

As previously mentioned, Fraunhofer is a global organization with a number of foreign clients. These firms are supplying an increasing larger proportion of revenues with each passing year. Outside of individual firms, FhG is also participating in a number of joint projects within the European Union. Examples include PROMETHEUS (electronic control systems), FAMOS (European Flexible Automated Assembly), and JESSI (semiconductor technology). FhG even set up Fraunhofer USA in 1994 to attract more American clients/partners and encourage technology transfer between the countries.

FhG is overseen by an administrative body comprised of representatives from industry, academia, and the government. It is this group which establishes the organization's priorities and objectives so as to keep pace with changing industrial interests. Consequently, the institutes comprising Fraunhofer are established and closed depending upon perceived industry needs. For instance, following the reunification of Germany, seventeen new research groups were created in the former Communist-controlled Eastern region. While these institutes have a variety of specialties, the FhG focuses their research in nine primary fields:

(i) Microelectronics;
(ii) Information technology;
(iii) Production automation and sensor technology;
(iv) Production technologies, materials, and components;
(v) Process engineering;
(vi) Energy technology and construction engineering;
(vii) Environmental research and health;
(viii) Technical and economic studies;
(ix) Technical information.

The FhG, as a contract research body partnering with sources of research capabilities, serves as a neutral organization for coordinating flows of knowledge among and between its clients and its research affiliates. The Institutes of the FhG themselves comprise the transorganizational knowledge management infrastructure for each technical field, by managing the interactions between diverse research partners. The FhG also has the influence to spark learning in a GUI setting through this interaction.

# 4

# Analyzing Transatlantic Public–Private Research Collaborations: A Mode of Global Knowledge Production and Dissemination

As part of the preparation for this book, a study was conducted to explore the dynamics of public–private research partnerships in the context of US–European research collaboration. In particular, the study analyzes a set of scientific publications where at least one co-author is based in the United States and one is based in the European Union, and which involve researchers from both private firms and public sector institutions. The results of this analysis are intended to inform both corporate managers and policy-makers about the nature of such collaborations and their impact on both private and public innovation systems.

The goal of this study was to explore the nature and characteristics of firms in the United States and European Union which participate in research collaborations involving both private sector and public sector organizations located in both the United States and the European Union. More specifically, this study uses a bibliometric approach based on co-authorship of scientific publications to identify cases of transatlantic public– private research collaborations, and then tests several hypotheses drawn from existing theories on the management of technology and innovation, corporate strategic management, and interorganizational knowledge transfers to determine how well these theories can predict the relationship between features of a firm's structure.

There are three compelling motivations driving the study of transatlantic public–private research collaborations.

First, a significant body of literature examines the issue of the "globalization" of various aspects of industrially relevant science and technology. This work encompasses issues such as the increasingly international scope of industrial research and development (OECD, 1999a; Dougherty *et al*., 2003), international flows of knowledge in science and technology (Guellec and van Pottelsberghe de la Potterie, 2001; Tijssen, 2001), and the emergence of various forms of transnational networks for the transfer of knowledge and the management of innovation (Rycroft, 2003). This literature suggests that various forms of interorganizational cooperation, such as strategic technological alliances and sourcing of knowledge from public research institutions, are increasingly transnational in character and a significant mode of building corporate technical competences and competitive advantage. Decision-makers in corporations could benefit from the results of this book by observing prevailing patterns in industrial participation in such collaborations, and establishing links (if any) between corporate technology needs, firm performance, and the use of these collaborations.

Second, national and transnational government bodies (including the United States Federal government and the European Union) have focused on public–private partnerships as a means to improve the effectiveness and speed of technological innovation (US House Committee on Science, 1998; OECD, 1999b). One contentious issue related to this policy is the involvement of foreign firms in government-sponsored collaborative research programs (for example, the Advanced Technology Program in the United States, and EUREKA in Europe). Advocates of so-called "techno-nationalism" argue that the benefits of publicly funded research programs should be carefully managed to flow only to "domestic" firms, and that foreign participation in such programs should be strictly controlled. However, there is a dearth of empirical data on the extent of the amount of collaboration in research and development that goes on between publicly funded organizations and foreign firms. This book attempts to rectify that situation by providing an empirical basis for the analysis of this issue.

Third, the comparison of technology development practices and outcomes in various nations is the subject of a growing body of theory and research on "national innovation systems" (Nelson and Rosenberg, 1993; OECD, 1999b). Firms are important actors in national innovation systems, as they are the dominant force in the commercialization of new technologies. If industrial research is now an international activity, and since governments in general desire to facilitate technological innovation to support and enhance economic growth, the study of transatlantic public–private research collaborations will address the linkage between the analysis of national innovation systems and the emergence of global networks for scientific research and industrial technology development.

This book addresses some of these issues by examining several questions related to public–private, transatlantic research collaborations:

(i) The first, purely descriptive question, is how prevalent are such collaborations in the international science and technology enterprise, and what are their trends in growth and research configurations?
(ii) A second question, of interest to corporate managers, is, how are such collaborations related to various aspects of technological innovation in firms, such as the nature of technology development in particular industries and corporate processes for acquiring and exploiting new scientific knowledge?
(iii) A third question, focusing on issues of national policy, is, how do such collaborations relate to specific aspects of national innovation systems, such as the technological strengths of particular nations and the characteristics of public research organizations in those nations?

By addressing these three questions, this book aims to advance the understanding of how and why transatlantic public–private research collaborations exist, the relevance of various theories on technological innovation and strategic management to such collaborations, and the implications of these collaborations for corporate technology strategy and national innovation policies.

This particular study extends previous work in two directions. First, it continues the examination of research collaborations involving both public and private sector organizations, linking those collaborations to both national-level scientific competences and firm-level industrial technology needs. Second, it focuses on transatlantic public–private research collaborations, providing further illumination of the dynamics of transnational collaborations and their relationship to both firm strategy and national science and technology policy.

The fact that the collaborations studied here are transatlantic in nature is an important characteristic of this study. The United States and Europe have a long history of interaction and cooperation in many fields of scientific research. There is also significant transatlantic trade in high-technology products, as measured in publications such as the Science & Engineering Indicators report from the US National Science Foundation (2002). US firms have extensive operations in the European Union, and vice versa. Despite extensive studies of these indicators of transatlantic industrial and scientific interactions, there are no studies which focus specifically on how public–private research collaborations play a role in the economic and technological relationship between the United States and the European Union.

The results of this book are of interest and relevance to the field of the management of science, technology and innovation for a number of reasons. First, the book will provide data concerning the quantity and character of these transatlantic public–private research collaborations. Second, for corporate managers, understanding the dynamics of such collaboration, and in particular if such collaborations are associated with firm performance and innovation, will aid in decisions on whether to participate in such collaborations in the future, and the role that such collaborations may play in corporate strategy and R&D management. Third, for decision-makers in public policy, this book will provide additional data on the internationalization of corporate research, and the relationship between that trend and the formation of public–private research collaborations in the United States and Europe.

Due to the availability of data and the practical limitations involved in the study of research collaborations, this book analyzes research collaborations (defined below) involving both public and private sector organizations, and involving organizations in both the United States and the European Union. Furthermore, this study focuses only on those collaborations which resulted in scientific publications in peer-reviewed journals published between 1988 and 1997.

## I Explanation of study method

Co-authorship studies are a well-established means of studying the dynamics and results of research interactions between the private sector (firms) and public sector organizations (such as universities) (see, for example, Hicks, 1993; Pechter and Kakinuma, 1999; Okubo and Sjoberg, 2000). While co-authorship is an imperfect measure of collaborative activities in research (Katz and Martin, 1997), it is one of the few methods that provide a quantitative measurement of such interactions (Hicks, 1993). Therefore, a co-authorship book provides a useful proxy for the overall degree of public–private research collaborations.

Public–private collaborations are studied, excluding purely private collaborations (e.g. joint ventures between firms) or purely public collaborations (e.g. collaborations between researchers at different universities), for a number a reasons. First, co-authorship studies are a less reliable means of measuring purely private collaborations, as industrial practices in scientific publications make it unlikely that most such collaborations will produce co-authored scientific research. For purely private collaborations, studies using databases of announced joint ventures and other forms of organization are generally used (see Hagedoorn and Schakenraad, 1990; Hagedoorn and Schakenraad, 1992; Hagedoorn *et al.*, 2000; and Siegel, 2001). Second, purely private collaborations involve different policy and strategic issues than public–private collaborations. Most notably, the involvement of public sector organizations brings up the issue of how government-supported research is being used for private gain by corporations. Third, purely public collaborations, while very common, do not raise issues related to corporate research strategies, nor do they involve directly the policy issues related to the relationship between public sector science and industrial technology development.

This study also focuses only on those collaborations where at least one participant is located in the United States and another is located in one of the Member States of the European Union. This type of transnational collaboration is analyzed because the norms of scientific research and publishing practices are roughly comparable between the United States and most nations of the European Union. Also, there is a long history of research collaborations of different forms between organizations in the United States and organizations in the European Union. Finally, foreign involvement in research and development activities has been an issue of concern for science and technology policy in both the United States and the European Union, making this a particularly relevant dynamic to explore.

The timeframe of 1988 to 1997 for the publications studied also provides some advantages. Using a ten-year period for this book provides a timeframe of sufficient length to capture some of the temporal dynamics of these collaborations. While the lag between research and publication varies by scientific field and by journal, the use of ten years of successive publications will give some indication of how collaborations have changed over time. Also, the ten-year period will help to moderate some potential extraneous complications which could affect the book, such as the effects of business cycles on corporate support for research collaborations.

There are several aspects of transnational public–private research collaborations which merit further research but are beyond the scope of this study. For example, this study does not attempt to compare these types of collaborations with purely domestic research collaborations, such as those involving universities and firms in the same nation. It also does not address issues related to the transfer of technologies from public research organizations to the private sector (generally indicated by patents and technology licenses), but rather addresses knowledge which is embodied and transferred between public and private organizations through the process of scientific research and publication. As this study examines cases of such collaborations, it cannot offer any comparison between firms which participate in these collaborations and those which do not.

Several alternative methodologies other than co-authorship studies are available for the analysis of public–private research partnerships, including data from government programs which support public– private partnerships; case studies; surveys; and data gathered by the organizations studied (see Siegel, 2001). Among these methodologies, a co-authorship book provides sufficient coverage and methodological integrity to offer useful insight into transnational, public–private research collaborations.

## II Concepts and definitions

Several of the terms used in this book are given particular meanings which should be clarified.

*Research*. In this book, the concept of research (and specifically scientific research) is identified as a structured form of inquiry which is aimed at understanding fundamental principles about the natural world. This is the definition adopted by, among others, the US National Science Foundation (1985). Note that this definition does not exclude the possibility that research can be applied; that is, research can be undertaken with the aim of utilizing the resulting knowledge to achieve a specific goal, as distinct from research which is undertaken only for the sake of generating new knowledge (Stokes, 1997).

*Innovation*. In the literature on the management of science, technology and innovation, one frequently cited definition of "innovation" is that given by Rogers (1995): "An innovation is an idea, practice or object that is perceived as new by an individual or other unit of adoption." This book focuses specifically on innovation in a technological and commercial context, which is defined as follows (US Office of Technology Assessment, 1995, p. 2):

> Innovation encompasses both the development and application of a new product, process or service. It assumes novelty in the device, the application, or both … Innovation encompasses many activities, including scientific, technical and market research; product, process

> or service development; and manufacturing and marketing to the extent they support dissemination and application of the invention.

The primary indicator of innovative activity used in this book is the production of inventions which are granted patents by the US Patent and Trademark Office and/or the European Patent Office.

*Research Collaboration.* For the purposes of this book, a research collaboration is an undertaking of a scientific book which involves researchers from multiple organizations and which results in a publication in a peer-reviewed scientific journal or similar publishing outlet. This excludes other forms of collaboration, such as informal conversations among researchers or technical cooperation which does not produce a publication.

*Private organizations* are any organizations which operate primarily to earn profits for their shareholders. In particular, private sector organizations are identified through the use of databases of corporations, such as Hoover's Information Service. In this book, however, hospital and healthcare facilities are not classified as private sector organizations, in order to mitigate the problems in the differing healthcare systems of different nations.

*Public organizations* are in this book more accurately characterized as non-private organizations: those which are not part of a private sector organization. This includes universities, government laboratories, not-for-profit foundations, and similar organizations. This expansive definition of public sector organizations is used because in some cases it is difficult to distinguish among different types of public sector organizations when conducting bibliometric study. For example, a government-owned laboratory which is operated by a university could be classified as both a university and as a government research organization. In this book, such a laboratory is identified simply as a public sector organization. Furthermore, hospitals and medical centers are also defined as public sector organizations. This avoids the problem of the contrasting healthcare systems of the United States and some European countries, as the United States has some private hospitals and medical centers while many European nations have a national system of health care.

*Transatlantic.* Due to the nature of the data collected for this book and the focus of the book itself, transatlantic collaborations refer to those where at least one participant is located in the United States (not Canada) and one in the European Union.

*United States.* For the purposes of this book, the United States refers to the fifty states and related US-owned territories.

*European Union.* For the purposes of this book, the European Union is defined as the fifteen Member States of the EU as of 1997 – namely Austria, Belgium, Denmark, Finland, France, Germany (unified), Greece, Ireland, Italy, Luxembourg, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom.

*United States (US) or European Union (EU) organization.* The issue of nationality is addressed in two different ways in this book. When an entity is referred to as a "US organization" or an "EU organization," the nationality is identified as the country where the organization is based: i.e. the country where the organization's headquarters or central management structure is located. In the case of multinational firms, this definition still applies; therefore, for example, Ford Motor Company would be identified as a US firm while DaimlerChrysler would be identified as an EU firm.

*United States (US) or European Union (EU) facility.* When used in this sense, the concept of the nationality of a facility is based upon the physical address of that facility – whether the organization is geographically located in the United States or an EU member nation. The second sense is one of the national origin of the organization. In this sense, nationality is determined by the country in which the organization has its primary headquarters location, where the locus of decision-making for that organization resides. For example, a research laboratory in Europe which is owned by a firm headquartered in the United States would be viewed as a European organization in the geographic sense, but as a US organization in terms of national origin. Due to the nature of the data set used in this book, a transnational collaboration is one where at least one participating organization is physically located in the United States and another is physically located in one of the Member States of the European Union.

*Industry and diversification.* In this book, the industry of a firm is defined using the industry classifications for that firm as assigned by Hoover's Information Service. Measures of firm-level diversification refer to situations where a firm is noted offering products or services in more than one such industry.

*Scientific discipline.* When analyzing the publications produced by each research collaboration, this book categorizes those publications by scientific discipline. As shown in Chapter 3, a scientific discipline in this case is the term used to identify research projects which investigate similar phenomena based on a similar body of knowledge. For example, within the body of knowledge of engineering, one discipline focuses on chemical processes (chemical engineering) and another on electrical and electronic devices (electrical engineering). Within the body of knowledge of clinical medicine, one discipline focuses on the book of aging (geriatrics) while another focuses on reproduction and fetal development (obstetrics and gynecology).

The rest of this chapter presents the research model, propositions, and provisional findings of the study for this book.

## III Model development for transatlantic public–private research collaboration

The knowledge-based view of the firm has been used in previous studies to analyze the conditions under which firms decide to conduct internal research and development or to "outsource" research to other entities (firms, universities, government laboratories, etc.) (Pisano, 1990). This current book does not examine the issue of R&D outsourcing, but rather the concept of research collaboration. In an R&D outsourcing relationship, the firm contracts with an outside entity which conducts the research internally and provides the results of that research to the contracting firm. In a research collaboration, researchers from the firm and from an outside entity work in a coordinated fashion on a specific project, with researchers from all participants in the collaboration contributing knowledge, expertise and effort towards the project. While the work can be conducted in tandem from separate locations, or in a more interactive fashion at the same location, the key determining factor is that all participants contribute intellectual resources towards the final goal of the collaboration.

The knowledge-based view of the firm can inform analyses about the decision by a firm to collaborate on research. Two aspects of the knowledge-based view are particularly relevant to this issue.

First, there is the explicit recognition in the knowledge-based view that it is not necessary for a firm control internally all the knowledge that it needs to compete in the marketplace. The boundaries of the firm are determined by the extent to which it is most efficient for the firm to accumulate organizational knowledge internally, while continuing to rely on outside sources for knowledge which can be acquired through arm's-length relationships (Grant, 1996).

A second key aspect is that knowledge can be transferred between organizations (Kogut and Zander, 1992; Cummings and Teng, 2003). Through interactions among members of two organizations, both tacit and explicit knowledge can be shared by the participants in a collaborative effort. Each organization can then absorb that knowledge into its stock of organizational knowledge, if appropriate. Thus, the knowledge-based view proposes that firms have both the motive and the means to acquire knowledge from external sources.

The issue addressed in this book is, under what conditions will a firm acquire new scientific and technical knowledge through collaborations with transatlantic, public sector research partners? To focus on this issue, this book draws on literature related to research collaboration, the relationship of scientific knowledge to technological innovation, management of technology and innovation, and the strategic management of technological learning.

## A Research collaborations and public–private knowledge transfer

A second aspect of the relationship between science and industrial technology is the role of the collaborative process in enabling the linkage between scientific research, which is generally carried out in public sector organizations, and technology development, which is generally carried out in private firms. Previous research on the nature of public–private research interactions, focusing on university–industry collaborations, has emphasized certain common characteristics of knowledge transfers between these two sectors.

Several studies have noted the strong influence of geographic proximity on public–private research interactions – that despite the global scope of scientific expertise, firms tend to utilize scientific knowledge developed by public research organizations located in the same geographic region. Jaffe (1989) used an indirect means of indicating this tendency. Using industry patenting as the dependent variable, and firm and university research expenditures as the independent variables, Jaffe showed that firms tend to produce more patents (i.e. show higher R&D productivity) in regions with high levels of university research expenditures. However, Jaffe's book does not indicate exactly how or why geographic proximity might matter for the actual flow of knowledge from universities to industry.

A more specific method for investigating knowledge flows looks at the citation of public sector research papers within industry patents (Narin and Olivastro, 1992). Studies such as Jaffe *et al.* (1993) again find evidence that a firm's patents tend to cite scientific papers authored by researchers in universities close to the patent's inventor(s). However, there are many factors which may confound the correlation of patent citations and knowledge flows, since a citation is at best an indirect measure of the flow of knowledge from the pool of public sector research to industry.

Co-authorship of scientific papers involving both industry and public sector authors may be a more direct indicator of public–private knowledge transfer (Hicks, 1993; Okubo and Sjoberg, 2000). If two or more researchers are listed as co-authors on a scientific paper, there is a reasonable expectation that those co-authors contributed in a collaborative fashion to the research embodied in that paper. Co-authorship measures are clearly an imperfect and incomplete measure of research collaboration (Katz and Martin, 1997). There are some forms of informal collaboration and knowledge transfer which are not captured by co-authorship studies. For example, a public sector researcher might be retained as a consultant on an industrial research project, and that project may not necessarily result in a published scientific paper. Similarly, an industrial researcher may have conversations with a public sector researcher and gain useful scientific insights from that conversation, without ever producing a published record of that interaction. At the same time, co-authorship may also overestimate collaboration, as there are several cases involving suspected scientific fraud where a co-author was added to a paper, sometimes without that researcher's knowledge, simply to give the paper greater credibility or to add to the curriculum vitae of that researcher. Even with these limitations, co-authorship does imply that some kind of interaction probably took place between the researchers listed as authors.

> **Proposition 1** Co-authorship of scientific publications provide a useful indicator of collaborative research activities involving two or more organizations, particularly those involving entities in both the public and private sectors.

Another important observation about public–private knowledge transfers is that the transfer of knowledge is not necessarily unidirectional. Several studies have focused on the extent to which industrial innovation is dependent upon scientific research, generally using the patent–paper citation method (see McMillan *et al.*, 2000; Toole, 2000; Hicks *et al.*, 2001; and Tijssen, 2001). However, there are ways in which industrial research contribute to scientific research at public institutions. For example, a firm may present a problem to a public sector researcher which inspires a new line of research leading to later publications. Also, an industry participant in a research project could contribute the data used in the analysis, or have access to specialized equipment and facilities required by the project. Therefore, it seems more relevant to analyze public–private collaboration and knowledge transfer as an issue of networking rather than simple flows of knowledge from one sector to another (Peters *et al.*, 1998; Murray, 2003).

> **Proposition 2** Knowledge transfers in research collaborations occur as part of an interactive process which differs from less direct methods of knowledge transfer, such as reading a scientific paper published by another institution. Therefore, research collaborations are a form of knowledge networking rather than simple knowledge transfer.

Another issue raised in the literature is the role of research collaboration in facilitating interdisciplinary research. Several authors propose that transorganizational research is better suited for integrating research across disciplines than research within a single organization. If true, this proposition could have significant implications for firm technology management. The cognitive approach to innovation notes that firms are often limited in their conception of which technologies can be used to produce new innovations (Dosi, 1982; Howells, 1995). This is one reason why incumbents in an industry often fail to recognize "disruptive technologies" when they are introduced into the market (Christensen, 1997). Diversity in the types of research partners involved in a collaboration with a firm, as well as diversity in the disciplines of research involved, may help to open up the firm to consider new technological solutions to the challenge of innovation.

> **Proposition 3** Research collaborations involving different types of partners, originating in different sectors and disciplines, will tend to focus on multidisciplinary research topics, which in turn lead to a greater range in the types of technologies produced by the private sector participants in such collaborations.

## B Scientific knowledge and industrial innovation

One clear feature of industrial technology development starting in the late twentieth century is that it has become increasingly linked to scientific knowledge (Rosenberg, 1983; Meyer-Krahmer and Schmoch, 1998). Technology development in the early twentieth century occurred primarily through experimentation and individual inventorship rather than scientific investigation. Modern industrial research in a number of fields now requires researchers with very specific skills in scientific research, and an understanding of the scientific principles underlying natural phenomena affecting industrial technologies.

One consequence of the increasing scientific component of industrial research and development is that no single corporation can be the repository of all the knowledge needed to innovate in key technology areas at a competitive rate. The shortening of the product life cycle, coupled with the increasing diffusion of scientific knowledge, motivates transorganizational cooperation in research and development (Roos *et al*., 1998. In particular, many industries now produce products which are themselves integrated systems composed of multiple inventions, increasing the range of technologies needed to achieve industrial innovation (Somaya and Teece, 2000). Most significantly, in the United States and other nations, large corporations have been reducing their expenditures and resources devoted to fundamental scientific research, focusing most of their spending on product development and other activities involved in putting an innovation into use. Therefore, to access the global stock of scientific knowledge relevant to their technical needs, firms must cooperate with external organizations as part of the innovation process (Myers and Rosenbloom, 1996; Chesbrough, 2003).

While it is common to observe that scientific breakthroughs lead to new technological inventions, Rosenberg (1983) notes that the actual linkage between a particular scientific discovery and a related technology is often difficult to discern. In some cases, such as the development of new therapeutics in the pharmaceutical industry, a specific scientific phenomenon is directly related to the resulting invention. In other cases, such as the development of optical fiber transmission systems, the path from basic research to product is less direct and involves the integration of diverse forms of knowledge and technologies. As a result, there are likely to be distinct differences in the way that firms which utilize different technologies obtain access to, and then apply, basic scientific knowledge.

One example of this difference is identifying the extent to which firms in particular industries are "science-based." Pavitt (1984) developed a definition of "science-based firms," as those where "the main sources of technology are the R&D activities of firms … based on the rapid development of the underlying sciences in universities and elsewhere" (p. 362). To operationalize this concept, Narin and Noma (1985) proposed a methodology for identifying science-based technologies. In their approach, technology fields where patents have a higher propensity to cite scientific publications as the basis for their inventions are more "science-based." This measurement approach has its limits, as often citations are inserted into patent applications by the examiners rather than the inventors and patent agents who authored the patent application. However, most examiners will tend to rely primarily on other patents as citations, not non-patent literature. Therefore, where a scientific publication is cited in a patent, it is likely that the original inventor(s) identified that source as an antecedent to the invention.

Using this measure, Grupp and his collaborators have developed an index of the degree to which various technologies are based on science, using the citation patterns of patents from the European Patent Office in the period from 1989 to 1992. In this analysis, technologies with the highest instance of scientific citations were biotechnology, pharmaceuticals, and semiconductors. Other information technologies, such as data processing (software) and telecommunications, were somewhat less science-based. Among the least science-based technologies were medical technology, transportation, mechanical devices and civil engineering.

This contrast among technologies reflects a theoretical distinction between science and engineering. While there are many definitions of science in the literature, most definitions focus on two aspects of science – the use of science as a process for generating new knowledge (through the postulation and verification or falsification of hypotheses) and as a set of cultural norms (utilizing empirical book based on common "paradigms" to determine the validity of theories). Engineering knowledge proceeds in a somewhat different fashion, as noted by Vincenti (1990) and Ferguson (1994). Engineering is not simply "applied science," but involves a different process of attaining an invention through experimental designs, which may or may not have their origins in scientific principles. Vincenti cites the British engineer G. F. C. Rogers as stating: "Engineering refers to the practice of organizing the design and construction of any artifice which transforms the physical world around us to meet some recognized need" (quoted in Vincenti, 1990, p. 6).

If engineering knowledge differs from scientific knowledge, then it would follow that firms access and utilize engineering knowledge differently from basic scientific research. It would also follow that the firms which rely on engineering-based knowledge for their core technological competencies will acquire such knowledge differently from those using science-based knowledge. Universities and other public research organizations have a much stronger tradition of research in basic or fundamental science than in engineering, although the discipline of engineering studies (such as chemical engineering) is now a common set of programs in major universities. Still, given this distinction, it is likely that firms in science-based industries will use public research partners more extensively than firms which focus on less science-based industries.

> **Proposition 4** Science-based technologies are developed in processes different from engineering-based technologies, and therefore firms in science-based industries will be more reliant on public research organizations for acquiring new knowledge than firms in less science-based industries.

Several surveys measuring the science and technology outputs of countries note that over time, the dispersion of scientific expertise across nations has increased (National Science Foundation, 1997). The concept of "national innovation systems" proposes that due to differences in the institutional structures involved in innovation, certain nations may be better suited for success in particular modes of innovation than other nations. In particular, nations seem to specialize in a particular set of scientific or technological fields, rather than displaying very broad competences across many disciplines. This stream of research relates to the book of the internationalization of industrial research and development (Kuemmerle, 1997; Dougherty *et al.*, 2003; Rycroft, 2003).

> **Proposition 5** Differences in national innovation systems give rise to differences in the scientific specializations of nations. Therefore, a firm which collaborates with public sector partners in different nations will choose to partner with organizations in nations that specialize in the areas of science most relevant to that firm.

## C Implications of theory on the management of technology and innovation for the study of public–private research collaboration

The field of technology and innovation management has several potential insights into the nature of transnational, public–private research collaborations. One stream of literature in this field concerns the issues facing "multi-technology" firms–those companies that are highly diversified and utilize multiple technologies in their products. These firms must take a different approach to the identification and management of their "core technologies" compared to firms which focus on a few technologies. "Multi-technology" firms are more likely to have multiple, distributed core technical competences, rather than a few core competences which are present throughout the entire organization. Also, multi-technology firms may depend more upon the mode of innovation called "technology fusion" as opposed to relying on a few specific technologies to produce new innovations (Kodama, 1991). As a result, firms which are diversified in their core technologies will need to acquire and manage technical knowledge very differently from single-technology firms.

> **Proposition 6** "Multi-technology" firms have multiple technological core competences, and need access to multiple sources of knowledge to support this range of competences. Therefore, multi-technology firms will have more widely distributed technological capabilities, and therefore will source knowledge from a wider variety of outside organizations in patterns which differ compared to single technology firms.

## D Strategic management of technological learning

Carayannis (1994) developed a framework for analyzing the strategic management of technological learning. Within this framework, organizations pursue operational learning, focusing on the management of core organizational capabilities. The second-order degree of learning is tactical learning (meta-learning), focusing on reengineering and restructuring the organization. The highest order of learning in this framework is strategic learning, which focuses on "re-inventing and re-engineering organizational tools (methods and processes)" (pp. 113–14). In this current book, the use of transatlantic public–private research collaborations could be viewed as one of the "organizational tools" which firms learn to utilize as a result of their strategic learning processes.

The effects of technological learning are comparable to a definition of organizational learning as enabling an organization to pursue a greater range of potential actions. In the strategic management of technological learning, technological learning processes are organizational transformation processes whereby individuals, groups, and/or the organization as a whole internalize (with both extrinsic and intrinsic motivation) technical and administrative experience to improve their decision making and the management of uncertainty and complexity (Carayannis, 1994). In this view, technological learning enables an organization to pursue a greater range of technology-based strategies and activities. The effective management of technological learning would therefore contribute to competitive advantage by expanding the horizon of possibilities for technology-based strategic action.

Effective practice in the strategic management of technological learning will enable a firm to better navigate market environments with a high degree of technological and competitive uncertainty. In other words, firms which engage in the strategic management of technological learning will exhibit decreased variability in their overall performance over an extended timeframe.

> **Proposition 7** Firms which participate in transatlantic public-private research collaborations to a greater extent than other firms will display reduced variance over time in their financial performance.

## E Synthesis

The integration of the perspectives of the knowledge-based firm, science and technology relationships, public–private knowledge transfers and the management of technology and innovation have some significant implications for the book of transnational, public–private research partnerships. Table 4.1 reviews the propositions developed above, which form the basis of the theoretical issues explored in this book.

First, given that disruptive technologies are likely to result from innovations from unexpected sources, and from technologies that are introduced into an industry by new entrants, is the interdisciplinary nature of public–private research collaboration related to the concept of

*Table 4.1* Review of propositions

| | |
|---|---|
| **Proposition 1** | Co-authorship of scientific publications provide a useful indicator of collaborative research activities involving two or more organizations, particularly those involving entities in both the public and private sectors. |
| **Proposition 2** | Knowledge transfers in research collaborations occur as part of an interactive process which differs from less direct methods of knowledge transfer, such as reading a scientific paper published by another institution. Therefore, research collaborations are a form of knowledge networking rather than simple knowledge transfer. |
| **Proposition 3** | Research collaborations involving different types of partners, originating in different sectors and disciplines, will tend to focus on multidisciplinary research topics, which in turn lead to a greater range in the types of technologies produced by the private sector participants in such collaborations. |
| **Proposition 4** | Firms in science-based industries will participate in transatlantic public–private research collaborations more intensively and more frequently than firms in less science-based industries. |

*Table 4.1* Continued

| | |
|---|---|
| **Proposition 5** | Differences in national innovation systems give rise to differences in the scientific specializations of nations. Therefore, a firm which collaborates with public sector partners in different nations will choose to partner with organizations in nations that specialize in the areas of science most relevant to that firm. |
| **Proposition 6** | "Multi-technology" firms have multiple technological core competences, and need access to multiple sources of knowledge to support this range of competences. Therefore, multi-technology firms will have more widely distributed technological capabilities, and therefore will source knowledge from a wider variety of outside organizations in patterns which differ compared to single technology firms. |
| **Proposition 7** | Firms which participate in transatlantic public–private research collaborations to a greater extent than other firms will display reduced variance over time in their financial performance. |

"disruptive" technologies? Do these collaborations relate to the degree of technological diversification in a firm, and can they help to expand the cognitive boundaries of the firm in investigating new ideas for technological innovation? (P3, P6)

Second, if the relationship between science and technology is increasing, does that necessarily mean that industrial research in all fields is becoming more integrated with the global scientific knowledge-base? Do differences in science-based versus engineering-based knowledge exist, and how does that knowledge, when applied in firms, affect the modes of knowledge acquisition in corporations? (P2, P4)

Third, in what ways is the analysis of transnational public–private research collaborations enhanced by the perspective of knowledge clusters and innovation networks? What role do these collaborations play in the networks which support knowledge flows between and within organizations? (P2, P5)

Fourth, how does the use of trans-Atlantic public-private research collaborations relate to firm performance? If such collaborations are an outcome of strategic technological learning, is increased participation in such collaborations correlated with reduced variance in firm performance over time? (P7)

The following section presents a model and some tentative hypotheses related to these theoretical issues.

## IV Research model and hypotheses

Based on the literature mentioned above, we can construct a model which notes some of the influences on transnational, public–private research collaborations. In particular, a review of the literature indicates that the formation, configuration and value of such collaborations will vary based on factors such as:

- The relationship of scientific knowledge to technology development in an industry;
- The types of technological competences developed and possessed by firms and nations;
- The degree to which collaborations enable a firm to become "embedded" in transnational knowledge networks supporting innovation.

### A Relationship of scientific knowledge to industrial research

Given the dichotomy between scientific knowledge and engineering knowledge, firms which rely more on different forms of knowledge will use transnational public–private research collaborations differently in their strategies for acquiring new knowledge. In particular, firms in science-based industries will tend to utilize collaborations to access fundamental scientific knowledge. Also, firms in industries which focus on the manufacturing of assembled goods will utilize these collaborations primarily to access engineering knowledge rather than scientific knowledge.

*Table 4.2* Hypotheses concerning the scientific basis of collaboration

| | |
|---|---|
| Hypothesis 1: | Firms utilizing science-based knowledge will participate in transnational, public–private research collaborations differently from those which do not utilize science-based knowledge. |
| Hypothesis 1A: | Firms in science-based industries will participate in transnational, public–private research collaborations more frequently than firms in less science-based industries. |
| Hypothesis 1B: | Firms in industries which are more science-based will participate in transnational, public–private research collaborations with a larger number of total partners than firms in industries which are less science-based. |

*Table 4.3* Hypotheses concerning diversification

| | |
|---|---|
| Hypothesis 2: | Diversified firms will utilize transnational, public–private research collaborations differently from less-diversified firms. |
| Hypothesis 2A: | Diversified firms will have a more diverse set of configurations of transnational, public–private research collaborations than less-diversified firms. |
| Hypothesis 2B: | Diversified firms will engage in transnational, public–private research collaborations across a broader range of scientific disciplines than less-diversified firms. |

*Table 4.4* Hypotheses concerning knowledge sourcing

| | |
|---|---|
| Hypothesis 3: | A firm's participation in transnational, public–private research collaborations will be related to the knowledge specialization of the other members' home nations. |
| Hypothesis 3A: | A firm will participate in transnational, public–private research collaborations with partners from nations which specialize in the fields of science most relevant to that firm's needs, regardless of the partners' locations. |
| Hypothesis 3B: | A science-based firm will engage in transnational, public–private research collaborations primarily with partners from nations which specialize in the same scientific field as that firm. |

## B Technological competences and research collaboration

Diversified firms, which rely on multiple technologies for their products and services, will need to have a more diverse portfolio of transnational, public–private research collaborations than those which focus on a few industries. Furthermore, diversified firms need access to a broader range of knowledge and technical expertise, and therefore will need to have access to a larger set of partners to acquire and supplement that expertise. Also, these firms will tend to collaborate in partnerships focused on interdisciplinary research.

Although public–private knowledge flows may emphasize geographic proximity, firms need to access the most relevant scientific knowledge from the best sources, regardless of their location. Therefore, participation in transnational, public–private research collaborations will be influenced more by the type of expertise of the members than their location.

*Table 4.5* Hypotheses concerning collaboration and performance

| | |
|---|---|
| Hypothesis 4: | Firms which participate in a greater diversity of transatlantic public–private R&D collaborative configurations will have a higher R&D productivity and technological diversity, and more stable and superior financial performance than those which participate in a narrower range of such collaborations. |
| Hypothesis 4A: | Firms which participate in a greater diversity of transatlantic public–private R&D collaborative configurations will produce more patents per dollar of R&D spending over the course of the book period than those which participate in a narrower range of such collaborations, and will exhibit greater diversity in the number of fields in which they patent. |
| Hypothesis 4B: | Firms which participate in a greater diversity of transatlantic public–private R&D collaborative configurations will show less variation in financial performance, measured by return on assets, and a higher average level of financial performance, measured by return on assets, over the course of the book period than those which participate in a narrower range of such collaborations. |

## C Knowledge networks and research collaboration

One potentially useful aspect of this research is the investigation of any relationship between participation in transatlantic public–private research partnerships and firm performance. In this book, performance has two primary aspects: the technical performance of the firm (its ability to produce new technologies) and financial performance.

In technical performance, participation in these kinds of collaborations could be linked to higher research productivity, as measured by the ratio of patent output to research and development spending. If these collaborations are an important mechanism for contributing new ideas to the firm on directions for future technology development and innovation, than over the long term, repeated use of these partnerships should be correlated with a higher degree of patenting.

In financial performance, sustained participation in such public–private partnership is believed to require some degree of organizational learning by the participating firm (Cyert and Goodman, 1997). In research partnerships, the firm learns both how to manage new scientific and technical knowledge, as well as how to manage the process of partnering with research institutions. One potential outcome of such strategic learning is not greater absolute financial performance (e.g., high profitability), but greater consistency in financial performance (Carayannis, 2000). If the firm's capacity for organizational and technological learning is increased through these partnerships, then that capacity should enable the firm to adjust more rapidly to changes in its competitive and technological environment, thus leading to lower volatility in operational performance.

## V Methodology

The Institute for Scientific Information (ISI) provided the data per the request of the Washington, DC representative office of the European Commission. The papers analyzed in this book were restricted to articles, notes, reviews and proceedings appearing in two ISI databases, the Science Citation Index (SCI) and Social Science Citation Index (SSCI). These data are limited to scientific papers published in peer-reviewed journals in the physical, natural and social sciences, with publication dates between 1988 and 1997. Further, papers in the dataset were only those where at least one author gave an address in a member nation of the European Union (EU) and one author gave an address in the United States. These publications were then classified by identifying the sector (public or private) of the institutional affiliations of the EU and US co-authors.

Closer inspection revealed numerous inconsistencies in the data fields which complicated analysis of these publications. The most difficult part in preparing the data pertaining to the industrial participation was to identify which organizations were in fact companies. In brief, the following complementary approaches were used.

First, all organizations with an address outside of the European nations of interest (the EU-15) or the United States were eliminated from the analysis. From the remaining organizations, those with an identifying abbreviation commonly used by private firms, such as Inc., Ltd., GmbH, Corp., BV, etc., were extracted. The names of these organizations without such abbreviations were then searched in the address field to capture all organizations associated with known firms. For example, Philips BV led to Philips Components, Philips Medical Systems, etc.

Of the remaining organizations, all obvious institutions of non-industrial nature were extracted to a separate list. Again, this was accomplished primarily by searching for common designations of public sector institutions (Univ., Akad, etc. for universities; Hospital or Hôpital for hospitals, and so on). Searches were conducted via the Internet and a database of corporate information from Hoover's Information Service to identify which of the remaining organizations were also private firms.

Of those organizations which could be conclusively identified as private firms, a single name was chosen for each firm. Any subsidiaries were renamed to correspond to their parent corporation. For example, Thomas J. Watson Laboratories was identified as IBM Corporation. Once a consolidated list of private firms was established, there were still thousands of organizations that were identified as private. To reduce the size of the target group for this analysis, any company with fewer than four publications in the database covering the ten-year period was excluded from the final sample set. This narrowed the sample set to a more manageable number. For example, the list of US firms was reduced from over 1,800 to 409.

Once the list of firms was created, a search of the database was constructed to extract only those publications where one of the firms was represented by a co-author. This, in turn, helped to reduce the number of publications in the dataset from nearly 136,000 to approximately 30,000. Following the definitions given in Chapter 1, each of these publications was then identified as a separate instance of transatlantic public–private research collaboration.

For the resulting set of publications, each publication was classified by major scientific field by matching the journal in which the publication appeared with the field classifications used by the US National Science Foundation (NSF, 1997) (see Table 1.1). To streamline this task, we applied a further filter to eliminate any journals where fewer than five publications from the data set appeared over the ten-year timeframe. Again, as the objective of this research is to identify dominant patterns and trends in transatlantic research collaboration, eliminating these publications is justified on the grounds that the journals eliminated from classification are not likely to be major outlets for publication of significant US–European joint research.

We grouped this final sample from the dataset into the eight groups identifying the different configurations of collaboration between EU and US public and private sector organizations, as show in Figure Six. A large set of publications which involve only EU and US public institutions, but no private sector organizations, was eliminated from the analysis, as the focus of this research is on collaborations with private sector involvement.

This study identifies transatlantic, public–private research collaborations based on the production of a co-authored scientific publication which is presumed to result from a collaboration between organizations. The research approach is intended to show relationships between collaboration patterns of firms and firm and industry characteristics.

*Table 4.6* Categorization of journal subjects by field

| Broad field | Fine fields | | |
|---|---|---|---|
| Clinical medicine | Addictive diseases<br>Allergy<br>Anesthesiology<br>Arthritis & rheumatism<br>Cancer<br>Cardiovascular system<br>Dentistry<br>Dermatology & venereal disease<br>Endocrinology<br>Environmental & occupational health<br>Fertility | Gastroenterology<br>General & internal medicine<br>Geriatrics<br>Hematology<br>Immunology<br>Miscellaneous clinical<br>Nephrology<br>Neurology & neurosurgery<br>Obstetrics & gynecology<br>Ophthalmology<br>Orthopedics<br>Otorhinolaryngology | Pathology<br>Pediatrics<br>Pharmacology<br>Pharmacy<br>Psychiatry<br>Radiology & nuclear medicine<br>Respiratory system<br>Surgery<br>Tropical medicine<br>Urology<br>Veterinary medicine |
| Biomedical Research | Anatomy & morphology<br>Biochemistry & molecular biology<br>Biomedical engineering<br>Biophysics<br>Cell biology, cytology & histology | Embryology<br>Genetics & heredity<br>General biomedical research<br>Microbiology<br>Microscopy | Miscellaneous biomedical research<br>Nutrition & dietetics<br>Parasitology<br>Physiology<br>Virology |
| Biology | Agriculture & food science<br>Botany<br>Dairy & animal science<br>Ecology | Entomology<br>General biology<br>General zoology | Marine and hydro-biology<br>Miscellaneous biology<br>Miscellaneous zoology |
| Chemistry | Analytical chemistry<br>Applied chemistry<br>General chemistry | Inorganic & nuclear chemistry<br>Organic chemistry | Physical chemistry<br>Polymers |
| Physics | Acoustics<br>Applied physics<br>Chemical physics | Fluids & plasmas<br>General physics<br>Miscellaneous physics | Nuclear & particle physics<br>Optics<br>Solid state physics |
| Earth and Space sciences | Astronomy & astrophysics<br>Earth & planetary science | Environmental science<br>Geology | Meteorology & atmospheric science<br>Oceanography & limnology |
| Engineering and Technology | Aerospace technology<br>Chemical engineering<br>Civil engineering<br>Computers<br>Electrical & electronics engineering | General engineering<br>Industrial engineering<br>Materials science<br>Mechanical engineering<br>Metals & metallurgy | Miscellaneous engineering & technology<br>Nuclear technology<br>Operations research & management |
| Mathematics | Applied mathematics<br>General mathematics | Miscellaneous mathematics | Probability & statistics |

The dependent variable in this book is the collaborative behavior of the firms, measured using Ward's cluster analysis to show variations in the size and diversity of collaborations across all firms in the book.

The independent variables used in the analysis are as follows.

*Industry and diversification.* Each firm was assigned one or more industries, represented by their three-digit SIC code, based on their listings in the Hoover's Business Information database and other sources. A diversification index score was then created for each firm, which simply counted the number of industries in which the firm operates. Each firm was also identified as being assembly-focused or science-focused based on the nature of its primary SIC code. Furthermore, each industry was identified as more science-based or more engineering-based, using the index developed by Grupp and his associates.

*Disciplinary scope.* Each article was assigned two field headings: a major field at a very general level (for example, clinical medicine or biology) and a subfield which gives a more specific description of the field of research (for example, immunology or optical physics). The field categories used were those adopted by the National Science Foundation and shown in the previous table. The disciplinary scope of a firm's research collaborations is measured by the number of minor fields in which the firm had collaborations in a given time period, divided by the total number of minor fields associated with the related major field.

*Nationality.* Each firm was assigned a national origin (flag), corresponding to the country where the firm's headquarters was located.

*National specialization.* Each nation in the dataset was assigned a scientific specialization. This was identified using the analysis of relative publication intensity for nations in the *National Science Foundation's Science and Engineering Indicators 1998* edition.

Using the data from the SCI database, this method constructs a profile of each research collaboration, represented by a single joint scientific publication. The data associated with each collaboration include:

- The scientific field of the collaboration, based on the journal where the publication appeared;
- Identities of the co-authors' home institutions;
- Whether each co-author's home institution is a public sector or private sector entity;
- Whether each co-author's home institution is a US or EU organization;
- Whether each co-author is located at a US or EU facility.

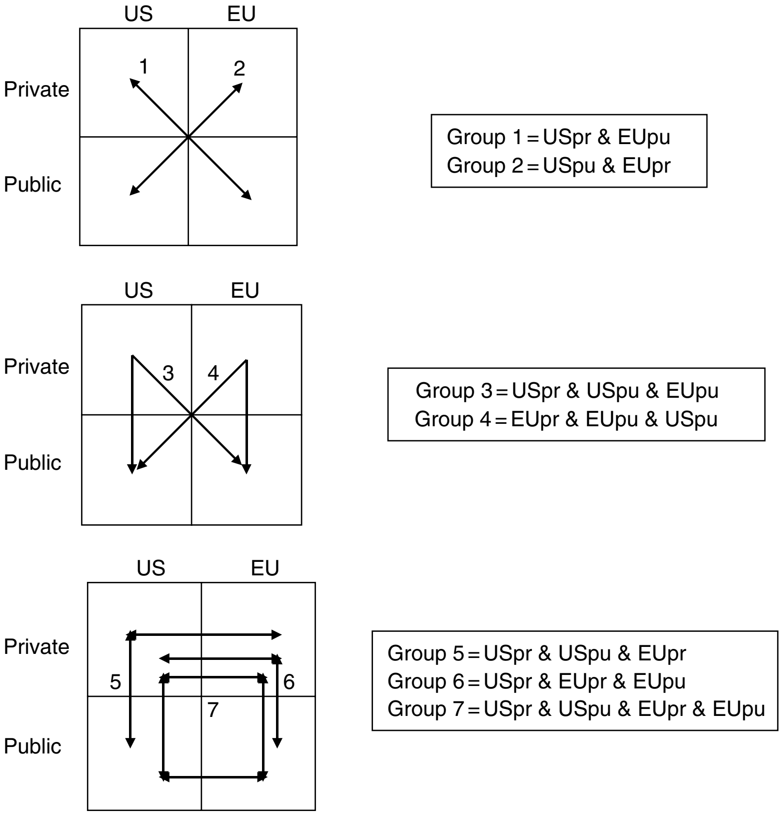

*Figure 4.1* Configurations of EU–US research collaboration by type of institution

For non-private sector organizations, the national knowledge specialization of that organization's home nation is used.

The dependent variables include:

- An indicator of diversification, calculated by taking the number of industries in which the firm competes (as classified by Hoover's Information Service) and normalizing that to the total assets of the firm (to control for size effects which may contribute to greater diversification);
- Patent diversification, measured by the number of the major International Patent Classification codes represented in the patents awarded to the firm in a particular time period, divided by the total number of patents issued to the firm;

- The “science-based” indicator from Grupp *et al.* (1992) for the main industry listed for the firm;
- Technological scope of the firm’s portfolio of patent applications, by year;
- Firm financial performance, measured by ROA, by year.

Following a methodology used by Bierly and Chakrabarti (1996), the ten-year period covered by the dataset is divided into three overlapping periods of four years each, as follows:

Period 1: 1988 to 1991
Period 2: 1991 to 1994
Period 3: 1994 to 1997

This set of three periods provides a means of making a longitudinal measure of each firm’s collaborative behavior, but providing a more stable timeframe for collaborative behavior to moderate the spurious effects of year-to-year changes in firm status on participation in collaborations. This mode of timeframe analysis is also helpful when analyzing patent data. Patents in the United States and elsewhere tend to issue at least two years after the filing of the patent application. Booking the relationship between collaboration in a particular period and patenting in the following period provides a better means of analyzing innovative performance

For Hypothesis 1 and its sub-hypotheses, firms were ranked by the indicator of the “science-based” nature of their industry from Grupp (1992). These firms were also classified by the number of collaborations in which they participated during each timeframe, and the number of partners in those collaborations over the same timeframe. Using an analysis of variance algorithm, a t-test was conducted to see if the average number of collaborations and the average number of partners per firm differs significantly by industry. If so, a further analysis was conducted to see if there is any relationship between the level at which the industry is science-based and the number of collaborations and number of partners.

For hypothesis 2 and its sub-hypotheses, firms were divided into multiple groups by degree of diversification. In a process similar to the test for Hypothesis 1, the firms were analyzed to see if the number of collaboration configurations for each firm differs significantly by firm. A further test investigated if the variation in the number of collaboration configurations is related to any significant degree to the level of diversification for each firm.

For hypothesis 3, firms were divided by the identities of the nationalities of their public sector research partners. The firms were analyzed to see if the fields in which they engage in transatlantic public–private research collaborations is related to the knowledge specialization of (in the case of US firms) the European Union or (in the case of European firms) the United States, based on the data from the National Science Foundation.

Hypothesis 4 was tested through the use of cluster analysis. In each of the four time periods, firms were clustered in two ways. The first clustering technique will be based on the number of patents issued to each firm in the following time period, and the number of primary IPC code fields for those patents. This will produce four groups of firms: those with high patent productivity and diversity; those with low patent productivity and diversity; those with high patent productivity and low patent diversity; and those with low patent productivity and high patent diversity. A series of t-tests were used to see if the number of collaboration configurations used by firms in each cluster differs significantly between the clusters.

In the second clustering analysis, firms were grouped by their average return on assets during each time period and the level of variance in return on assets, measured by standard deviation. Firms were clustered as high performing with high variance; low performing with low variance; high performing with low variance, and low performing with low variance. Again, a series of t-tests were used to see if the use of multiple collaboration configurations differs among each of these four clusters.

The book is longitudinal, in that it associates participation in transatlantic public–private research collaborations with the independent variables measuring outcomes over a set of overlapping time periods.

## VI Results of analysis

This section presents the results of the hypothesis tests outlined earlier in this chapter. The first section provides a descriptive overview of the data analyzed for this book. The second section presents the variables used in the analysis, the justification for the construction of those variables, and the expected reliability of the variables. The third section provides an explanation of the correlation and regression analyses conducted as the test for each hypothesis. The final section summarizes the results of the hypothesis testing and the key points of this chapter.

## A Descriptive analysis

This section presents general demographic information on the nature of the firms included in the sample for this analysis.

The level of analysis adopted for this project is the individual firm. The objective of the project is to explore the relationship between transatlantic, public–private research collaborations, and various aspects of firm performance, strategy, and structure. Therefore, this project analyzes how the features of a firm are related to its collaborative behavior.

The methodology for creating the data set used for this book is described above. The dataset itself consists of three major components:

- A list of all US and EU firms found in the ISI database and meeting the criteria described above.
- A resulting database of papers representing transatlantic, public–private research collaborations where at least one of the above firms was a participant.
- A further list of non-firm participants in the papers listed in the above database.

The listing of firms was then transferred from Microsoft Access™ (the original format of the ISI database) into a Microsoft Excel™ spreadsheet. The information corresponding to the variables of interest for each firm, based on the research design, was then fed into the spreadsheet. For each firm, this information included:

- Total sales, from the annual reports for each year or from the Hoover's Corporate Information database.
- Major industry for the firm, according to Hoover's.
- Other industries in which the firm is classified as a member, according to Extel.
- Degree to which the major industry is "science-based" using the index created by Grupp (see p. 90).
- Nationality of the firm, based on the location of the corporate parent of all affiliates, taken from the Directory of Corporate Affiliations published by Gale Research and Hoover's Corporate Information, supplemented by searches of the World Wide Web for references to defunct firms.
- R&D spending per year, taken from corporate financial regulatory filings for each year.
- US Patents awarded per year, taken from the US Patent and Trademark Office Web site and an analysis by CHI Research.

- Return on assets per year, calculated from corporate financial regulatory filings.

To limit the analysis to articles published in major journals, the database from ISI was analyzed, and only those journals which included at least ten articles over the ten-year time period were selected. Note that the database includes all EU–US articles, including those involving purely public–public collaborations. Therefore, this selection process is a reasonable step to limit the set of articles to only those published in significant journals. This process reduced the number of journals from 5,113 to 2,097.

To compile the list of firms used in this book, the names of all organizations located in the United States and the European Union were extracted from the ISI database. To ensure a comprehensive listing of firms, all organizations were associated with their city. This step was necessary in order to group organization names more accurately. For example, in one case the name IBM Corporation appeared in the "organization" field, but in other cases that name appeared in other address fields. Grouping the organization names by city helped to ensure first that all organization names associated with one firm in one city were grouped together, and also to ensure that two organizations with similar names but located in different nations were not lumped together. For example, there were numerous organizations labeled "Dept Math" (for Department of Mathematics), but organizing the list by city revealed that this organization name covered several mathematics departments spread across several universities.

Each organization name and city pair was assigned a unique identifying number. The organization list was divided into those organizations located in the European Union and those located in the United States. Then, a process of elimination was used to delete any non-firm organizations from each list. For example, a global search for any records with the string "univ" in the organization name or address identified all universities in the list, and these universities were then deleted. Through a combination of eliminating known non-firm organizations, and ensuring that organizations associated firms were retained, a comprehensive list of firm-type organizations was created.

Through a manual review, the "organization" name for each record of a firm was standardized. For example, organizations listed as "Three M" and "3 M" were labeled as "3M." This helped to eliminate redundancies in the naming of the firms in the database. As one example, the company Novo Nordisk appeared over 150 times in the listing of organization-city pairs.

Consolidating all organization names into unique firm names yielded a list of approximately 1,800 firms. To eliminate those firms which were not active collaborators during this time period, any firm which had fewer than ten articles attributed to it during the ten-year book period was deleted from the list.

The final list consisted of 261 firms. For firms listed with locations in both the United States and the EU, those firms were again consolidated, and identified by a new variable (FLAG) which denoted whether their parent company was based in the US or the EU (according to Gale's Directory of Corporate Affiliations and other sources). Of these, 102 were identified as EU firms, and 159 were US firms. As one side note, the original list of over 1,800 firms (even those with fewer than ten publications) included approximately 760 firms located in the US (although this number includes some duplications). Therefore, of the original list, approximately 40 percent of firms were located in the US, while among those which were active participants in collaborations, approximately 60 percent are identified as US firms. This indicates that a larger number of EU firms engage in these types of collaborations compared to the number of US firms; however, many of the EU firms are not active, consistent participants in transatlantic research partnerships.

The 261 firms identified on this list were co-authors on a total of 14,029 articles during this time period. The average number of articles co-authored by each firm was approximately sixty, while the median number was twenty-three. Again, note that this sample consists of only those firms with at least ten articles in the time period sampled. This suggests that the firm participation is somewhat "top-heavy" – a small set of firms that publish a large numbers of articles tend to dominate over the large set of firms that publish fewer articles. The standard deviation in articles was 126.8, again indicating the wide disparity between the most active firm participants in transatlantic collaborations and the least active.

This suggestion is borne out in the analysis of the article distribution. Two firms – IBM and AT&T Bell Labs – were co-authors on 1,259 and 1,258 articles, respectively, in this sample. The next most active firm participant, Merck, was a co-author in 504 articles. Forty-two of the firms in the sample published one hundred or more articles.

Looking at chronological trends in these collaborations, the set of papers analyzed shows that collaborations grew through the early part of the book period, approximately 1988 to 1995, and then stabilized and declined slightly in 1996 and 1997. This is shown in the following histogram.

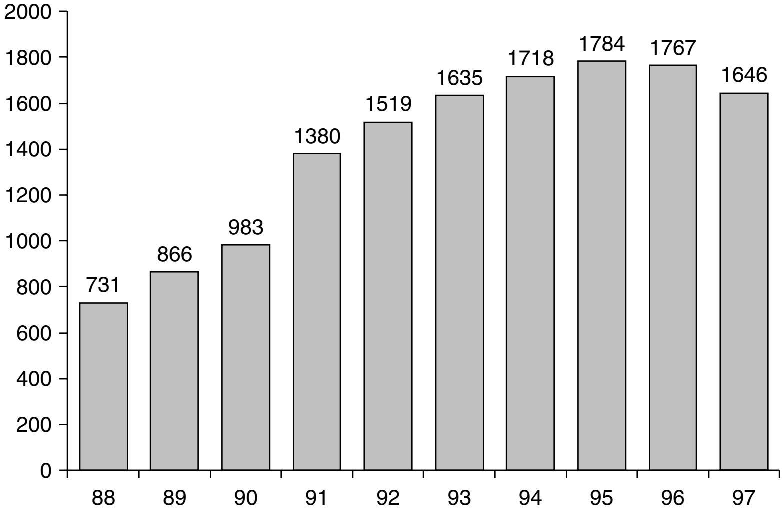

*Figure 4.2* Trend in number of transatlantic public–private research collaborations, 1988 to 1997

*Table 4.7* Distribution of articles surveyed by collaborative configuration

| Group | Number of articles |
|---|---|
| 1 | 5596 |
| 2 | 1727 |
| 3 | 3682 |
| 4 | 1718 |
| 5 | 373 |
| 6 | 633 |
| 7 | 300 |

The articles were then broken down into the seven configurations of transatlantic, public–private research collaborations identified in. A categorization of the articles into the seven mutually exclusive groups is shown above.

Put another way, of the 14,029 articles, the largest share (approximately 40 percent) is composed of those in Group 1 (US private entities working with EU public organizations). The second largest share (approximately 26 percent) consists of articles in Group 3 (US private entities and public institutions working with EU public organizations). The smallest group, predictably, is Group 7 (approximately 2 percent) – those involving all four types of participants. By way of comparison, articles identified as purely firm–firm collaborations numbered 1,140. If included, it would have been the fifth-largest group of articles in this book. Since this book focuses only on public–private collaborations, this group was excluded from further analysis.

Again adopting a chronological view of this data, while all categories of collaboration saw some increase over this time period, certain categories grew more significantly than others. In absolute terms, group 7 collaborations grew most significantly, from 8 in 1988 to 53 in 1997. Group 5 also increased significantly, from 13 in 1988 to 59 in 1997. In relative terms, groups 5, 6, and 7 increased in prevalence to a much greater degree than any other group. Only group 1 collaborations (US firms and EU public organizations) decreased as a percentage of all collaborations between the year 1988 and 1997, although groups 2 and 4 remained relatively constant.

## B Explanation of variables and correlation analysis

The four groups of hypotheses tested for this book each involve a different set of independent variables. The general definitions of these variables are explained in the section. This section describes in more detail how the variables were derived, and provides an analysis of their face validity.

*Table 4.8* Variables related to Hypothesis 1

| | |
|---|---|
| Hypothesis 1: | Firms utilizing science-based knowledge will participate in transnational, public–private research collaborations differently from those which do not utilize science-based knowledge. |
| Hypothesis 1A: | Firms in science-based industries will participate in transnational, public–private research collaborations more frequently than firms in less science-based industries. |
| Hypothesis 1B: | Firms in industries which are more science-based will participate in transnational, public–private research collaborations with a larger number of total partners than firms in industries which are less science-based. |

Hypothesis 1 relates to the concept that certain industries are dependent upon technologies which are more “science-based” than others. As stated earlier in this book, the methodology developed to determine which technologies are more “science-based” than others was first proposed by Narin and Noma (1985) and operationalized by Grupp and his research team based on European Patent Office data. The basis of measurement is a calculation of the degree to which patents in a particular field of technology cite academic research literature. For this dataset, the scientific factors calculated by Grupp *et al.* for each technology are used as the proxy to determine the “science-relatedness” of each industry. For example, biotechnology companies were assigned a science factor of 81, reflecting the calculated relationship to academic literature found in biotechnology patents. Grupp’s research group derived their figures from data provided by the European Patent Office, but its appears reasonable to treat these numbers as roughly comparable to similar figures that could be calculated based on US Patent and Trademark Office data (since many firms file nearly identical patent applications in the US and the EU).

To determine the frequency of participation in transatlantic, private–public research collaborations, the dataset was analyzed to identify how the publications for each firm were distributed across the seven categories of collaboration. The number of publications in each group was then normalized by calculating the percentage of all documents of each group were those in which the firm was a co-author. These numbers were then used to calculate a weighted average, where the average percentage for all seven groups was weighted by the relative prevalence of each group across all articles.

To determine the average number of partners, the articles in which each firm was a co-author were compiled, and a comprehensive list of co-authors was extracted from that list. The home institution of each co-author was identified from the article’s bibliographic information. This list of institutions was consolidated to avoid double-counting, creating a list for each firm of all institutions with which that firm collaborated at least once. Then, based on the nationality (FLAG) of each firm, a list of that firm’s transatlantic partners (both firms and non-firms) was created. This produced a total count of partners (PRTR) for each firm.

A preliminary test of correlation found that there is a strong positive relationship between the number of articles in which a firm is a co-author and its number of partners. In other words, while some firms repeatedly co-author articles with a few institutions, there is a strong tendency for those firms which co-author large numbers of articles to do so with a larger number of partner institutions. Therefore, the variable PRTR was normalized by expressing the variable as the ratio of partner

*Table 4.9* Variables related to Hypothesis 2

| | |
|---|---|
| Hypothesis 2: | Diversified firms will utilize transnational, public–private research collaborations differently from less-diversified firms. |
| Hypothesis 2A: | Diversified firms will have a more diverse set of configurations of transnational, public–private research collaborations than less-diversified firms. |
| Hypothesis 2B: | Diversified firms will engage in transnational, public–private research collaborations across a broader range of scientific disciplines than less-diversified firms. |

institutions to the total number of articles associated with each firm. Therefore, a firm which partnered with ten institutions among ten articles received a score of "1," while a firm which partnered with ten institutions among fifty articles received a score of "0.2."

For each firm, a diversification factor was calculated based on the number of three-digit SIC codes associated with each firm, as listed the corporate profiles compiled by the database firm Extel (which lists major publicly held and privately held firms located in both the US and Europe). While there is a strong bias that larger firms tend to be more diversified, this bias is not relevant to this set of hypotheses, which relates the absolute degree of product diversification to participation in transatlantic, public–private collaborations. Therefore, the diversification variable (DIVR) was not normalized to firm size.

The diversity of collaborations was derived by first calculating the percentage distribution of all of a firm's articles across the seven configurations of collaborations. If a firm did not have any collaborations of a certain configuration, it was assigned a score of zero for that category. This produced a percentage figure for each firm for each of the seven categories of collaborations. The diversity of collaborations utilized by each firm was derived by calculating the population variance (VARP) across the seven categories for each firm. As a result, those firms whose articles were more equally distributed across all seven categories (i.e. the proportion of articles in each category was close to $\frac{1}{7}$ or 14.3 percent) had a low variance, while those firms whose articles were concentrated in only one or two categories of collaboration had a high variance. Since this variable measures degree of diversity from highest diversity to lowest, the actual value of the variable was calculated as the inverse of VARP or $\frac{1}{\text{VARP}}$.

Due to the structure of the VARP formula, it was possible that a firm which participated in a relatively small range of collaborative configurations could reflect a low degree of variance. To adjust for this, the value for $\frac{1}{\text{VARP}}$ was multiplied by a factor reflecting the number of different collaborative configurations for that firm, divided by the number of potential configurations. A firm which had at least one collaboration of each category had its value for $\frac{1}{\text{VARP}}$ multiplied by 1 ($\frac{7}{7}$), while one with six configurations had its score multiplied by $\frac{6}{7}$, and so on. Thus, the firm with the greatest degree of diversification (Behringwerke) had a DIVC value of 268.4, while those with the lowest degree of diversity in collaborations (all articles were in a single category of collaboration) had a DIVC value of 8.17.

For diversity in the number of scientific disciplines for each article, first the discipline (FIELD) of each article in the dataset was determined. This process involved compiling a list of all journals in which at least one article from the database was published, and using the ISI Master List of journals to find the exact title for each journal. The ISI Science Citation Index and Enhanced Science Citation Index were used to categorize each journal in one field, based on the classifications used by ISI.

The ISI table of disciplines assigns journals to a set of approximately 115 scientific fields. Examples of fields identified within the ISI database include "acoustics," "horticulture," "applied mathematics," and "polymer science." In the ISI classification, journals can be assigned to more than one discipline (for example, the *Journal of Biomedical Optics* is classified under "biochemical research methods," "optics," and "radiology, nuclear medicine and medical imaging."

To simplify the classification of journals across scientific fields, and to ensure that the field classification used matched the classification scheme required for Hypothesis 3, each journal's discipline was reclassified according to the categorization developed by CHI Research and found in US National Science Foundation (2000). This scheme associates each discipline in the ISI classification list to one of thirteen major fields. The distribution of the 1,462 journals across this set of fields is shown below.

*Table 4.10* Count of articles by field

| **Field** | **Article count** |
|---|---|
| Biology | 74 |
| Biomedical research | 286 |
| Chemistry | 156 |
| Clinical medicine | 488 |
| Earth & space sciences | 87 |
| Engineering & technology | 223 |
| Mathematics | 42 |
| Multi-disciplinary | 7 |
| Physics | 89 |
| Psychology | 10 |

The 14,029 articles were distributed across the scientific fields as follows:

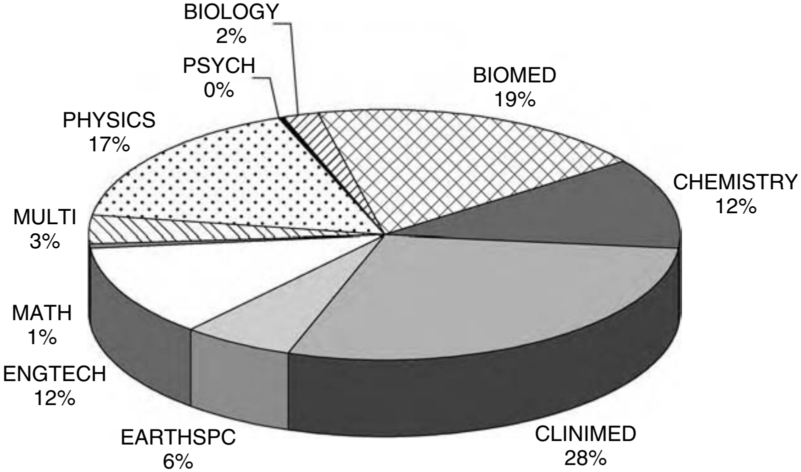

*Figure 4.3* Distribution of articles surveyed by field

To calculate the breadth of fields in which a firm publishes, a methodology was adopted similar to calculating the diversity of collaborative configurations. For each firm, the proportion of articles in the dataset co-authored by that firm was calculated according to scientific field. The variance from the predicted average across the ten fields was then generated, and that value was inverted to order the firms from those with the least variance (with articles approaching equal distribution across all fields) to greatest variance (those with articles concentrated in only one field). Adopting this algorithm still produced high scores for field diversity in firms which published in only one or two fields. To mitigate that tendency, the inverted variance value was multiplied by a factor based on the number of fields in which a firm published, as shown below.

The resulting DIVF scores for the 261 firms in the dataset ranged from a high of 91.1 to a low of 1.11.

The concept of "knowledge specialization" is operationalized through extant research on national-level bibliometric indicators of scientific activity. The ten fields contained in the CHI Research classification of disciplines are identical to those used by the US National Science Foundation to analyze the global scientific competitiveness of nations. For the purpose of this book, the NSF indicator on scientific

*Table 4.11* Variables related to Hypothesis 3

| | |
|---|---|
| Hypothesis 3: | A firm's participation in transnational, public–private research collaborations will be related to the knowledge specialization of the other members' home nations. |
| Hypothesis 3A: | A firm will participate in transnational, public–private research collaborations with partners from nations which specialize in the fields of science most relevant to that firm's needs, regardless of the partners' locations. |
| Hypothesis 3B: | A science-based firm will engage in transnational, public–private research collaborations primarily with partners from nations which specialize in the same scientific field as that firm. |

competitiveness was adopted to denote the "specialization" of individual European nations in particular fields of scientific research.

The NSF's biannual Science and Engineering Indicators report estimates the prominence of various nations in each scientific field using the widely accepted method of citation measurements. In this approach, individual articles which are most commonly cited in other articles in that same field are viewed as those which are particularly prominent, and therefore significant. The NSF methodology calculates international citation rates – i.e. the frequency with which a particular nation's publications are cited within scientific publications originating in other countries.

This methodology first calculates the total number of articles cited in other articles for each field. It then determines the national origin of each of those articles. This is used to calculate each nation's share of all cited literature in a field. This particular calculation removes instances where an article from a particular nation is cited by an article from that same nation, thus eliminating "self-citations" within a particular nation. Each nation's share of internationally cited literature in a particular scientific field is then divided by that nation's share of all articles in that particular field. The resulting index score is taken to indicate the relative prominence of a nation in the research community for each discipline. An index score greater than one indicates that the nation's publications are disproportionately cited more frequently compared to the prevalence of that nation's publications among all scientific articles for that year.

To capture the concept of relevance, each firm's articles were reviewed to identify which two fields accounted for the greatest share of that firm's publications. It is assumed that firms will tend to publish most frequently in those fields which are most relevant to the firm's needs. The hypothesis assumes that firms will choose to partner most frequently with organizations in those countries which are most prominent in those fields of greatest interest. Within each field, a list of firms which publish most often in that field was developed. The list was used to generate a dataset of which organizations co-authored articles with those particular firms in that particular field. Each organization was counted only once, so that if a firm partnered several times in the same year with a particular organization, that partner was counted only once.

From that list, the frequency with which organizations in a particular nation appeared as partners for that particular firm was calculated. For each firm, all articles published by that firm were analyzed to determine the proportion of articles which were co-authored with partners from each nation. That proportion determined how frequently the firm collaborated with organizations from each nation. This value was later used to analyze which nations were the most frequent partners of each firm, and how the scientific specialization of each firm related to frequency of collaboration.

For this set of hypotheses, several types of data were integrated to provide basic measures for testing.

The key independent variable in the first hypothesis is the research productivity of each firm, measured using patents per dollar of R&D

*Table 4.12* Variables related to Hypothesis 4

| | |
|---|---|
| Hypothesis 4: | Firms which participate in a greater diversity of transatlantic public–private R&D collaborative configurations will have a higher R&D productivity and technological diversity, and more stable and superior financial performance than those which participate in a narrower range of such collaborations. |
| Hypothesis 4A: | Firms which participate in a greater diversity of transatlantic public–private R&D collaborative configurations will produce more patents per dollar of R&D spending over the course of the book period than those which participate in a narrower range of such collaborations, and will exhibit greater diversity in the number of fields in which they patent. |
| Hypothesis 4B: | Firms which participate in a greater diversity of transatlantic public–private R&D collaborative configurations will show less variation in financial performance, measured by return on assets, and a higher average level of financial performance, measured by return on assets, over the course of the book period than those which participate in a narrower range of such collaborations. |

spending. This hypothesis required the availability of data on the number of patents awarded each year to a firm, and that firm's same-year R&D spending. As a result, the number of firms in the population used for testing the hypothesis was very limited. A total of 55 firms from the 261 firms in the book were used for this phase of the research.

The concept of using patent statistics to measure innovative activity in firms is well established in the literature on technology and innovation management (Griliches, 1984). Patent analysis has certain limitations as well as strengths. In particular, any analysis of research productivity based on patenting will suffer from certain distortions:

First, firms differ in their strategies for intellectual property protection – for example, some firms may choose to protect IP as trade secrets rather than patents. In such cases, patents will tend to underestimate innovative activity in the firm.

Second, national differences exist in patenting practices and strategies. For example, in the United States, it is common for firms to file patent applications with many claims on a single application, while firms in other countries would tend to distribute the same number of claims across a number of patent applications. Therefore, patenting statistics are not always directly comparable across nations.

Third, patents are not always an indicator of current innovative activity, due to the fact that patent applications can take many months or years before they issue (the pendancy of the patent). While information on patent applications is now available, the US Patent and Trademark Office did not disclose applications until it harmonized its practices with those of other national patent offices in 2000, following the American Inventors Protection Act of 1999. Therefore, the issuance of a patent to a firm may be a reflection of innovative activity at that firm some years before the issue date.

Fourth, patenting behavior is affected by conditions extrinsic to corporate innovative activity. For example, as noted in Kortum and Lerner (1997), there is a belief that increases in patent protection brought about by legal and institutional changes in the US patent system promoted an increase in US patenting starting in 1985. The authors also hypothesize that patenting can increase due to the increase in technological opportunities available for exploitation by firms, and by the increased financial support for innovation from venture capital and other sources. These shifts would tend to skew direct patent counts to overestimate firm innovation.

Despite these limitations, patent data is a valuable and valid proxy for corporate innovation. First, patent data is documented according to specific public procedures, and is fairly reliable in its content. Second, the criteria for patent awards have remained relatively stable through the years, providing a foundation for time-series analysis. Third, Kortum and Lerner's book (1997) suggests that while internal firm innovation is not the only factor affecting patenting rates, it is the most significant factor behind recent increases in patenting.

Patenting is not costless, and filing patents does require some resources for legal expertise and other inputs. Company size will tend to influence patenting rates. To adjust for that distortion, the current book measures R&D productivity as the number of patents per dollar of R&D spending by a firm. Furthermore, to adjust for the effect of patent pendency on patenting rates, the patent counts for each firm were derived from the patent issued to that firm two years after the year of measurement. In other words, the patent data in this book spans the timeframe from 1990 to 1999 in order to reflect innovative activity between 1988 and 1997.

The use of return on assets as a measure of financial performance is well established in the strategic management literature (see, for example, Porter, 1980). Return on assets is preferable to profit margin in this case, as the value of a firm's assets will tend not to fluctuate as widely as revenues. To increase the consistency of the data, ROA was calculated using the figure for each firm's net income excluding extraordinary charges. For the fifty five firms included in the sample for this phase of the book, return on assets was calculated and recorded for the years 1988 to 1997.

The variable for diversity of collaborations (DIVC) is the same as described above.

## C Tests of hypothesis

This section describes the statistical analysis conducted to test the hypotheses outlined in the previous section. The statistical analysis included the means for testing the validity of the measures used, as well as the direct testing of hypotheses using the measures described in the previous section.

Hypothesis 1A was tested using an Analysis of Variances (ANOVA) equation to determine the variance between two populations: firms in science-based industries (those with a measure of SCIFACTOR greater than zero) and firms in non-science-based industries (those with a measure of SCIFACTOR less than zero). The dependent variable used in the test was the number of collaborations in which firms from each industry participated, calculated by taking the total number of collaborations

*Table 4.13* Tests of Hypothesis 1

| | |
|---|---|
| Hypothesis 1 | Firms utilizing science-based knowledge will participate in transnational, public–private research collaborations differently from those which do not utilize science-based knowledge. |
| Hypothesis 1A: | Firms in science-based industries will participate in transnational, public–private research collaborations more frequently than firms in less science-based industries. |
| Hypothesis 1B: | Firms in industries which are more science-based will participate in transnational, public–private research collaborations with a larger number of total partners than firms in industries which are less science-based. |

*Table 4.14* Results of Tests of Hypothesis 1

| **Source of variation** | **SS** | **Df** | **MS** | **F** | ***P*-value** | **F crit** |
|---|---|---|---|---|---|---|
| Between groups | 33.21488 | 1 | 33.21488 | 0.007006 | 0.93433 | 4.493998 |
| Within groups | 75851.02 | 16 | 4740.689 | | | |
| Total | 75884.24 | 17 | | | | |

and dividing by the number of firms within each industry. This produced an average number of collaborations per industry. The variance in collaborations per industry for science-based industries was then compared to the variance for non-science-based industries.

The analysis of variance resulted in an estimation that the two populations (firms in science-based industries and those in non-science-based industries) exhibit statistically significant variance with a *P*-value of 0.93433. This means that the two populations vary significantly at a confidence level of at least 10 percent, but not at 5 percent. Due to the small number of observations, it is not possible to conclude with strong confidence that the two populations vary significantly, and the null hypothesis is supported. Therefore, it does not appear that science-based firms tend to participate in transatlantic, public–private research collaborations more frequently than those in non-science-based industries.

Hypothesis 1B posits that firms in industries which are relatively more science-based will tend to have a greater number of partners than those in industries which are less science-based. This hypothesis follows from the proposition that firms in science-based industries need access to a broader and richer knowledge-base of scientific research and expertise in order to innovate successfully.

*Table 4.15* Tests of Hypothesis 2

| | |
|---|---|
| Hypothesis 2: | Diversified firms will utilize transnational, public–private research collaborations differently from less-diversified firms. |
| Hypothesis 2A: | Diversified firms will have a more diverse set of configurations of transnational, public–private research collaborations than less-diversified firms. |
| Hypothesis 2B: | Diversified firms will engage in transnational, public–private research collaborations across a broader range of scientific disciplines than less-diversified firms. |

A correlation analysis was conducted to determine if there is any correlation with the degree to which an industry is science-based (SCIFACTOR) and number of partners for firms in that industry. The analysis showed a very low level of correlation between SCIFACTOR and the number of partners. Therefore, it does not appear that firms in science-based industries necessarily partner with a greater or fewer number of partners than those in non-science-based firms for transatlantic, public–private partnerships.

Hypothesis 2 concerns the relationship between the degree of industry-level diversification for a firm, based on the number of industries in which that firm competes, and patterns in the forms of transatlantic, public–private research collaborations in which that firm chooses to participate. This hypothesis is derived from the proposition that to gain technical competitiveness in particular industries, firms will need to partner with different types of research partners. Therefore, those firms which are more diversified will tend to have a broader set of partners. Similarly, due to the fact that different industries require firms to excel in unlike sets of technologies, more diversified firms will need to access a much broader range of scientific disciplines than less diversified ones.

The test for hypothesis 2A involved a regression analysis to determine the relationship between industry-level diversification and the diversity of collaborative configurations (DIVC) for the firms in the sample. A preliminary correlation analysis showed that these two variable are not closely correlated. Any relationship identified by the regression analysis will be due to influences other than an inherent correspondence of the two measures.

The regression analysis showed a relatively low degree of relatedness between the level of industry diversification and the variance in configurations of research collaborations chosen by each firm (adjusted R2 of less than 0.10). While firms which are more diversified clearly participate in transatlantic, public–private research collaborations, there is

*Table 4.16* Tests of Hypothesis 3

| | |
|---|---|
| Hypothesis 3: | A firm's participation in transnational, public–private research collaborations will be related to the knowledge specialization of the other members' home nations. |
| Hypothesis 3A: | A firm will participate in transnational, public–private research collaborations with partners from nations which specialize in the fields of science most relevant to that firm's needs, regardless of the partners' locations. |
| Hypothesis 3B: | A science-based firm will engage in transnational, public–private research collaborations primarily with partners from nations which specialize in the same scientific field as that firm. |

no clear pattern by which more diversified firms will engage in collaborations which span a greater range of configurations.

For Hypothesis 2B, a similar regression analysis was conducted to determine the relationship between industry-level diversification and the range of scientific disciplines at the focus of each firm's collaborations. Again, a correlation analysis produced a Pearson value which indicates that the two variables, DIVR and DIVF, are not normally correlated to each other.

The regression shows a significant degree of interrelatedness between DIVR and DIVF. This supports the hypothesis that firms with a higher degree of diversification will use transatlantic, public–private research collaborations to access a diverse knowledge-base of scientific research compared to that which the firm can develop internally.

For Hypothesis 3, the relationship between national competence in certain fields of scientific research (based on a methodology developed and implemented by the consulting firm CHI Research) and the decision by firms to partner with public research organizations from specific nations. Using the measure of national competence contained in the National Science Foundation's Science and Engineering Indicators, a correlation analysis was conducted to determine the existence of any relationship between the scientific fields of greatest interest to each firm, and the nations where each firm's public research partners were located.

Hypothesis 3A examined the relationship between the national location of each firm's partners and the scientific disciplines which are the focus of that firm's industry. The hypothesis was tested by comparing the ranking of the scientific disciplines which were the most common focus of collaborations within each industry with the frequency with which firms in that industry collaborated with organizations in nations which demonstrated particular competence in that industry. A simple test of the frequency at which these two measures were correlated established that there is a fairly low correlation factor between the two. Therefore, Hypothesis 3A is not supported.

Hypothesis 3B concerns the decision by science-based firms to partner with research organizations from nations with specific competence in certain scientific disciplines. In contrast to Hypothesis 3A, this hypothesis determines which scientific disciplines are the focus of each firm's own collaborations, and determines whether that firm tends to partner with organizations in those nations which publish predominantly in those same fields. A direct test of correlation was used to determine if each firm's partners were concentrated in particular nations. The NSF data was then compared to each firm's patterns in choice of research partners to see if the nations published most frequently in the same area as that firm's collaborations. The correlation analysis showed that firms tend to partner with organizations from a few nations, and that those nations are those most closely associated with the firm's own scientific interest, with a high degree of confidence ($P$-value exceeding 0.95). Therefore, Hypothesis 3B is supported.

Hypothesis 4 attempts to investigate any relationship between firm performance, in both innovative capabilities and in financial returns, and participation in transatlantic public–private partnerships. Drawing

*Table 4.17* Tests of Hypothesis 4

| | |
|---|---|
| Hypothesis 4: | Firms which participate in a greater diversity of transatlantic public–private R&D collaborative configurations will have a higher R&D productivity and technological diversity, and more stable and superior financial performance than those which participate in a narrower range of such collaborations. |
| Hypothesis 4A: | Firms which participate in a greater diversity of transatlantic public–private R&D collaborative configurations will produce more patents per dollar of R&D spending over the course of the book period than those which participate in a narrower range of such collaborations, and will exhibit greater diversity in the number of fields in which they patent. |
| Hypothesis 4B: | Firms which participate in a greater diversity of transatlantic public–private R&D collaborative configurations will show less variation in financial performance, measured by return on assets, and a higher average level of financial performance, measured by return on assets, over the course of the book period than those which participate in a narrower range of such collaborations. |

from existing literature on organizational learning, and particularly strategic technological learning, Hypothesis 4 focuses on the proposition that exposure to a more diverse array of partnership and partners will tend to promote greater organizational learning, which in turn will lead firms to be more innovative and to be able to adjust better to market conditions.

For Hypothesis 4A and 4B, the data for this sample of firms were first divided into three overlapping time periods: 1988 to 1991, 1991 to 1994, and 1994 to 1997. The firms in the sample were then clustered for each time period to separate those which had high innovative performance (based on patents per unit of R&D spending) and financial performance (based on return on assets) from those demonstrating lower levels for both measures in each time period. Thus, for each time period, the firms in the sample were divided into four quadrants:

*Table 4.18* Configuration of financial versus innovative performance

| | | **Innovative performance** | |
|---|---|---|---|
| | | Low | High |
| **Financial performance** | Low | I | II |
| | High | III | IV |

Using an analysis of variance methodology, the diversity in collaborations (DIVC) for each set of firms was compared to the measurements for innovation performance and financial performance.

There is no clear relationship between diversity in collaboration configurations and financial performance (Hypothesis 4B). The classification of firms by time period within each quadrant does not show any correlation with the diversity in the types of collaborations pursued by those firms. The very low adjusted *R2* produced by this analysis indicates that other factors are predominantly responsible for the clustering of firms by financial performance measures.

The analysis of variance seems to show that there is some indication of a relationship between DIVC and patent productivity (Hypothesis 4A). Over the three time periods studied, those firms which show higher innovation performance (as measured by patent productivity) also showed a tendency towards greater diversity in the configurations of their transatlantic research collaborations. While this correlation does not provide any indication that there is a causal linkage between diversity in collaborations and the innovation performance of a firm, the existence of some correlation is notable.

This section discusses the results of the research detailed in the previous chapter, but in the context of both the implications of the results for the theoretical literature on public–private research collaborations and firm technology strategy. It first covers any potential implications of the book regarding the validity of various theories on the nature of research collaborations and the globalization of research, based on the empirical results of the hypothesis-testing. It then discusses how the nature of the book and the book design may limit the scope of any implications of the research for the development of further theory in these areas. Based on the findings and their limitations, the section offers some suggestions about the lessons that the book offers for firm management and government policy. Finally, it recommends areas for future research to continue refining knowledge in the areas addressed by this book.

## D Implications of the results for theory on research collaborations

Current theory on the nature of research collaborations suggests that collaboration is becoming the dominant mode of global industrial research. Assuming that this is the case, the book provides some possible implications for greater understanding about the nature of public–-private research collaboration in the context of transatlantic national and corporate relationships. In particular, this book provides certain insights regarding how firms arrange their portfolio of collaborations, and suggests possible connections between various aspects of firm research strategy and performance, and participation in transatlantic public–private partnerships.

The first set of hypotheses addresses industry differences in the approach of firms to transatlantic, public–private research collaborations. These hypotheses focus on the effect of the nature of an industry's knowledgebase for technology development.

Assuming that this model is a relatively accurate representation of the interaction between the firm and its industry environment for innovation, firms in science-based industries will rely more heavily on the scientific research knowledge-base for innovative ideas. This would imply that science-based firms would need to participate more frequently in partnerships with non-firm research institutions. In particular, due to the globalization of industries, firms in science-based industries will participate more frequently in transatlantic public–private research collaborations.

Consistent with the hypothesized conclusion, this book suggests that there is a some significant difference in the degree of participation in these collaborations between firms in science-based industries and those in non-science-based industries. Even removing the influence of the two most significant outliers in the data set, AT&T Bell Labs and IBM, the same conclusion is reached. However, the degree of correlation between the degree to which an industry is "science-based" and its participation in collaborations is not as strong as expected. This indicates that non-science-based industries also feature extensive participation in these collaborations. Transatlantic public–private research collaborations can be assumed to be an important form of research organization for firms regardless of whether the firm's industry is found to be more or less reliant on academic research for technological innovation.

The finding that there is no significant difference in the number of partners for firms regardless of industry also illustrates that firms design their portfolio of partners and collaborations based on reasons other than industry-level tendencies in the importance of academic research to innovation.

For Hypothesis 1, it appears that firms even in non-science-based industries need to view transatlantic public–private research collaborations as a useful tool in innovation management. Other firms in such industries use collaborations extensively, even if not quite as extensive as in science-based industries. Also, many firms in non-science-based industries have very large assortments of research partners in their collaborations.

In Hypothesis 2, the relationship between firm diversification and research collaboration is explored. The level of diversification appears to have much less of a relationship to the use of a broad set of partners in a broad range of collaborative configurations than predicted by theoretical literature. However, for those firms which need to access a broader knowledgebase of scientific expertise, transatlantic public–private research collaborations clearly support that need. Firms which are more diversified are less able to capture a sufficient range of scientific knowledge through a few partners in a few research configurations.

In Hypothesis 3, the literature on national technological competitiveness and collaborations suggests that firms would tend to partner with organizations in those nations which have a particular focus on specific scientific disciplines This assertion is not strongly supported by this book's results. One potential explanation for this is that firms may select partners for reasons very different from the overall national-level degree of technological competitiveness. As explained in other research works, firms may choose both public and private partners based on the presence of “star scientists” at those organizations. Also, it could be that the organizations are selected because they specialize in scientific areas which are much more narrowly focused than broad scientific categories. For example, companies in the computer software industry participate in collaborations related to mathematics. While certain countries may have a national-level strength in mathematics research, software firms may find that individual institutions in other countries have competence in much narrower fields, such as encryption algorithms.

For Hypothesis 4, the lack of strong findings does not indicate that there is no relationship between research productivity or financial performance and collaborative activity. There are many potential confounding factors which would interfere with such a relationship, including other development internal to the management of the firm or external market conditions. However, it does appear that there is some correlation between higher research productivity and more active participation in transatlantic, public–private research partnerships. However, it is impossible based on the current research to determine the direction of that relationship. Therefore, it could be that more productive and innovative firms naturally are more inclined to engage in these collaborations.

# 5

# Glocalized Knowledge Structures through Transnational Public–Private Research and Technology Development Partnerships: Conclusions and Recommendations for Policies and Practices

The conclusions of this book should be noted as being rather tentative due to several inherent limitations in the design and conduct of the research. These limitations are noted below, and provide potential suggestions for ways to refine and expand the research into the future.

One clear limitation of the results of this book is the very rarefied nature of the sample constructed for the book. The sample only focuses on those instances of research collaboration which produce peer-reviewed academic publications. Therefore, it provides insight mostly into a subset of actual transatlantic research collaborations. Also, the sample is drawn from the ISI database, which was found to have numerous flaws in the data fields and in the content of the records produced. Therefore, limitations in the ISI system for capturing bibliometric data could contribute to misleading findings in this research.

A major limitation, which is noted as a topic for further research, is that the sample excludes consideration of the role of collaboration participants outside of the US or the EU. Even within the sample, many collaborations involved organizations from other countries: Japan, Israel, Switzerland, Russia, Taiwan, etc. The role of these other participants in the pattern of transatlantic research collaboration has yet to be explored.

Another key limitation to this research design is that it looks only at outcomes of research collaborations, not processes as some other studies have attempted to do. Focusing on interactions at the organizational level masks internal organizational decision-making which may have a significant influence over the design and management of research collaborations.

Also, the measurements used in this book suffer from several drawbacks. While these limitations may be unavoidable due to the nature of the research topic and the lack of availability of comprehensive quantitative information, the limitations do introduce the risk of skewed research results.

The measurement of research collaborations as scientific publications is itself somewhat suspect. A single instance of collaboration, for example, can result in a stream of publications. Defining each publication as a discrete collaborative act tends to overstate the extent of collaborations.

One of the major measures used in the book is the concept of "science-based industries" derived from Pavitt (1991). This construct is derived from data about patent citations, which in and of themselves are not completely reliable. As noted in Tijssen (2001), citations are often added to patents by the patent examiners, or at least as a result of suggestions by the examiner. Therefore, the citations may reflect a linkage to academic knowledge which did not, in fact, exist in the mind of the researcher(s) who invented that technology. Also, while intellectually useful, the idea that certain technologies are more "science-based" than others is open to criticism. Certain aspects of industries identified as not being "science-based" are increasingly focused on academic research. In computers, for example, key technical activities such as software development, systems integration and hardware assembly are now informed by academic research. Labeling some of these industries as being less "science-based" distorts the true nature of such industries by painting them with too broad of a brush.

The measures derived from the bibliometric data, such as diversity in collaboration configurations or the scientific disciplines, can also be attacked as somewhat misleading. While the measurement of "diversity" is an established concept, it is not completely clear that the construct of "diversity" or variance in this book accurately reflects the true range of collaborative activities undertaken by companies in the sample.

As noted in Chapter 2, any measures based on patent data (as those used in Hypothesis 4) are subject to the problems inherent in the system for patent applications and approval. These defects introduce potential confounding elements into any research results. Also, the relationship between patenting and/or return on assets and any single factor (such as research collaborations) can be spurious, due to the enormous range of other factors influencing those two measures of firm performance.

A notable limitation of the book is the nature of the quantitative data analysis techniques applied in this research. While this method is very useful for booking general trends across the large number of collaborations, it focuses attention on particular aspects of a phenomenon and not necessarily on understanding the phenomenon as a comprehensive whole. This book has helped to identify which factors do or do not contribute to the approach that firms take to transatlantic, public–private research collaborations. It has not helped to understand the motivations behind that approach, and why some issues are more significant than others in the formation and conduct of such collaboration.

A second limitation of the technique used in this book is that it examines each issue raised in the literature in isolation. It cannot address the potential influence that interactions among those issues may have on the phenomenon under book. Past studies of research collaborations show that they can be rather complex processes, and that even serendipity may play a major role in how they evolve.

A third limitation is that most of the statistical techniques used in this book measure degrees of correlation or variance among the variables considered. It is very possible that such correlation (or lack thereof) may be spurious and due to confounding factors extrinsic to the book. Therefore, while our research shows that certain assumptions or propositions about these research collaborations may be less powerful than suggested by the literature, it cannot definitively eliminate these issues as ones which influence the phenomenon under study.

## I Research directions and future research

The limitations noted above provide useful guidance to map out opportunities for future research on this and related phenomena in research collaborations.

First, it would be very instructive to complement the statistical and quantitative analysis in this book with a more qualitative research approach, such as the development of case histories on specific firms and/or collaborations. Case histories are helpful in capturing the complexities and interactions among multiple forces affecting a particular phenomenon. Case histories of particular segments of the sample studied here would help to address the problem of identify the motivations and the directionality of the forces which influence transatlantic public–private partnerships.

Second, a series of case histories could contribute to an attempt at further theory-building on these collaborations using the grounded theory approach. Grounded theory is an inductive process for theory-building which would complement the more deductive, reductionist approach adopted for this book.

Third, the research themes explored in this book could be expanded to include issues such as the role of organizations outside the EU and the US on transatlantic public–private research collaborations. In particular, the research in this book could be replicated but expanded to address issues involved in "triad" relations between the US, EU and Asia as cited by Aoki (1988) and others. Since the globalization of research extends beyond the borders of the US and Western Europe, patterns in transborder collaborations in other regions of the world could add to the global knowledgebase about the nature of international, public–private research collaborations.

## II Lessons learned and recommendations for policy and practice in public–private partnerships for research and technological development (PPPRTDs)

The proliferation of public–private partnerships for research and technology development is a concern for three major sets of stakeholders:

(i) Government agencies, which promote PPPRTDs through funding mechanisms and which contribute the expertise and facilities of public research institutes to such partnerships;
(ii) Academic researchers, who are often the key source of expertise motivating the creation of a PPPRTD; and
(iii) Corporate managers, who must decide on when, how, and why PPPRTDs can deliver value to their firms and provide competitive strategic advantage through technological innovation and enhanced intellectual capital.

The first set of findings relates to the implications of the book for the understanding of firm-level management issues related to these transatlantic, public–private research collaborations. The second set of findings relates to the implications of the book for national and regional policies related to these research collaborations.

It should also be noted that the general public is a key stakeholder in this process in many ways. The public often provides the funding, through tax revenue, which is used to support at least some of the costs of the PPPRTD. The academic and government participants in the PPPRTD are often accountable to the public for their activities (at least in the case of public university systems). Also, the general public will eventually receive the expected benefit of the PPPRTDs, if realized, in the form of an increase in the scope and scale of technological innovation, which in turn becomes a "high-performance engine" for the economy by increasing productivity and expanding job opportunities.

This book was written to help these stakeholders understand that PPPRTDs have become a very significant feature of national, transnational, and even global innovation systems, and therefore the effects of PPPRTDs on those systems, as well as the results of those PPPRTDs (both good and bad), must be recognized.

For policy-makers, the book offers a few potential insights into how to treat research collaborations involving private entities from other nations. First, promoting technological competence in specific scientific disciplines plays little role in attracting particular firms' research interests. If a national government wishes to increase foreign investment in domestic research activities, it could be advantageous to focus on developing much more specific and focused technological competences than those indicated by broad disciplinary analyses.

The glocalized nature of knowledge makes engagement in Transatlantic Public–Private Partnerships TNPPPs almost inevitable (in the same way that you cannot avoid risk, but you have to manage it; and you cannot abolish uncertainty, but you have to filter it).

The nature, dynamics and structure of the processes of knowledge creation, diffusion and use that manifest themselves effectively in the form of innovation networks and knowledge clusters dictate that an understanding of the implications of participating in PPRTDPs as well as the trade-offs and opportunity costs of participation or abstention are essential elements of technology policy- and strategy-making.

It is imperative that we understand how these innovation networks and knowledge clusters – these networks, in other words, of flows and these repositories of intangibles – form, evolve, and dissolve. Better understanding and anticipation of the behavior of these modalities of intangibles formation, evolution and reallocation lies at the heart of long-term sustainable and superior policies and practices in the glocalized knowledge economy.

As a result of the glocalized nature and dynamics of state-of-the-art, specialized knowledge, the creation, safeguarding and leveraging of co-specialized intangible assets necessitates effective and efficient architecting of transnational and transorganizational knowledge interfaces.

In conjunction with that necessity, one needs to cope with and leverage two mutually reinforcing and complementary trends:

(a) The symbiosis and co-evolution of top-down national and multinational science, technology and innovation public policies (for example the National Innovation Initiative report and the US National Nanotechnology Initiative) and bottom-up technology development and knowledge acquisition private initiatives.
(b) The leveling of the competitive field across regions of the world via technology diffusion and adoption accompanied and complemented by the formation and exacerbation of *multidimensional, multilateral, multimodal, and multinodal* divides (cultural, technological, socio-economic, political, and even racial and religious in nature). (Carayannis and Campbell, 2006a)

As a result of these two co-evolving and interacting pairs of mutually reinforcing and complementary trends, science and technology policy-makers and practitioners are confronted with three fundamental challenges and opportunities:

(i) They need to be both "obsessed maniacs" and "clairvoyant oracles" (Carayannis and Sipp, 2006). regarding the formulation and implementation of strategies in the face of increased turbulence and rivalry, and uncertainty and risks.
(ii) They need to be *allocentric*: namely public sector policy-makers need to develop private sector intuition, instincts and predilections in the same manner that private sector managers need to develop more public and social awareness and conscience. This lies at the heart of an emerging, truly post-capitalist redefinition of the fundamental concepts of modern civilized society such as property (both tangible and intangible, or intellectual, property), as well as concepts that define and differentiate public and private goods, transaction costs, and increasing versus diminishing returns.
(iii) In conjunction with the above two points, there is a clear and present need, opportunity and challenge to redefine the way that we develop the lifeblood of the *glocalized knowledge economy* – namely, its human and intellectual capital – in a manner that we would like to call a socio-technical renaissance of the twenty-first century. That implies truly transdisciplinary curricula as well as transnational mindsets and learning covenants (echoing Rousseau's social contract). In essence, we consider it essential that twenty-first

> century education and training in advanced as well as fundamental socio-technical concepts and skills be reinvented and adopted locally and globally to enable both public sector policy-makers and private sector managers and entrepreneurs to better cope with the challenges and opportunities outlined above – in other words, to better enable, empower and incentivize individuals, groups and societies at large to behave more wisely and intelligently. In the specific context of our manuscript, to enable individuals, groups and government, university or industry entities participating in PPRTDPs to more effectively and efficiently practice two essential functions of the twenty-first century executive and policy-maker (echoing Barnard's 1938 *The Function of the Executive*): (a) *strategic knowledge arbitrage*, and (b) *strategic knowledge serendipity* (Carayannis and Juneau, 2003). The readiness, capacity and propensity to more effectively and efficiently leverage these two functions lies in our opinion at the heart of winning co-opetitive policies and strategies in the twenty-first century knowledge society and economy. These two functions, when properly understood and practiced, prepare one to leverage and not suffer from the Schumpeterian creative destruction which seems to be the "Osirian shadow" which is cast upon entrenched interests and rapidly obsolescing knowledge and techniques in the knowledge society and economy.

In closing, being able to practice these two functions – being able to be a superior manager *and* policy-maker in the twenty-first century – relies on a team's, firm's, or society's capacity to be superior learners in terms of both learning new facts as well as adopting new rules for *learning-how-to-learn* and establishing superior strategies for *learning to learn-how-to-learn* (Carayannis, 2001). Those superior learners will, by necessity, be both courageous and humble as these virtues lie at the heart of successful learning.

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