Introduction to Part I: Product and process innovation

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PART I

PRODUCT AND PROCESS INNOVATION

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Introduction

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Industrial innovation is considered fundamental to productivity growth and thereby to long-term socio-economic development in industrialized countries. According to growth accounting that emerged in the 1950s, the main source of growth in labor productivity is the 'residual,' which mainly consists of new products and processes based on the advancement of knowledge and technology. Increasing physical and human capital (through education) is seen as less important for increasing productivity. On the one hand, empirical research has revealed that innovation enhances the growth and survival of firms (Brouwer and Kleinknecht 1994; Archibugi and Pianta 1996; Audretsch 1995; Lawless and Anderson 1996; Metcalfe 1995). On the other hand, innovation is a very complex and risky process, with low success rates, and sometimes lethal effects. Innovations potentially disrupt and reform the organizational fabric, often in a fairly unpredictable and situation-specific way (Zammuto and O'Connor 1992; Dean and Snell 1991; Lundvall 1992; Leonard-Barton 1988; Dougherty and Hardy 1996).

After the cost cutting, downsizing, and re-engineering in the 1980s, both product and process innovation became levers in the late 1990s for companies to generate sustained competitive advantages. Intel, Nokia, Ericsson, Daimler-Chrysler, Microsoft, Du Pont, and many other multinational companies have generated continuous streams of innovations protecting their market positions. Yet there were as many examples of world-leading, market-dominating large firms like SSIH—the Swiss watch consortium—or IBM that were unable to respond to technological shifts such as the introduction of electronic watches and laptops. Christensen (1997) has shown that it was not their large competitors that had out-innovated them, but new entrants. This success paradox (Tushman *et al.* 1997) frames some of the questions in this part:

(*a*) What is innovation anyway, and how has it been conceptualized?
(*b*) What do we know about the antecedents of the rate of product and process innovation?
(*c*) How radical is the innovation?

Besides the variety in innovative performance of firms, there is the variety in innovative performance of economies at different levels: sectors, countries, and continents. This issue frames the second set of questions answered here:

(*d*) how do larger market environments, and
(*e*) how do regulatory and institutional environments impact on patterns of industrial innovation?

The innovation concept

Schumpeter described innovation as ‘a historic and irreversible change in the way of doing things,’ and ‘creative destruction’ (Schumpeter 1943). Innovations are here defined as new creations of economic significance, primarily carried out by firms. They include both product and process innovations. Product innovations are new or better products (or product varieties) being produced and sold; it is a question of *what* is produced. They include new material goods as well as new intangible services. Process innovations are new ways of producing goods and services; it is a matter of *how* existing products are produced. They may be technological or organizational. In this taxonomy, only goods and technological product innovations are material. The other categories are non-technological and intangible.[1] This taxonomy can be illustrated as in Table I.1.

Some product innovations are transformed into process innovations in a second incarnation. This concerns only investment products, not products intended for immediate consumption. For example, an industrial robot is a product when it is produced and a process when it is used in the production process. There are several other taxonomies of innovations and they can certainly be combined with each other. One may, for example, distinguish between:

(*a*) continuous small incremental changes;
(*b*) discontinuous radical innovations;
(*c*) massive shifts in some pervasive general purpose technology (GPT), sometimes called ‘techno-economic paradigms’ (Edquist and Riddell 2000).

Table I.1. A taxonomy of innovations

Types of Innovations			
Product Innovation		Process Innovation	
In goods	In services	Technological	Organizational

The idea is that some innovations change the entire order of things, making obsolete the old ways and perhaps sending entire businesses into the ditch of history. Other innovations, requiring only modest modifications of the old-world view (Van de Ven *et al.* 1999; Rogers 1995; Tidd *et al.* 2001), simply build on what is already present. An example of a radical or breakthrough innovation might be the first (marketed) design of an aircraft, the first integrated circuit, or the first development of penicillin. Examples of GPTs are information and communications technologies (ICTs), electricity, and the internal combustion engine. Such innovations might lead to the creation of brand-new industries. The incremental mode implies a more step-by-step approach of gradually improving existing products or processes. Damanpour and Aravind's chapter tries to find out which determinants of product and process innovation have been identified as having a consistent empirical effect.

Because their definitions ignore other aspects related to innovation processes, the distinction between what is incremental and what is radical has been reworked many times. To be more precise, it is useful to distinguish between three types of changes: changes at the level of the innovative product or process (technological characteristics, functions, quality); changes induced by the innovation at the level of the innovating agent (competencies, organizational structures, market position); changes induced by the innovation throughout the value chain—for example, for users' competencies, or supplier involvement. The dimensions of incremental and radical are mostly used to specify changes at the level of the product or process, but the incremental-radical continuum applies to the other aspects as well. Henderson and Clark (1990), Christensen (1992, 1997), and Afuah and Bahram (1995) developed this conceptualization. Each author showed, in different ways, how collaborative and competitive impacts and diffusion of innovations could be related to the innovation concept. Henderson and Clark (1990) and Christensen (1992, 1997) conceptualized innovation at the level of an artifact as changes in two dimensions: that is, linkage between core concepts and components on the one hand, and in reinforcement or replacement (= overturning) of core concepts on the other hand. 'Architectural innovation' is a re-arrangement of the ways in which components relate to each other within a product's system design; the core concepts—the technological basis—are, at most, reinforced (for example, CPU-time is optimized in a computer). It is primarily a design- and production-driven innovation activity exemplified in Dell computers or Toyota in its supply-chain management. In the case of 'modular innovation,' the core concepts deployed in a component are overturned, while the product architecture is left unchanged: examples of this are read-write heads in disk drives, that were replaced first by ferrite technologies (in thin film heads), and later by magneto resistive heads.

'Incremental innovation' here refers to:

(*a*) improvements in component performance that build upon the established technological concept; or
(*b*) refinements in systems design that involve no significant changes in the technical relationships among components.

'Radical innovations' here involve both a new architecture and a new fundamental technological approach at the component level:

- mainframe—PC—laptop—palm;
- watermill—windmill;
- integrated steel production and minimills;
- standard spring-powered watch—the electric watch—the tuning watch—the quartz crystal watch.

The example of disk drives, taken from Christensen (1992, 1997), is helpful to understand both collaborative and competitive impacts of using this classification. In the disk drive industries, the drivers of performance improvement along the dimensions of performance most

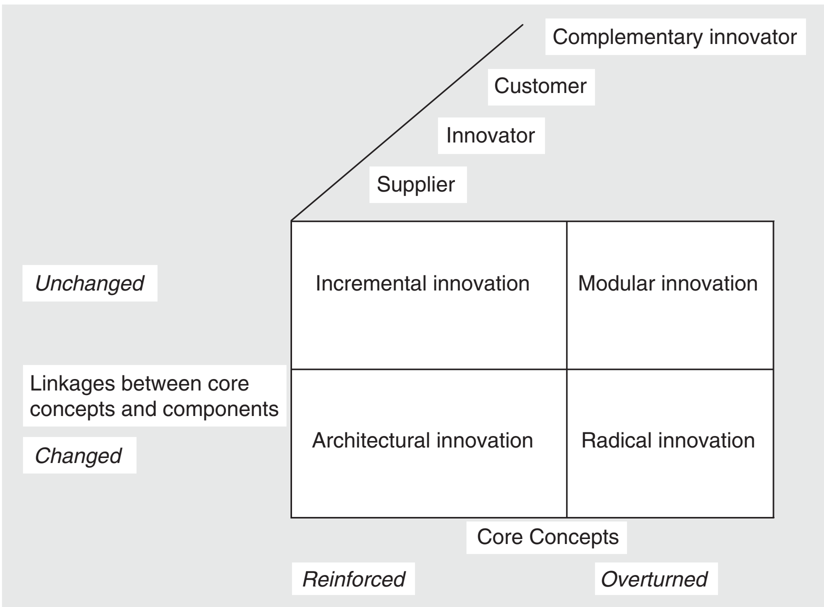

Fig. I.1. The hypercube of innovation

Note: The X and Y axes are the innovation-classifying factors. The Z axis is the innovation value-adding chain of key components: innovator, customer and supplier of complementary innovators.

Source: Afuah and Bahram 1995.

valued in established markets were generally new component technologies. Hence, market introduction of new components improving on main performance aspects was straightforward and easily sold to major customers. New architectural technologies, however, tended to redefine the product's functionality—the parameters by which system performance was assessed. Because of this, new architectures were generally deployed in new market applications. What seems to underlie the failure of established firms at points of architectural technology change in the history of disk drive industry is not failure to innovate in the laboratory, but failure to innovate in the market (see Figure I.1).

As is typical of architectural innovations, they employed proven component technologies and, at first, according to criteria highly valued in established markets, underperformed the dominant architectural technologies. The principal customers for the 14- and 8-inch architectures were the makers of mainframes and minicomputers, who applied total capacity and the speed of information storage and retrieval as performance criteria. The 5.25-inch drive architecture that emerged in 1980 was inferior to the 14- and 8-inch architecture along both dimensions (5.25: 5 MB storage, 160 ms access speed; larger drives' average storage 100–500 MB, speed 30 ms). For this reason, the established makers of mainframes and minicomputers ignored the new architecture. They continued to listen to their main customers, and this created a lock-in in the old architecture.

However, the emerging market of desktop PCs demanded this new functionality. It was based on performance dimensions that were new and overlooked because of the market segments serviced by the established firms. The firms that introduced the 5.25 architecture were new entrants to the industry. The point is that the substitution of new architecture for the old began long before the new technology became performance competitive. Christensen[2] gives a very nice summary of the way this competitive impact of architectural innovation was pulled by new user needs and unfolded between the late 1970s and 1995.

In the late 1970s, the market for disk drives consisted of makers of large mainframe computers. These customers demanded an aggressive improvement in capacity of more than 20 per cent a year, above the minimum required capacity of 300 MB. The leading and most innovative 14-inch drive makers (namely IBM, Memorex, EMM, and Ampex) competed vigorously, maintaining the industry's aggressive rate of R&D investment that had led to dramatic improvements in capacity and cost. During those years, a few start-ups developed 8-inch drives with less than 50 MB capacity, but only minicomputer start-up companies used them. Because these drives were easy to make, and because mainframe customers did not want them, profits margins and sales volume were extremely low.

New entrants struggled to find a viable market for these drives; mostly only minicomputer start-ups were interested in them. IBM and other established drive makers had to decide between two options: either they could divert scarce engineering and financial resources to this small new market and risk eroding their market share of the high-margin, high-growth 14-inch market; alternatively, they could wait until the market was big enough, and then invest aggressively to capture it. Unexpectedly, 8-inch drive makers sustained a capacity increase of more than 40 per cent a year. Their products soon met the needs of mainframe computer makers, while offering advantages intrinsic to a smaller disk, such as reduced vibration. Within four years, 8-inch drives had taken over the mainframe market. Although one-third of the 14-inch makers had introduced 8-inch models, with very competitive performance, every independent 14-inch drive maker had been driven out of the industry by the end of the 1980s. And of the seventeen disk drive companies existing in 1976, all but IBM had failed or had been acquired by 1995. The 8-inch manufacturers, however, were no wiser to the disruptive technology phenomenon, and found themselves fighting a losing battle several years later against the 5.25-inch drive.

The main inferences to be drawn from this example are:

(*a*) established firms could not anticipate the performance jumps in the 8-inch drives, so technological discontinuities remained the most important challenge in technology management;
(*b*) established firms remained top performers in radical component innovation, but they underestimated the competitive impacts of new architectures;
(*c*) the structure of established firms, combined with preferences of their lead users, made them bet on the wrong competences, and made them overlook new performance criteria.

Whereas Christensen emphasized the competitive impact of architectural innovation, Afuah and Bahram (1995) differentiated the focus of innovation in another way. They suggested that, in addition to probing the impact of an innovation on the innovator's own competences and assets, the innovator should also ask the question: 'What will my innovation do to the competence and products of my suppliers (original equipment manufacturers (OEM)), customers, end-user customers, and of key complementary innovators (software producers for IBM)?' What is, from the perspective of the innovators, a radical innovation may turn out to be an incremental innovation for the customer or the complementary innovator; what is, from the perspective of the innovator, incremental could be a radical innovation from the perspective of the customer, or the complementary innovator.

The impact of an innovation on the capabilities and assets of the other actors in the innovation chain is what largely determines the market success or failure of an innovation. Many complex high-technology products require that users invest time and money in learning how to operate and maintain the products. An innovation that destroys the knowledge that the customer has acquired is less likely to be adopted than one that enhances this knowledge and assets. The case of the electric car is a good example here. The Toyota Prius is a radical innovation to the car companies, to suppliers of key components like the power train, and to suppliers of the key complementary innovation—gasoline; to the customers, however, it is an incremental innovation. The DSK (Dvorak Simplified Keyboard) keyboard arranges the keyboard such that it allows 20–40 per cent faster typing than with the QWERTY keyboard; but this rival design implied enormous switching costs on behalf of the users, and would have such an impact on typing skills that adoption rates were minimal. The DSK keyboard was an architectural innovation in which core concepts and components had not changed; only the linkages had been changed.

These refinements in the innovation concept call for further reflections on two questions: How do radical innovations emerge? How is knowledge synthesized into new competencies in a firm while interacting with many partners? These issues are dealt with in the Nonaka and Peltokorpi chapter on the Toyota Prius case. The phenomenon of interorganizational linkages is addressed in the chapter by Meeus and Faber, which focuses on two questions: What effects do interorganizational relations have on the innovative behavior of firms? What induces the formation of interorganizational relations during innovation projects?

Comparing patterns of innovation: variety across the EU and the US, and within the EU

Many comparative studies have shown that patterns of innovation (Nelson 1993; Freeman and Soete 1997) within Europe and between Europe and the US are very different. What explains this uneven distribution of innovation?

The focus of this part of the book is on industrial innovation, and which factors are considered dominant in describing and explaining the occurrence and outcomes of innovation processes. Comparative analysis of performance indicators related to innovation in the European Union (EU) and the US shows remarkable differences (cf. Figure I.2). The European Innovation Scoreboard (EIS) 2003 explores in detail the

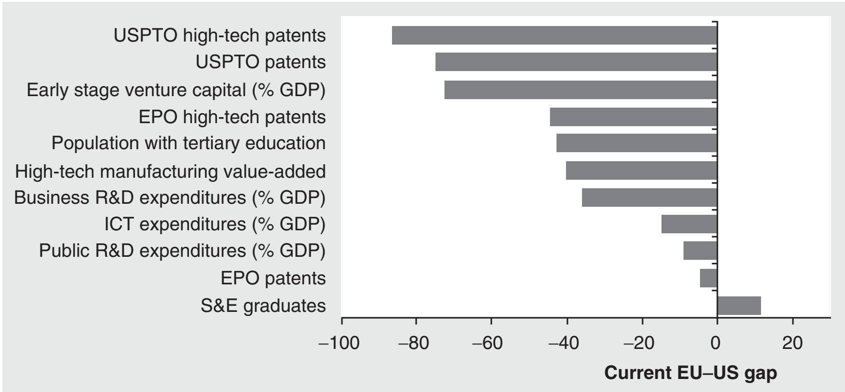

Fig. I.2. Current EU–US gap

Source: European Innovation Scoreboard 2003.

development of the EU/US gap for those indicators for which comparable data are available. As of last year, the US leads the EU in the majority of these indicators (10 out of 11).

The EIS (2003) reports that, at the current rates of change, none of the current EU/US gaps would be closed before 2010. Business R&D shows some weak signs of recovery but, since 2001, a new and increasing gap has appeared in public R&D (gross domestic expenditure on R&D minus business enterprise expenditure on R&D). Early-stage venture capital improves slowly, but the gap remains huge. As for human resources, the large gap in tertiary education persists. The EU weakness in education is further illustrated by the worrisome decline of the EU trend in lifelong learning (no comparable US data are available). The EU's only advance is in Science and Engineering (S&E) graduates. Only two indicators justify a more positive note: a very slow but noticeable, catching-up, value-adding process can be observed in high-tech manufacturing; a long-lasting catching-up process in ICT expenditures (EU/US gap cut by half since 1996).

Figure I.3 shows how the EU/US gap, measured from 1996 to 2002, evolves on the main innovation indicators. Variety in patterns of innovation is seen not only between the EU and the US. Figure I.4 shows that there is considerable variety in successful market introduction as a percentage of turnover in European countries. Italy is the leading country, followed by Spain, Ireland, and France, which all have performance scores above average. There is a large group of followers; among them are the UK, Germany, and Sweden.

At the level of innovation output, there is considerable variety within the EU. This also goes for innovation expenditures, one of the main input variables. What is especially interesting is that high innovation results—in

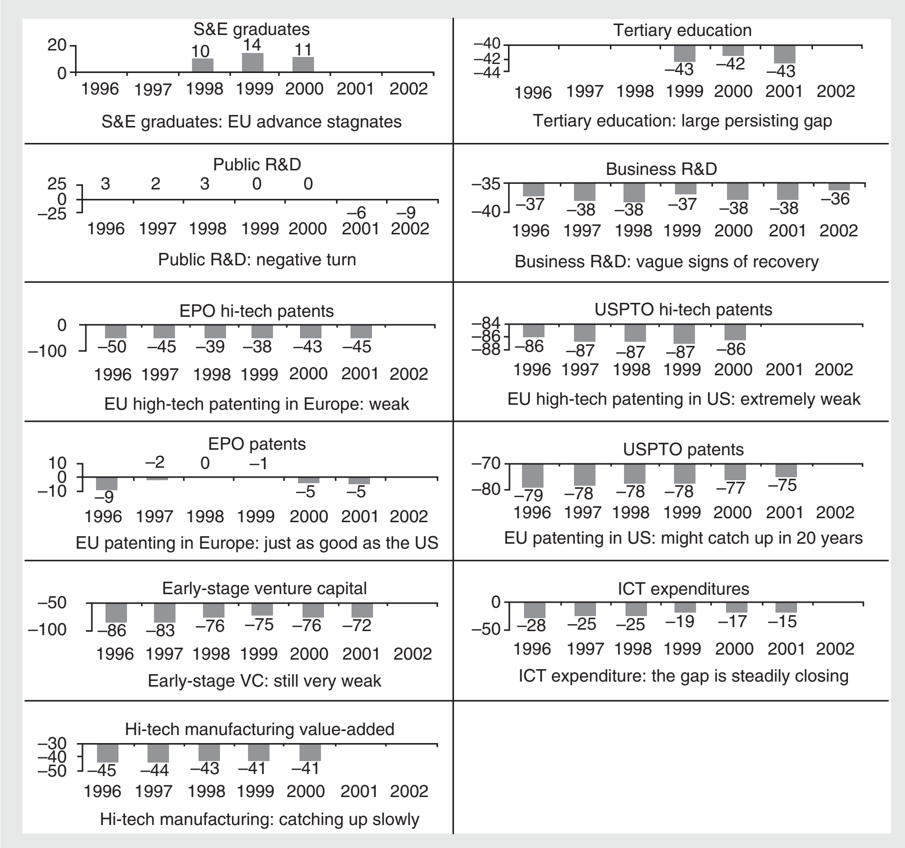

Fig. I.3. EU and US innovation indicators compared

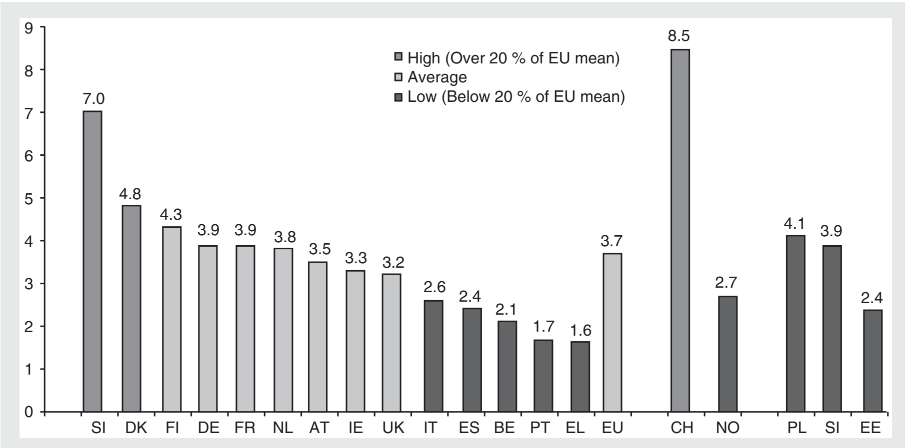

Fig. I.4. Sales due to products new to the market

Note: IT=Italy, ES=Spain, IE=Ireland, FR=France, FI=Finland, PL=Poland, DE=Germany, DK=Denmark, S=Sweden, NL=The Netherlands, UK=United Kingdom, AT=Austria, BE=Belgium, EU=European Union, IS=Iceland, NO=Norway, CH=Switzerland, EE=Estonia, SI=Slovenia, PT=Portugal, EL=Greece.

Source: European Innovation Scoreboard 2003.

terms of a high proportion of new-to-the-market products as a percentage of turnover—do not seem to be associated strongly with innovation expenditures of firms. Sweden has the highest innovation expenditures, but is outperformed in sales due to new-to-the-market products by seven other countries (cf. Figure I.4). This large variety in innovation indicators invites the question of which factors do determine innovation intensity, an issue that is taken up in the chapter by Damanpour and Aravind.

Innovation, market, and non-market factors: the innovation systems perspective

The variety in innovative inputs and outputs across countries and continents begs an explanation. In an innovation system, a broad number of market and non-market factors are brought together. The environment in which innovation emerges consists of many elements, often summarized in systems of innovation schemes (cf. Figure I.5). Several linkages connect the various players and subsystems in Figure I.5. Galli and Teubal (1997: 347) distinguish three types of linkages:

(*a*) market transactions, which involve backward and forward linkages as well as horizontal linkages;
(*b*) unilateral flows of funds, skills, and knowledge (embodied and disembodied) within and National System of Innovation as well as externally, between organizations and others located in other countries or NSIs;
(*c*) interactions, such as user-supplier networks.

These linkages are embedded in a wide variety of institutional arrangements, e.g. laws, norms, and traditions; regulations; policy-induced incentives and disincentives; specific allocation and decision-making mechanisms within organizations; cooperation agreements.

Innovation is highly contingent on historical circumstances, often captured as path dependency, and on the co-evolution of agents' behaviors and innovation. Institutional infrastructures and networks of research and innovation systems are historical products; they, in turn, continue to shape current innovation processes. In the past half-century, this area of society has been shaped by (national) state political interventions and private initiatives: political systems have developed research and innovation policy, in which they acted as catalysts, promoters, and regulators of innovation-related activities.

Since the 1970s, the triumph of high technologies has induced a broad spectrum of technology policy intervention measures in industrialized countries, and sparked off a technology race among them. In the same period, the spectrum of implemented instruments of research, technology, and innovation policy was widely differentiated, reflecting the scope of institutions and interests involved—from public funding of research organizations with various forms of financial incentives, to conducting research and experimental development in public or industrial research

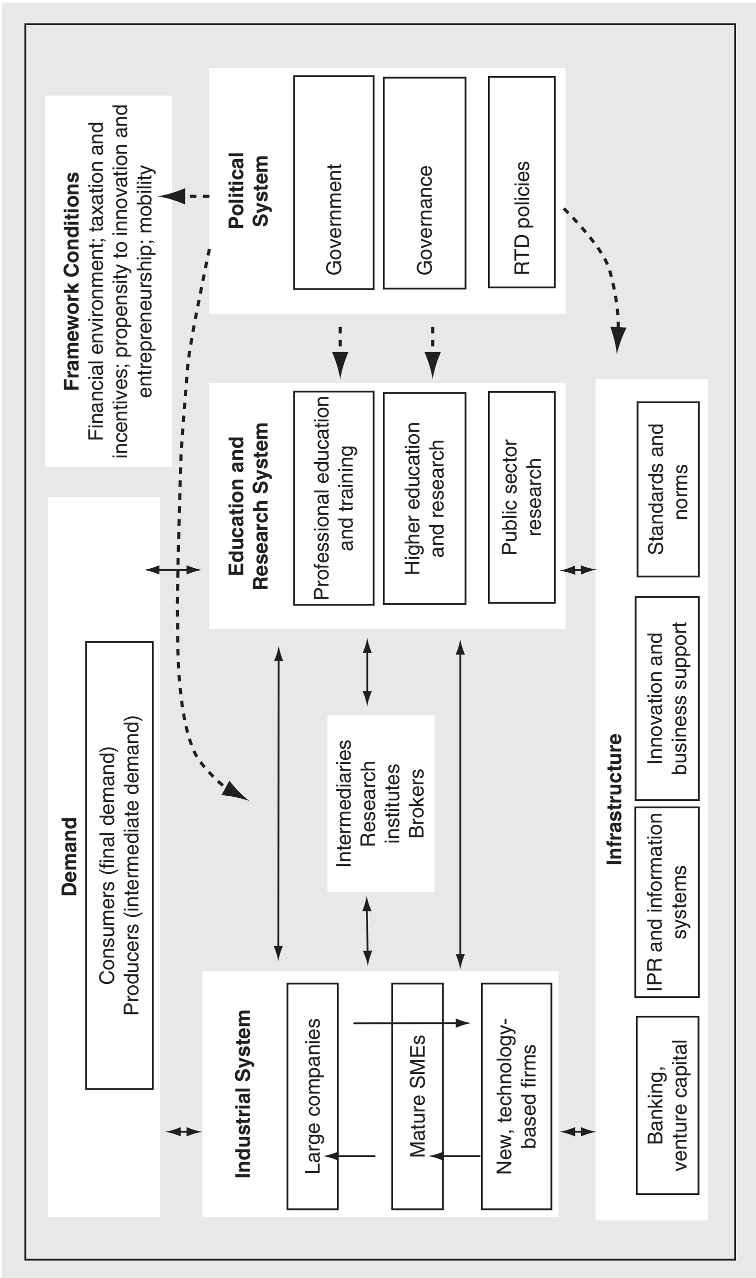

Fig. I.5. A system of innovation

Source: Kulmann and Arnold 2001.

laboratories, to the design of an innovation-oriented infrastructure, including the institutions, organizations, and mechanisms of technology transfer. In many European countries, these instruments have dominated research and technology policy for the last three decades.

Many different approaches to the relations between regulation, environment, and innovative firm behavior have evolved, especially in the field of environmental regulation. It has been argued that the deterministic nature of environmental laws establishing standards designed to control the material and energy outputs of society to the biophysical environment limits firms' strategic choices, and constrains their ability to innovate (Breyer 1982). More specifically, critics argue that the bureaucracy required to comply with environmental regulation restricts firms from pursuing cutting-edge technology. Managers of environmentally regulated firms argue that it is harder to innovate because regulations often change unexpectedly, and because regulators are unpredictable. This increased uncertainty motivates firms to de-emphasize risky strategies such as innovation. The net effect of these constraints is reduced innovation, which many argue puts environmentally regulated firms at a competitive disadvantage (Guttmann *et al.* 1992; Scherer and Ross 1990).

A competing argument is that, if viewed as an external jolt, environmental regulation can stimulate innovation within an organization (Marcus and Weber 1989; Meyer 1982). Such a jolt may appear disruptive and threatening to a firm, but it may be necessary to induce innovation (Schon 1971). In the absence of such stimuli, existing organizational practices are often not challenged, and members may resist innovation, fearing it will change the status quo (Van de Ven 1986). An example of the positive effect of environmental regulation on product innovation is found in chemical manufacturing. Faced with the rapidly approaching deadline for the worldwide phase-out of chlorofluorocarbons (CFCs), Imperial Chemical Industries (ICI), Du Pont, and Elf Atochem developed the technology required to produce CFC substitutes in record time, reduced from the industry norm of more than a decade to only five years (Weber 1993).

One can conclude that there are competing views on the link between (environmental) regulation and innovation (Porter and van der Linde 1995*a*, 1995*b*). Both positive and negative effects are reported and empirically confirmed. Of course this overview is not exhaustive and probably applies to many divergent contexts but, to say the least, it gives clear indications that we need better-specified theoretical models and data allowing us to test these competing views, as well as the factors mediating the effects of environmental regulation on environmental innovation.

These issues are addressed in the chapters of Foster *et al.* and of Metcalfe. Foster *et al.* discuss the issue of what the role of the state and related organizations can be in environmental innovation. They ask three questions:

(*a*) Is it generally possible, and under what conditions, can public interventions induce innovations?
(*b*) How does the intervention affect the economic and environmental performance of the firm?
(*c*) Can the induced innovations bring about beneficial societal effects?

Metcalfe deals with market features like competition and concentration and their impacts on innovation, adoption, and diffusion. He elaborates Schumpeterian ideas proposing that firms in concentrated markets have more incentives to innovate because they can more easily appropriate the returns from innovation. Scholars like Cohen and Levin (1989) and Baldwin *et al*. (2002) have qualified this proposal in different ways; for example:

(*a*) the firm's gains from innovation are greater in competitive than monopolistic industries;
(*b*) innovation is more intensive in the early stages of an industry's development when markets are less concentrated;
(*c*) large firms are more innovative in concentrated industries with high barriers to entry.

Furthermore, Metcalfe (1988) considers the relative importance of supply and demand. This is brought out most sharply when one considers the question of profitability as the incentive to the adoption and diffusion of a new technology. But profitability to whom? To the potential adopter or the potential producer (for innovations cannot be produced unless they can be profitably produced)? These and other issues are further elaborated in Metcalfe's chapter on markets and innovation.

Finally, Chaminade and Edquist discuss the institutional environment, the framework conditions and the infrastructure (cf. Figure I.5) governing innovation. They advance an alternative operationalization of the systems-of-innovation approach based on ten distinct activities that influence the development and diffusion of innovations. After a discussion of each activity, the field of innovation policy is entered, including reasons for public intervention in the innovation process and ways of identifying problems that should be subject to policy.

Notes

1. For further specifications of this taxonomy of innovations, see Edquist *et al*. (forthcoming: 10–17).
2. This summary (2004) can be found at this website: **www.christensen.com**

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