

## CHAPTER 1

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# INNOVATION

## A GUIDE TO THE LITERATURE

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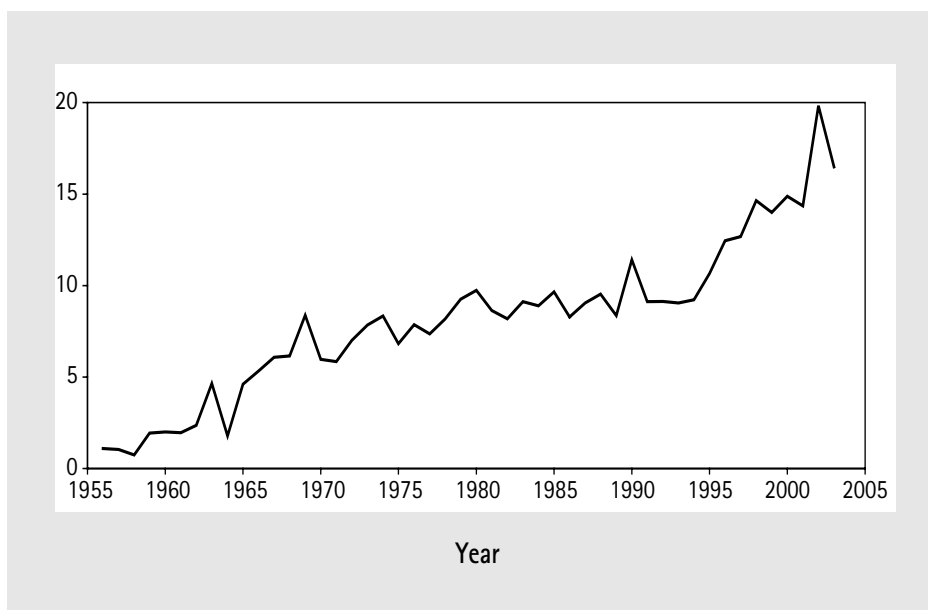
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### 1.1 INTRODUCTION<sup>1</sup>

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INNOVATION is not a new phenomenon. Arguably, it is as old as mankind itself. There seems to be something inherently “human” about the tendency to think about new and better ways of doing things and to try them out in practice. Without it, the world in which we live would look very, very different. Try for a moment to think of a world without airplanes, automobiles, telecommunications, and refrigerators, just to mention a few of the more important innovations from the not-too-distant past. Or—from an even longer perspective—where would we be without such fundamental innovations as agriculture, the wheel, the alphabet, or printing?

In spite of its obvious importance, innovation has not always received the scholarly attention it deserves. For instance, students of long-run economic change used to focus on factors such as capital accumulation or the working of markets, rather than on innovation. This is now changing. Research on the role of innovation in economic and social change has proliferated in recent years, particularly within the social sciences, and with a bent towards cross-disciplinarity. In fact, as illustrated in Figure 1.1, in recent years the number of social-science publications focusing on innovation has increased much faster than the total number of such publications.



**Fig. 1.1 Scholarly Articles with "Innovation" in the title, 1955–2004 (per 10,000 social science articles)**

*Note:* The source is the ISI Web of Knowledge. Social Sciences Citation Index (SSCI) from 1956 to present were included. A search has been done, for the number of articles and in English, and the total number of publications in each database, from the year 1975 to present. The results are presented as shares of total articles/documents were included in the calculations, so the numbers from that period are not strictly comparable to those for later years.

As a result, our knowledge about innovation processes, their determinants and social and economic impact has been greatly enhanced.

When innovation studies started to emerge as a separate field of research in the 1960s, it did so mostly outside the existing disciplines and the most prestigious universities. An important event in this process was the formation in 1965 of the Science Policy Research Unit (SPRU) at the University of Sussex (see Box 1.1). The name of the center illustrates the tendency for innovation studies to develop under other (at the time more acceptable?) terms, such as, for instance, "science studies" or "science policy studies." But as we shall see in the following, one of the main lessons from the research that came to be carried out is that science is only one among several ingredients in successful innovation. As a consequence of these findings, not only the focus of research in this area but also the notions used to characterize it changed. During the late twentieth/early twenty-first century, a number of new research centers and departments have been founded, focusing on the role of innovation in

### Box 1.1 SPRU, Freeman, and the spread of innovation studies

SPRU—Science Policy Research Unit—at the University of Sussex, UK was founded in 1965 with Christopher Freeman as its first director. From the beginning, it had a cross-disciplinary research staff consisting of researchers with backgrounds in subjects as diverse as economics, sociology, psychology, and engineering. SPRU developed its own cross-disciplinary Master and Ph.D. programs and carried out externally funded research, much of which came to focus on the role of innovation in economic and social change. It attracted a large number of young scholars from other countries who came to train and work here.

The research initiated at SPRU led to a large number of projects, conferences, and publications. *Research Policy*, which came to be the central academic journal in the field, was established in 1972, with Freeman as the first editor (he was later succeeded by Keith Pavitt, also from SPRU). Freeman's influential book, *The Economics of Industrial Innovation*, was published two years later, in 1974, and has since been revised twice. In 1982, the book, *Unemployment and Technical Innovation*, written by Freeman, Clark, and Soete, appeared, introducing a systems approach to the role of innovation in long-term economic and social change. Freeman later followed this up with an analysis of the national innovation system in Japan (Freeman 1987). He was also instrumental in setting up the large, collaborative IFIAS project which in 1988 resulted in the very influential book, *Technical Change and Economic Theory*, edited by Dosi, Freeman, Nelson, Silverberg, and Soete (both Dosi and Soete were SPRU Ph.D. graduates).

In many ways, SPRU came to serve as a role model for the many centers/institutes within Europe and Asia that were established, mostly from the mid-1980s onwards, combining cross-disciplinary graduate and Ph.D. teaching with extensive externally funded research. Most of these, as SPRU itself, were located in relatively newly formed (so-called “red-brick”) universities, which arguably showed a greater receptivity to new social needs, initiatives, and ideas than the more inert, well-established academic “leaders,” or at other types of institutions such as business or engineering schools. SPRU graduates were in many cases instrumental in spreading research and teaching on innovation to their own countries, particularly in Europe.

economic and social change. Many of these have a cross-disciplinary orientation, illustrating the need for innovation to be studied from different perspectives. Several journals and professional associations have also been founded.

The leaning towards cross-disciplinarity that characterizes much scholarly work in this area reflects the fact that no single discipline deals with all aspects of innovation. Hence, to get a comprehensive overview, it is necessary to combine insights from several disciplines. Traditionally, for instance, economics has dealt primarily with the allocation of resources to innovation (in competition with other ends) and its economic effects, while the innovation process itself has been more or less treated as a “black box.” What happens within this “box” has been left to scholars from other disciplines. A lot of what happens obviously has to do with learning, a central topic in cognitive science. Such learning occurs in organized settings (e.g. groups, teams, firms,

and networks), the working of which is studied within disciplines such as sociology, organizational science, management, and business studies. Moreover, as economic geographers point out, learning processes tend to be linked to specific contexts or locations. The way innovation is organized and its localization also undergo important changes through time, as underscored by the work within the field of economic history. There is also, as historians of technology have pointed out, a specific technological dimension to this; the way innovation is organized, as well as its economic and social effects, depends critically on the specific nature of the technology in question.

Two decades ago, it was still possible for a hard-working student to get a fairly good overview of the scholarly work on innovation by devoting a few years of intensive study to the subject. Not any more. Today, the literature on innovation is so large and diverse that even keeping up-to-date with one specific field of research is very challenging. The purpose of this volume is to provide the reader with a guide to this rapidly expanding literature. We do this under the following broad headings:

- I Innovation in the Making
- II The Systemic Nature of Innovation
- III How Innovation Differs
- IV Innovation and Performance.

Part One focuses on the process through which innovations occur and the actors that take part: individuals, firms, organizations, and networks. As we will discuss in more detail below, innovation is by its very nature a systemic phenomenon, since it results from continuing interaction between different actors and organizations. Part Two outlines the systems perspective on innovation studies and discusses the roles of institutions, organizations, and actors in this process at the national and regional level. Part Three explores the diversity in the manner in which such systems work over time and across different sectors or industries. Finally, Part Four examines the broader social and economic consequences of innovation and the associated policy issues. The remainder of this chapter sets the stage for the discussion that follows by giving a broad overview of some of the central topics in innovation studies (including conceptual issues).

## 1.2 WHAT IS INNOVATION?

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An important distinction is normally made between invention and innovation.<sup>2</sup> Invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out into practice. Sometimes, invention and innovation are closely linked, to the extent that it is hard to distinguish one from

another (biotechnology for instance). In many cases, however, there is a considerable time lag between the two. In fact, a lag of several decades or more is not uncommon (Rogers 1995). Such lags reflect the different requirements for working out ideas and implementing them. While inventions may be carried out anywhere, for example in universities, innovations occur mostly in firms, though they may also occur in other types of organizations, such as public hospitals. To be able to turn an invention into an innovation, a firm normally needs to combine several different types of knowledge, capabilities, skills, and resources. For instance, the firm may require production knowledge, skills and facilities, market knowledge, a well-functioning distribution system, sufficient financial resources, and so on. It follows that the role of the innovator,<sup>3</sup> i.e. the person or organizational unit responsible for combining the factors necessary (what the innovation theorist Joseph Schumpeter (see Box 1.2) called the “entrepreneur”), may be quite different from that of the inventor. Indeed, history is replete with cases in which the inventor of major technological advances fails to reap the profits from his breakthroughs.

Long lags between invention and innovation may have to do with the fact that, in many cases, some or all of the conditions for commercialization may be lacking. There may not be a sufficient need (yet!) or it may be impossible to produce and/or market because some vital inputs or complementary factors are not (yet!) available. Thus, although Leonardo da Vinci is reported to have had some quite advanced ideas for a flying machine, these were impossible to carry out in practice due to a lack of adequate materials, production skills, and—above all—a power source. In fact, the realization of these ideas had to wait for the invention and subsequent commercialization (and improvement) of the internal combustion engine.<sup>4</sup> Hence, as this example shows, many inventions require complementary inventions and innovations to succeed at the innovation stage.

Another complicating factor is that invention and innovation is a continuous process. For instance, the car, as we know it today, is radically improved compared to the first commercial models, due to the incorporation of a very large number of different inventions/innovations. In fact, the first versions of virtually all significant innovations, from the steam engine to the airplane, were crude, unreliable versions of the devices that eventually diffused widely. Kline and Rosenberg (1986), in an influential paper, point out:

it is a serious mistake to treat an innovation as if it were a well-defined, homogenous thing that could be identified as entering the economy at a precise date—or becoming available at a precise point in time. . . . The fact is that most important innovations go through drastic changes in their lifetimes—changes that may, and often do, totally transform their economic significance. The subsequent improvements in an invention after its first introduction may be vastly more important, economically, than the initial availability of the invention in its original form. (Kline and Rosenberg 1986: 283)

Thus, what we think of as a single innovation is often the result of a lengthy process involving many interrelated innovations. This is one of the reasons why

### Box 1.2 The innovation theorist Joseph Schumpeter

Joseph Schumpeter (1883–1950) was one of the most original social scientists of the twentieth century. He grew up in Vienna around the turn of the century, where he studied law and economics. For most of his life he worked as an academic, but he also tried his luck as politician, serving briefly as finance minister in the first post-World War I (socialist) government, and as a banker (without much success). He became professor at the University of Bonn in 1925 and later at Harvard University in the USA (1932), where he stayed until his death. He published several books and papers in German early on, among these the *Theory of Economic Development*, published in 1911 and in a revised edition in English in 1934. Among his most well-known later works are *Business Cycles* in two volumes (from 1939), *Capitalism, Socialism and Democracy* (1943), and the posthumously published *History of Economic Analysis* (1954).

Very early he developed an original approach, focusing on the role of innovation in economic and social change. It was not sufficient, Schumpeter argued, to study the economy through static lenses, focusing on the distribution of given resources across different ends. Economic development, in his view, had to be seen as a process of qualitative change, driven by innovation, taking place in historical time. As examples of innovation he mentioned new products, new methods of production, new sources of supply, the exploitation of new markets, and new ways to organize business. He defined innovation as “new combinations” of existing resources. This combinatory activity he labeled “the entrepreneurial function” (to be fulfilled by “entrepreneurs”), to which he attached much importance. One main reason for the important role played by entrepreneurs for successful innovation was the prevalence of inertia, or “resistance to new ways” as he phrased it, at all levels of society that entrepreneurs had to fight in order to succeed in their aims. In his early work, which is sometimes called “Schumpeter Mark I,” Schumpeter focused mostly on individual entrepreneurs. But in later works he also emphasized the importance of innovation in large firms (so-called “Schumpeter Mark II”), and pointed to historically oriented, qualitative research (case studies) as the way forward for research in this area.

In his analysis of innovation diffusion, Schumpeter emphasized the tendency for innovations to “cluster” in certain industries and time periods (and the derived effects on growth) and the possible contribution of such “clustering” to the formation of business cycles and “long waves” in the world economy (Schumpeter 1939). The latter suggestion has been a constant source of controversy ever since. No less controversial, and perhaps even better known, is his inspired discussion of the institutional changes under capitalism (and its possible endogenous transformation into “socialism”) in the book *Capitalism, Socialism and Democracy* (1943).

Sources: Swedberg 1991; Shionoya 1997; Fagerberg 2003.

many students of technology and innovation find it natural to apply a systems perspective rather than to focus exclusively on individual inventions/innovations.

Innovations may also be classified according to “type.” Schumpeter (see Box 1.2) distinguished between five different types: new products, new methods of production, new sources of supply, the exploitation of new markets, and new ways to

organize business. However, in economics, most of the focus has been on the two first of these. Schmookler (1966), for instance, in his classic work on “Invention and Economic Growth,” argued that the distinction between “product technology” and “production technology” was “critical” for our understanding of this phenomenon (ibid. 166). He defined the former type as knowledge about how to *create or improve* products, and the latter as knowledge about how to *produce* them. Similarly, the terms “product innovation” and “process innovation” have been used to characterize the occurrence of new or improved goods and services, and improvements in the ways to produce these good and services, respectively.<sup>5</sup> The argument for focusing particularly on the distinction between product and process innovation often rests on the assumption that their economic and social impact may differ. For instance, while the introduction of new products is commonly assumed to have a clear, positive effect on growth of income and employment, it has been argued that process innovation, due to its cost-cutting nature, may have a more ambiguous effect (Edquist et al. 2001; Pianta in this volume). However, while clearly distinguishable at the level of the individual firm or industry, such differences tend to become blurred at the level of the overall economy, because the product of one firm (or industry) may end up as being used to produce goods or services in another.<sup>6</sup>

The focus on product and process innovations, while useful for the analysis of some issues, should not lead us ignore other important aspects of innovation. For instance, during the first half of the twentieth century, many of the innovations that made it possible for the United States to “forge ahead” of other capitalist economies were of the organizational kind, involving entirely new ways to organize production and distribution (see Bruland and Mowery in this volume, while Lam provides an overview of organizational innovation). Edquist et al. (2001) have suggested dividing the category of process innovation into “technological process innovations” and “organizational process innovations,” the former related to new types of machinery, and the latter to new ways to organize work. However, organizational innovations are not limited to new ways to organize the process of production within a given firm. Organizational innovation, in the sense used by Schumpeter,<sup>7</sup> also includes arrangements across firms such as the reorganization of entire industries. Moreover, as exemplified by the case of the USA in the first half of the previous century, many of the most important organizational innovations have occurred in distribution, with great consequences for a whole range of industries (Chandler 1990).

Another approach, also based on Schumpeter’s work, has been to classify innovations according to how radical they are compared to current technology (Freeman and Soete 1997). From this perspective, continuous improvements of the type referred to above are often characterized as “incremental” or “marginal” innovations,<sup>8</sup> as opposed to “radical” innovations (such as the introduction of a totally new type of machinery) or “technological revolutions” (consisting of a cluster of innovations that together may have a very far-reaching impact). Schumpeter focused in particular on the latter two categories, which he believed to be of greater

importance. It is a widely held view, however, that the cumulative impact of incremental innovations is just as great (if not greater), and that to ignore these leads to a biased view of long run economic and social change (Lundvall et al. 1992). Moreover, the realization of the economic benefits from “radical” innovations in most cases (including those of the airplane and the automobile, discussed earlier) requires a series of incremental improvements. Arguably, the bulk of economic benefits come from incremental innovations and improvements.

There is also the question of how to take different contexts into account. If A for the first time introduces a particular innovation in one context, while B later introduces the same innovation in another, would we characterize both as innovators? This is a matter of convention. A widely used practice, based on Schumpeter’s work, is to reserve the term innovator for A and characterize B as an imitator. But one might argue that, following Schumpeter’s own definition, it would be equally consistent to call B an innovator as well, since B is introducing the innovation for the first time in a new context. This is, for instance, the position taken by Hobday (2000) in a discussion of innovation in the so-called “newly industrializing countries” in Asia.<sup>9</sup> One might object, though, that there is a qualitative difference between (a) commercializing something for the first time and (b) copying it and introducing it in a different context. The latter arguably includes a larger dose of imitative behavior (imitation), or what is sometimes called “technology transfer.” This does not exclude the possibility that imitation may lead to new innovation(s). In fact, as pointed out by Kline and Rosenberg (1986, see Box 1.3), many economically significant innovations occur while a product or process is diffusing (see also Hall in this volume). Introducing something in a new context often implies considerable adaptation (and, hence, incremental innovation) and, as history has shown, organizational changes (or innovations) that may significantly increase productivity and competitiveness (see Godinho and Fagerberg in this volume).<sup>10</sup>

### Box 1.3 What innovation is not: the linear model

Sometimes it is easier to characterize a complex phenomenon by clearly pointing out what it is NOT. Stephen Kline and Nathan Rosenberg did exactly this when they, in an influential paper from 1986, used the concept “the linear model” to characterize a widespread but in their view erroneous interpretation of innovation.

Basically, “the linear model” is based on the assumption that innovation is applied science. It is “linear” because there is a well-defined set of stages that innovations are assumed to go through. Research (science) comes first, then development, and finally production and marketing. Since research comes first, it is easy to think of this as the critical element. Hence, this perspective, which is often associated with Vannevar Bush’s programmatic statements on the organization of the US research systems (Bush 1945), is well suited to defend the interests of researchers and scientists and the organizations in which they work.



The problems with this model, Kline and Rosenberg point out, are twofold. First, it generalizes a chain of causation that only holds for a minority of innovations. Although some important innovations stem from scientific breakthroughs, this is not true most of the time. Firms normally innovate because they believe there is a commercial need for it, and they commonly start by reviewing and combining existing knowledge. It is only if this does not work, they argue, that firms consider investing in research (science). In fact, in many settings, the experience of users, not science, is deemed to be the most important source of innovation (von Hippel 1988; Lundvall 1988). Second, “the linear model” ignores the many feedbacks and loops that occur between the different “stages” of the process. Shortcomings and failures that occur at various stages may lead to a reconsideration of earlier steps, and this may eventually lead to totally new innovations.

### 1.3 INNOVATION IN THE MAKING

Leaving definitions aside, the fundamental question for innovation research is of course to explain how innovations occur. One of the reasons innovation was ignored in mainstream social science for so long was that this was seen as impossible to do. The best one could do, it was commonly assumed, was to look at innovation as a random phenomenon (or “manna from heaven,” as some scholars used to phrase it). Schumpeter, in his early works, was one of the first to object to this practice. His own account of these processes emphasized three main aspects. The first was the fundamental uncertainty inherent in all innovation projects; the second was the need to move quickly before somebody else did (and reap the potential economic reward). In practice, Schumpeter argued, these two aspects meant that the standard behavioral rules, e.g., surveying all information, assessing it, and finding the “optimal” choice, would not work. Other, quicker ways had to be found. This in his view involved leadership and vision, two qualities he associated with entrepreneurship. The third aspect of the innovation process was the prevalence of “resistance to new ways”—or inertia—at all levels of society, which threatened to destroy all novel initiatives, and forced entrepreneurs to fight hard to succeed in their projects. Or as he put it: “In the breast of one who wishes to do something new, the forces of habit raise up and bear witness against the embryonic project” (Schumpeter 1934: 86). Such inertia, in Schumpeter’s view, was to some extent endogenous, since it reflected the embedded character of existing knowledge and habit, which, though “energy-saving,” tended to bias decision-making against new ways of doing things.

Hence, in Schumpeter’s early work (sometimes called “Schumpeter Mark I”) innovation is the outcome of continuous struggle in historical time between individual *entrepreneurs*, advocating novel solutions to particular problems, and *social*

*inertia*, with the latter seen as (partly) endogenous. This may, to some extent, have been an adequate interpretation of events in Europe around the turn of the nineteenth century. But during the first decades of the twentieth century, it became clear to observers that innovations increasingly involve teamwork and take place within larger organizations (see Bruland and Mowery (Ch. 13), Lam (Ch. 5), and Lazonick (Ch. 2) in this volume). In later work, Schumpeter acknowledged this and emphasized the need for systematic study of “cooperative” entrepreneurship in big firms (so-called “Schumpeter Mark II”). However, he did not analyze the phenomenon in much detail (although he strongly advised others to).<sup>11</sup>

Systematic theoretical and empirical work on innovation-projects in firms (and the management of such projects) was slow to evolve, but during the last decades a quite substantial literature has emerged (see chapters by Pavitt and Lam in this volume). In general, research in this area coincides with Schumpeter’s emphasis on uncertainty (Nelson and Winter 1982; Nonaka and Takeuchi 1995; Van de Ven et al. 1999). In particular, for potentially rewarding innovations, it is argued, one may simply not know what are the most relevant sources or the best options to pursue (still less how great the chance is of success).<sup>12</sup> It has also been emphasized that innovative firms need to consider the potential problems that “path dependency” may create (Arthur 1994). For instance, if a firm selects a specific innovation path very early, it may (if it is lucky) enjoy “first mover” advantages. But it also risks being “locked in” to this specific path through various self-reinforcing effects. If in the end it turns out that there actually existed a superior path, which some other firm equipped with more patience (or luck) happened to find, the early mover may be in big trouble because then, it is argued, it may simply be too costly or too late to switch paths. It has been suggested, therefore, that in the early phase of an innovation project, before sufficient knowledge of the alternatives is generated, the best strategy may simply be to avoid being “stuck” to a particular path, and remain open to different (and competing) ideas/solutions. At the level of the firm, this requires a “pluralistic leadership” that allows for a variety of competing perspectives (Van de Ven et al. 1999), in contrast to the homogenous, unitary leader style that, in the management literature, is sometimes considered as the most advantageous.<sup>13</sup>

“Openness” to new ideas and solutions? is considered essential for innovation projects, especially in the early phases. The principal reason for this has to do with a fundamental characteristic of innovation: that every new innovation consists of a new combination of existing ideas, capabilities, skills, resources, etc. It follows logically from this that the greater the variety of these factors within a given system, the greater the scope for them to be combined in different ways, producing new innovations which will be both more complex and more sophisticated. This evolutionary logic has been used to explain why, in ancient times, the inhabitants of the large Eurasian landmass came to be more innovative, and technologically sophisticated, than small, isolated populations elsewhere around the globe (Diamond 1998). Applied mechanically on a population of firms, this logic might perhaps be taken to

imply that large firms should be expected to be more innovative than small firms.<sup>14</sup> However, modern firms are not closed systems comparable to isolated populations of ancient times. Firms have learnt, by necessity, to monitor closely each other's steps, and search widely for new ideas, inputs, and sources of inspiration. The more firms on average are able to learn from interacting with external sources, the greater the pressure on others to follow suit. This greatly enhances the innovativeness of both individual firms and the economic systems to which they belong (regions or countries, for instance). Arguably, this is of particular importance for smaller firms, which have to compensate for small internal resources by being good at interacting with the outside world. However, the growing complexity of the knowledge bases necessary for innovation means that even large firms increasingly depend on external sources in their innovative activity (Granstrand, Patel, and Pavitt, 1997; and in this volume: Pavitt; Powell and Grodal; Narula and Zanfei).

Hence, cultivating the capacity for absorbing (outside) knowledge, so-called "absorptive capacity" (Cohen and Levinthal 1990), is a must for innovative firms, large or small. It is, however, something that firms often find very challenging; the "not invented here" syndrome is a well-known feature in firms of all sizes. This arguably reflects the cumulative and embedded character of firm-specific knowledge. In most cases, firms develop their knowledge of how to do things incrementally. Such knowledge, then, consists of "routines" that are reproduced through practice ("organizational memory": Nelson and Winter 1982). Over time, the organizational structure of the firm and its knowledge base typically co-evolve into a set-up that is beneficial for the day-to-day operations of the firm. It has been argued, however, that such a set-up, while facilitating the daily internal communication/interaction of the firm, may in fact constrain the firm's capacity for absorbing new knowledge created elsewhere, especially if the new external knowledge significantly challenges the existing set-up/knowledge of the firm (so-called "competence destroying technical change": Tushman and Anderson 1986). In fact, such problems may occur even for innovations that are created internally. Xerox, for instance, developed both the PC and the mouse, but failed to exploit commercially these innovations, primarily because they did not seem to be of much value to the firm's existing photo-copier business (Rogers 1995).

Thus organizing for innovation is a delicate task. Research in this area has, among other things, pointed to the need for innovative firms to allow groups of people within the organization sufficient freedom in experimenting with new solutions (Van de Ven 1999), and establishing patterns of interaction within the firm that allow it to mobilize its entire knowledge base when confronting new challenges (Nonaka and Takeuchi 1995; Lam, Ch. 5 in this volume). Such organizing does not stop at the gate of the firm, but extends to relations with external partners. Ties to partners with whom communication is frequent are often called "strong ties," while those that are more occasional are denoted as "weak ties" (Granovetter 1973; see Powell and Grodal, Ch. 3 in this volume). Partners linked together with strong ties, either

directly, or indirectly via a common partner, may self-organize into (relatively stable) networks. Such networks may be very useful for managing and maintaining openness. But just as firms can display symptoms of path-dependency, the same can happen to established networks, as the participants converge to a common perception of reality (so-called “group-think”). Innovative firms therefore often find it useful to also cultivate so-called “weak ties” in order to maintain a capacity for changing its orientation (should it prove necessary).

## 1.4 THE SYSTEMIC NATURE OF INNOVATION

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As is evident from the preceding discussion, a central finding in the literature is that, in most cases, innovation activities in firms depend heavily on external sources. One recent study sums it up well: “Popular folklore notwithstanding, the innovation journey is a collective achievement that requires key roles from numerous entrepreneurs in both the public and private sectors” (Van de Ven et al. 1999: 149). In that particular study, the term “social system for innovation development” was used to characterize this “collective achievement.” However, this is just one among several examples from the last decades of how system concepts are applied to the analysis of the relationship between innovation activities in firms and the wider framework in which these activities are embedded (see Edquist, Ch. 7 in this volume).

One main approach has been to delineate systems on the basis of technological, industrial, or sectoral characteristics (Freeman et al. 1982; Hughes 1983; Carlsson and Stankiewicz 1991; Malerba, Ch. 14 in this volume) but, to a varying degree, to include other relevant factors such as, for instance, institutions (laws, regulations, rules, habits, etc.), the political process, the public research infrastructure (universities, research institutes, support from public sources, etc.), financial institutions, skills (labor force), and so on. To explore the technological dynamics of innovation, its various phases, and how this influences and is influenced by the wider social, institutional, and economic frameworks has been the main focus of this type of analysis. Another important approach in the innovation-systems literature has focused on the spatial level, and used national or regional borders to distinguish between different systems. For example, Lundvall (1992) and Nelson et al. (1993) have used the term “national system of innovation” to characterize the systemic interdependencies within a given country (see Edquist in this volume), while Braczyk et al. (1997) similarly have offered the notion of “regional innovation systems” (see Asheim and Gertler, Ch. 11 in this volume). Since the spatial systems are delineated on the basis of political and administrative borders, such factors

naturally tend to play an important role in analyses based on this approach, which has proven to be influential among policy makers in this area, especially in Europe (see Lundvall and Borrás, Ch. 22 in this volume). (Part II of this volume analyzes some of the constituent elements of such systems in more detail.<sup>15</sup>)

What are the implications of applying a system perspective to the study of innovation? Systems are—as networks—a set of activities (or actors) that are interlinked, and this leads naturally to a focus on the working of the linkages of the system.<sup>16</sup> Is the potential for communication and interaction through existing linkages sufficiently exploited? Are there potential linkages within the system that might profitably be established? Such questions apply of course to networks as well as systems. However, in the normal usage of the term, a system will typically have more “structure” than a network, and be of a more enduring character. The structure of a system will facilitate certain patterns of interaction and outcomes (and constrain others), and in this sense there is a parallel to the role of “inertia” in firms. A dynamic system also has feedbacks, which may serve to reinforce—or weaken—the existing structure/functioning of the system, leading to “lock in “(a stable configuration), or a change in orientation, or—eventually—the dissolution of the system. Hence, systems may—just as firms—be locked into a specific path of development that supports certain types of activities and constrains others. This may be seen as an advantage, as it pushes the participating firms and other actors in the system in a direction that is deemed to be beneficial. But it may also be a disadvantage, if the configuration of the system leads firms to ignore potentially fruitful avenues of exploration. The character of such processes will be affected by the extent to which the system exchanges impulses with its environment. The more open a system is for impulses from outside, the less the chance of being “locked out” from promising new paths of development that emerge outside the system. It is, therefore, important for “system managers”—such as policy makers—to keep an eye on the openness of the system, to avoid the possibility of innovation activities becoming unduly constrained by self-reinforcing path-dependency.

Another important feature of systems that has come into focus is the strong complementarities that commonly exist between the components of a system. If, in a dynamic system, one critical, complementary component is lacking, or fails to progress or develop, this may block or slow down the growth of the entire system. This is, as pointed out earlier, one of the main reasons why there is often a very considerable time lag between invention and innovation. Economic historians have commonly used concepts such as “reverse salients” and “bottlenecks” to characterize such phenomena (Hughes 1983; Rosenberg 1982). However, such constraints need not be of a purely technical character (such as, for instance, the failure to invent a decent battery, which has severely constrained the diffusion of electric cars for more than century), but may have to do with lack of proper infrastructure, finance, skills, etc. Some of the most important innovations of this century, such as electricity and automobiles (Mowery and Rosenberg 1998), were dependent on very extensive

infrastructural investments (wiring and roads/distribution-systems for fuel, respectively). Moreover, to fulfil the potential of the new innovation, such investments often need to be accompanied by radical changes in the organization of production and distribution (and, more generally, attitudes: see Perez 1983, 1985; Freeman and Louçá 2001). There are important lessons here for firms and policy makers. Firms may need to take into account the wider social and economic implications of an innovation project. The more radical an innovation is, the greater the possibility that it may require extensive infrastructural investments and/or organizational and social change to succeed. If so, the firm needs to think through the way in which it may join up with other agents of change in the private or public sector. Policy makers, for their part, need to consider what different levels of government can do to prevent “bottlenecks” to occur at the system level in areas such as skills, the research infrastructure, and the broader economic infrastructure.

## 1.5 HOW INNOVATION DIFFERS

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One of the striking facts about innovation is its variability over time and space. It seems, as Schumpeter (see Box 1.2) pointed out, to “cluster,” not only in certain sectors but also in certain areas and time periods. Over time the centers of innovation have shifted from one sector, region, and country to another. For instance, for a long period the worldwide center of innovation was in the UK, and the productivity and income of its population increased relative to its neighboring countries, so that by the mid-nineteenth century its productivity (and income) level was 50 per cent higher than elsewhere; at about the beginning of the twentieth century the center of innovation, at least for the modern chemical and electrical technologies of the day, shifted to Germany; and now, for a long time, the worldwide center of innovation has been in the USA, which during most of the twentieth century enjoyed the highest productivity and living standards in the world. As explained by Bruland and Mowery in this volume, the rise of the US to world technological leadership was associated with the growth of new industries, based on the exploitation of economies of scale and scope (Chandler 1962, 1990) and mass production and distribution.

How is this dynamic to be explained? Schumpeter, extending an earlier line of argument dating back to Karl Marx,<sup>17</sup> held technological competition (competition through innovation) to be the driving force of economic development. If one firm in a given industry or sector successfully introduces an important innovation, the argument goes, it will be amply rewarded by a higher rate of profit. This functions

as a signal to other firms (the imitators), which, if entry conditions allow, will “swarm” the industry or sector with the hope of sharing the benefits (with the result that the initial innovator’s first mover advantages may be quickly eroded). This “swarming” of imitators implies that the growth of the sector or industry in which the innovation occurs will be quite high for a while. Sooner or later, however, the effects on growth (created by an innovation) will be depleted and growth will slow down.

To this essentially Marxian story Schumpeter added an important modification. Imitators, he argued, are much more likely to succeed in their aims if they improve on the original innovation, i.e., become innovators themselves. This is all the more natural, he continued, because one (important) innovation tends to facilitate (induce) other innovations in the same or related fields. In this way, innovation–diffusion becomes a creative process—in which one important innovation sets the stage for a whole series of subsequent innovations—and not the passive, adaptive process often assumed in much diffusion research (see Hall in this volume). The systemic interdependencies between the initial and induced innovations also imply that innovations (and growth) “tend to concentrate in certain sectors and their surroundings” or “clusters” (Schumpeter 1939: 100–1). Schumpeter, as is well known, looked at this dynamic as a possible explanatory factor behind business cycles of various lengths (Freeman and Louçá 2001).

This simple scheme has been remarkably successful in inspiring applications in different areas. For instance, there is a large amount of research that has adapted the Marx–Schumpeter model of technological competition to the study of industrial growth, international trade, and competitiveness,<sup>18</sup> although sometimes, it must be said, without acknowledging the source for these ideas. An early and very influential contribution was the so-called “product-life-cycle theory” suggested by Vernon (1966), in which industrial growth following an important product innovation was seen as composed of stages, characterized by changing conditions of and location of production.<sup>19</sup> Basically what was assumed was that the ability to do product innovation mattered most at the early stage, in which there were many different and competing versions of the product on the market. However, with time, the product was assumed to standardize, and this was assumed to be accompanied by a greater emphasis on process innovation, scale economics, and cost-competition. It was argued that these changes in competitive conditions might initiate transfer of the technology from the innovator country (high income) to countries with large markets and/or low costs. Such transfers might also be associated with international capital flows in the form of so-called foreign direct investments (FDIs), and the theory has therefore also become known as a framework for explaining such flows (see Narula and Zanfei in this volume).

The “product-life-cycle theory,” attractive as it was in its simplicity, was not always corroborated by subsequent research. While it got some of the general conjectures (borrowed from Schumpeter) right, the rigorous scheme it added,

with well-defined stages, standardization, and changing competitive requirements, was shown to fit only a minority of industries (Walker 1979; Cohen 1995). Although good data are hard to come by, what emerges from empirical research is a much more complex picture,<sup>20</sup> with considerable differences across industrial sectors in the way this dynamic is shaped. As exemplified by the taxonomy suggested by Pavitt (see Box 1.4), exploration of such differences (“industrial dynamics”) has evolved into one of the main areas of research within innovation studies (see in this volume:

#### Box 1.4 What is high-tech? Pavitt's taxonomy

The degree of technological sophistication, or innovativeness, of an industry or sector is something that attracts a lot of interest, and there have been several attempts to develop ways of classifying industries or sectors according to such criteria. The most widely used in common parlance is probably the distinction between “high-tech,” “medium-tech,” and “low-tech,” although it is not always clear exactly what is meant by this. Often it is equated with high, medium, and low R&D intensity in production (or value added), either directly (in the industry itself) or including R&D embodied in machinery and other inputs. Based on this, industries such as aerospace, computers, semiconductors, telecommunications, pharmaceuticals, and instruments are commonly classified as “high-tech,” while “medium-tech” typically include electrical and non-electrical machinery, transport equipment, and parts of the chemical industries. The remaining, “low-tech,” low R&D category, then, comprises industries such as textiles, clothing, leather products, furniture, paper products, food, and so on (Fagerberg 1997; see Smith in this volume for an extended discussion).

However, while organized R&D activity is an important source of innovation in contemporary capitalism, it is not the only one. A focus on R&D alone might lead one to ignore or overlook innovation activities based on other sources, such as skilled personnel (engineers, for instance), learning by doing, using, interacting, and so forth. This led Pavitt (1984) to develop a taxonomy or classification scheme which took these other factors into account. Based a very extensive data-set on innovation in the UK (see Smith in this volume), he identified two (“high-tech”) sectors in the economy, both serving the rest of the economy with technology, but very different in terms of how innovations were created. One, which he labeled “science-based,” was characterized by a lot of organized R&D and strong links to science, while another—so-called “specialized suppliers” (of machinery, instruments, and so on)—was based on capabilities in engineering, and frequent interaction with users. He also identified a scale-intensive sector (transport equipment, for instance), also relatively innovative, but with fewer repercussions for other sectors. Finally, he found a number of industries that, although not necessarily non-innovative in every respect, received most of their technology from other sectors.

An important result of Pavitt's analysis was the finding that the factors leading to successful innovation differ greatly across industries/ sectors. This obviously called into question technology or innovation policies that only focused on one mechanism, such as, for instance, subsidies to R&D.



Ch. 14 by Malerba; Ch. 15 by VonTunzelmann and Acha; Ch. 16 by Miles). Inspired, to a large extent, by the seminal work by Nelson and Winter (see Box 1.5), research in this area has explored the manner in which industries and sectors differ in terms of their internal dynamics (or “technological regimes”: see Malerba and Orsenigo 1997), focusing, in particular, on the differences across sectors in knowledge bases, actors, networks, and institutions (so called “sectoral systems”: see Malerba, Ch. 14 in this volume). An important result from this research is that, since the factors that influence innovation differ across industries, policy makers have to take such differences into account when designing policies. The same policy (and policy instruments) will not work equally well everywhere.

### Box 1.5 Industrial dynamics—an evolutionary interpretation

The book *An Evolutionary Theory of Economic Change* (1982) by Richard Nelson and Sidney Winter is one of the most important contributions to the study of innovation and long run economic and social change. Nelson and Winter share the Schumpeterian focus on “capitalism as an engine of change.” However, building on earlier work by Herbert Simon and others (so-called “procedural” or “bounded” rationality), Nelson and Winter introduce a more elaborate theoretical perspective on how firms behave. In Nelson and Winter’s models, firms’ actions are guided by routines, which are reproduced through practice, as parts of the firms’ “organizational memory.” Routines typically differ across firms. For instance, some firms may be more inclined towards innovation, while others may prefer the less demanding (but also less rewarding) imitative route. If a routine leads to an unsatisfactory outcome, a firm may use its resources to search for a new one, which—if it satisfies the criteria set by the firm—will eventually be adopted (so-called “satisficing” behavior).

Hence, instead of following the common practice in much economic theorizing of extrapolating the characteristics of a “representative agent” to an entire population (so-called “typological thinking”), Nelson and Winter take into account the social and economic consequences of interaction within populations of heterogeneous actors (so-called “population thinking”). They also emphasize the role of chance (the stochastic element) in determining the outcome of the interaction. In the book, these outcomes are explored through simulations, which allow the authors to study the consequences of varying the value of key parameters (to reflect different assumptions on technological progress, firm behavior, etc.). They distinguish between an “innovation regime,” in which the technological frontier is assumed to progress independently of firms’ own activities (the “science based” regime), and another in which technological progress is more endogenous and depends on what the firms themselves do (the “cumulative” regime). They also vary the ease/difficulty of innovation and imitation.

Nelson and Winter’s work has been an important source of inspiration for subsequent work on “knowledge-based firms,” “technological regimes,” and “industrial dynamics,” and evolutionary economics more generally, to mention some important topics.

*Sources:* Nelson and Winter 1982; Andersen 1994; Fagerberg 2003.

## 1.6 INNOVATION AND ECONOMIC PERFORMANCE

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The Marx–Schumpeter model was not intended as a model of industrial dynamics; its primary purpose was to explain long run economic change, what Schumpeter called “development.” The core of the argument was (1) that technological competition is the major form of competition under capitalism (and firms not responding to these demands fail), and (2) that innovations, e.g. “new combinations” of existing knowledge and resources, open up possibilities for new business opportunities and future innovations, and in this way set the stage for continuing change. This perspective, while convincing, had little influence on the economics discipline at the time of its publication, perhaps because it did not lend itself easily to formal, mathematical modeling of the type that had become popular in that field. More recently, however, economists (Romer 1990), drawing on new tools for mathematical modeling of economic phenomena, have attempted to introduce some of the above ideas into formal growth models (so-called “new growth theory” or “endogenous growth theory”).<sup>21</sup>

In developing this perspective, Schumpeter (1939) was, as noted, particularly concerned with the tendency of innovations to “cluster” in certain contexts, and the resulting structural changes in production, organization, demand, etc. Although these ideas were not well received by the economic community at the time, the big slump in economic activity worldwide during the 1970s led to renewed attention, and several contributions emerged viewing long run economic and social change from this perspective. Both Mensch (1979) and Perez (1983, 1985), to take just two examples, argued that major technological changes, such as, for instance, the ICT revolution today, or electricity a century ago, require extensive organizational and institutional change to run their course. Such change, however, is difficult because of the continuing influence of existing organizational and institutional patterns. They saw this inertia as a major growth-impeding factor in periods of rapid technological change, possibly explaining some of the variation of growth over time (e.g. booms and slumps) in capitalist economies. While the latter proposition remains controversial, the relationship between technological, organizational, and institutional change continues to be an important research issue (Freeman and Louçã 2001), with important implications both for the analysis of the diffusion of new technologies (see Hall in this volume) and the policy discourse (see Lundvall and Borrás in this volume).

Although neither Marx nor Schumpeter applied their dynamic perspective to the analysis of cross-national differences in growth performance, from the early 1960s onwards several contributions emerged that explore the potential of this perspective for explaining differences in cross-country growth. In what came to be a very influential contribution, Posner (1961) explained the difference in economic growth

between two countries, at different levels of economic and technological development, as resulting from two sources: innovation, which enhanced the difference, and imitation, which tended to reduce it. This set the stage for a long series of contributions, often labeled “technology gap” or “north–south” models (or approaches), focusing on explaining such differences in economic growth across countries at different levels of development (see Fagerberg 1994, 1996 for details). As for the lessons, one of the theoretical contributors in this area summed it up well when he concluded that: “Like Alice and the Red Queen, the developed region has to keep running to stay in the same place” (Krugman 1979: 262).

A weakness of much of this work was that it was based on a very stylized representation of the global distribution of innovation, in which innovation was assumed to be concentrated in the developed world, mainly in the USA. In fact, as argued by Fagerberg and Godinho in this volume, the successful catch-up in technology and income is normally not based only on imitation, but also involves innovation to a significant extent. Arguably, this is also what one should expect from the Schumpeterian perspective, in which innovation is assumed to be a pervasive phenomenon. Fagerberg (1987, 1988) identified three factors affecting differential growth rates across countries: innovation, imitation, and other efforts related to the commercial exploitation of technology. The analysis suggested that superior innovative activity was the prime factor behind the huge difference in performance between Asian and Latin American NIC countries in the 1970s and early 1980s. Fagerberg and Verspagen (2002) likewise found that the continuing rapid growth of the Asian NICs relative to other country groupings in the decade that followed was primarily caused by the rapid growth in the innovative performance of this region. Moreover, it has been shown (Fagerberg 1987; Fagerberg and Verspagen 2002) that, while imitation has become more demanding over time (and hence more difficult and/or costly to undertake), innovation has gradually become a more powerful factor in explaining differences across countries in economic growth.

## 1.7 WHAT DO WE KNOW ABOUT INNOVATION? AND WHAT DO WE NEED TO LEARN MORE ABOUT?

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Arguably, we have a good understanding of the role played by innovation in long run economic and social change, and many of its consequences:

- The function of innovation is to introduce novelty (variety) into the economic sphere. Should the stream of novelty (innovation) dry up, the economy will settle into a “stationary state” with little or no growth (Metcalfe 1998). Hence, innovation is crucial for long-term economic growth.
- Innovation tends to cluster in certain industries/sectors, which consequently grow more rapidly, implying structural changes in production and demand and, eventually, organizational and institutional change. The capacity to undertake the latter is important for the ability to create and to benefit from innovation.
- Innovation is a powerful explanatory factor behind differences in performance between firms, regions, and countries. Firms that succeed in innovation prosper, at the expense of their less able competitors. Innovative countries and regions have higher productivity and income than the less innovative ones. Countries or regions that wish to catch up with the innovation leaders face the challenge of increasing their own innovation activity (and “absorptive capacity”) towards leader levels (see Godinho and Fagerberg in this volume).

Because of these desirable consequences, policy makers and business leaders alike are concerned with ways in which to foster innovation. Nevertheless, in spite of the large amount of research in this area during the past fifty years, we know much less about why and how innovation occurs than what it leads to. Although it is by now well established that innovation is an organizational phenomenon, most theorizing about innovation has traditionally looked at it from an individualistic perspective, as exemplified by Schumpeter’s “psychological” theory of entrepreneurial behavior (Fagerberg 2003). Similarly, most work on cognition and knowledge focuses on individuals, not organizations. An important exception was, of course, Nelson and Winter (1982), whose focus on “organizational memory” and its links to practice paved the way for much subsequent work in this area.<sup>22</sup> But our understanding of how knowledge—and innovation—operates at the organizational level remains fragmentary and further conceptual and applied research is needed.

A central finding in the innovation literature is that a firm does not innovate in isolation, but depends on extensive interaction with its environment. Various concepts have been introduced to enhance our understanding of this phenomenon, most of them including the terms “system” or (somewhat less ambitious) “network.” Some of these, such as the concept of a “national system of innovation,” have become popular among policy makers, who have been constrained in their ability to act by lack of a sufficiently developed framework for the design and evaluation of policy. Still, it is a long way from pointing to the systemic character of innovation processes (at different levels of analysis), to having an approach that is sufficiently developed to allow for systematic analysis and assessment of policy issues. Arguably, to be really helpful in that regard, these system approaches are in need of substantial elaboration and refinement (see the chapter by Edquist in this volume).

One obstacle to improving our understanding is that innovation has been studied by different communities of researchers with different backgrounds, and the failure of these communities to communicate more effectively with one another has impeded progress in this field. One consequence of these communication difficulties has been a certain degree of “fuzziness” with respect to basic concepts, which can only be improved by bringing these different communities together in a constructive dialogue, and the present volume should be seen as a contribution towards this aim. Different, and to some extent competing, perspectives should not always be seen as a problem: many social phenomena are too complex to be analyzed properly from a single disciplinary perspective. Arguably, innovation is a prime example of this.

## NOTES

1. I wish to thank my fellow editors and contributors for helpful comments and suggestions. Thanks also to Ovar Andreas Johansson for assistance in the research, Sandro Mendonça for his many creative inputs (which I unfortunately have not have been able to follow to the extent that he deserves), and Louise Earl for good advice. The responsibility for remaining errors and omissions is mine.
2. A consistent use of the terms invention and innovation might be to reserve these for the first time occurrence of the idea/concept and commercialization, respectively. In practice it may not always be so simple. For instance, people may very well conceive the same idea independently of one another. Historically, there are many examples of this; writing, for instance, was clearly invented several times (and in different cultural settings) throughout history (Diamond 1998). Arguably, this phenomenon may have been reduced in importance over time, as communication around the globe has progressed.
3. In the sociological literature on diffusion (i.e. spread of innovations), it is common to characterize any adopter of a new technology, product, or service an innovator. This then leads to a distinction between different types of innovators, depending on how quick they are in adopting the innovation, and a discussion of which factors might possibly explain such differences (Rogers 1995). While this use of the terminology may be a useful one in the chosen context, it clearly differs from the one adopted elsewhere. It might be preferable to use terms such as “imitator” or “adopter” for such cases.
4. Similarly for automobiles: while the idea of a power-driven vehicle had been around for a long time, and several early attempts to commercialize cars driven by steam, electricity, and other sources had been made, it was the incorporation of an internal combustion engine driven by low-cost, easily available petrol that made the product a real hit in the market (Mowery and Rosenberg 1998).
5. A somewhat similar distinction has been suggested by Henderson and Clark (1990). They distinguish between the components (or modules) of a product or service and the way these components are combined, e.g. the product “design” or “architecture.” A change only in the former is dubbed “modular innovation,” change only in the latter “architectural innovation.” They argue that these two types of innovation rely on different types of knowledge (and, hence, create different challenges for the firm).

6. In fact, many economists go so far as to argue that the savings in costs, following a process innovation in a single firm or industry, by necessity will generate additional income and demand in the economy at large, which will “compensate” for any initial negative effects of a process innovation on overall employment. For a rebuttal, see Edquist 2001 and Pianta, Ch. 21 in this volume.
7. Schumpeter 1934: 66.
8. In the sociological literature on innovation, the term “reinvention” is often used to characterize improvements that occur to a product or service, while it is spreading in a population of adopters (Rogers 1995).
9. In the Community Innovation Survey (CIS) firms are asked to qualify novelty with respect to the context (new to the firm, industry or the world at large). See Smith in this volume for more information about these surveys.
10. Kim and Nelson (2000a) suggest the term “active imitation” for producers who, by imitating already existing products, modify and improve them.
11. For instance, in one of his last papers, he pointed out: “To let the murder out and start my final thesis, what is really required is a large collection of industrial and locational monographs all drawn up according to the same plan and giving proper attention on the one hand to the incessant historical change in production and consumption functions and on the other hand to the quality and behaviour of leading personnel” (Schumpeter 1949/1989: 328).
12. Even in cases where the project ultimately is successful in aims, entrepreneurs face the challenge of convincing the leadership of the firm to launch it commercially (which may be much more costly than developing it). This may fail if the leadership of the firm has doubts about its commercial viability. It may be very difficult for management to foresee the economic potential of a project, even if it is “technically” successful. Remember, for instance, IBM director Thomas Watson’s dictum in 1948 that “there is a world market for about five computers” (Tidd et al. 1997: 60)!
13. “A unified homogenous leadership structure is effective for routine trial-and-error learning by making convergent, incremental improvements in relatively stable and unambiguous situations. However, this kind of learning is a conservative process that maintains and converges organizational routines and relationships towards the existing strategic vision . . . although such learning is viewed as wisdom in stable environments, it produces inflexibility and competence traps in changing worlds” (Van de Ven et al. 1999: 117).
14. It would also imply that large countries should be expected to be more innovative than smaller ones, consistent with, for instance, the prediction of so-called “new growth” theory (Romer 1990). See Verspagen in this volume.
15. See, in particular, Ch. 10 by Granstrand (intellectual property rights), Ch. 8 by Mowery and Sampat (universities and public research infrastructure), and Ch. 9 by O’Sullivan (finance).
16. This is essentially what was suggested by Porter (1990).
17. See Fagerberg 2002, 2003 for a discussion of this “Marx–Schumpeter” model.
18. See Fagerberg (1996), Wakelin (1997), and Cantwell, Ch. 20 in this volume for overviews of some of this literature.
19. For a more recent analysis in this spirit, with a lot of empirical case-studies, see Utterback (1994).

20. Available econometric evidence suggests that innovation, measured in various ways (see Smith in this volume), matters in many industries, not only those which could be classified as being in the early stage of the product-cycle (Soete 1987; Fagerberg 1995).
21. For an overview, see Aghion and Howitt (1998). See also the discussion in Fagerberg (2002, 2003), and Ch. 18 by Verspagen in this volume.
22. For a discussion of the role of different types of knowledge in economics, including the organizational dimension, see Cowan et al. (2000) and Ancori et al. (2000).

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