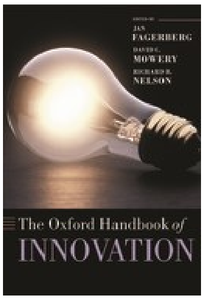

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CHAPTER

14 Sectoral Systems: How and Why Innovation Differs across Sectors

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Abstract

This article briefly discusses the previous literature on differences across sectors in innovation and then puts forward the concept of sectoral systems of innovation. It also discusses the basic building blocks of sectoral systems: knowledge, technological domains, and sectoral boundaries; actors, relationships, and networks; and institutions. Furthermore, this article examines the dynamics and transformation of sectoral systems. Finally, it discusses some policy implications and the challenges ahead. This article looks at a large number of sectors that are highly innovative and technologically advanced and have strong links with science, which nevertheless organize innovation very differently: computers, semiconductors, telecommunication equipment and services, software, chemicals, pharmaceuticals and biotechnology, and machine tools. The role of innovation in the dynamics and transformation of these sectors is highly diverse.

Keywords: innovation, sectoral systems, computers, semiconductors, telecommunication equipment, pharmaceuticals and biotechnology, machine tools

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14.1 Introduction

INNOVATION greatly differs across sectors in terms of characteristics, sources, actors involved, the boundaries of the process, and the organization of innovative activities. A focus on a "representative firm" as the main actor; on narrowly, well defined, and static boundaries as a sector delimitation; on R&D and learning-by-doing as the only two sources of innovation; on competition and formal R&D joint ventures as the only kind of interaction among firms; and on the patent system and public support for R&D as the only relevant institutions and policies that matter for innovation, would capture only part of the action that takes place in sectors and would identify only a few of the key variables that matter for innovation and performance.

A comparison of actors, sources, institutions, and policies for innovation in different sectors (e.g. in pharmaceuticals and biotechnology, chemicals, software, computers, semiconductors,
p. 381 telecommunications, or machine tools) shows striking ↳ differences. The role of innovation in the dynamics and transformation of these sectors is highly diverse.

How is it possible to analyze consistently these differences and their effects on sectoral growth and performance? The industrial economics approach pays a lot of attention to differences across sectors in R&D intensity, market structure, the range of viable R&D strategies and R&D alliances, the intensity of the patent race, the effectiveness of patent protection, the role of competition policy and the extent of R&D support. But, while these are very important factors, they are not the only ones nor are they the most relevant for a full understanding of the differences in innovation across sectors.

A rich and heterogeneous tradition of sectoral studies has clearly shown both that sectors differ in terms of the knowledge base, the actors involved in innovation, the links and relationships among actors, and the relevant institutions, and that these dimensions clearly matter for understanding and explaining innovation and its differences across sectors. However, these case studies are quite different in terms of methodology, variables, and countries examined.

This chapter will briefly discuss the previous literature on differences across sectors in innovation (Section 14.2) and then propose the concept of sectoral systems of innovation (14.3). In the next sections, the basic building blocks of sectoral systems will be discussed: knowledge, technological domains, and sectoral boundaries (14.4); actors, relationships and networks (14.5); and institutions (14.6). Then the dynamics and transformation of sectoral systems (14.7) is examined. Finally, some policy implications (14.8) and the challenges ahead (14.9) are discussed.

The chapter will discuss a large number of sectors that are highly innovative and technologically advanced and have strong links with science, which nevertheless organize innovation very differently: computers, semiconductors, telecommunication equipment and services, software, chemicals, pharmaceuticals and biotechnology, and machine tools. Most of the sectoral examples in this paper are drawn from Mowery and Nelson (1999) and Malerba (2004).

14.2 Previous Literature on Sectoral Differences in Innovation

The literature has advanced some distinctions among sectors in innovation and diffusion based on different dimensions. The simplest one, widely used in international studies by the OECD, EU, and international
p. 382 organizations, refers to sectors ↳ that are high R&D-intensive (such as electronics or drugs) and low R&D-intensive (such as textiles or shoes).

Another distinction, coming from the Schumpeterian legacy, focuses on differences in market structure and industrial dynamics among sectors. Schumpeter Mark I sectors are characterized by "creative destruction," with technological ease of entry and a major role played by entrepreneurs and new firms in innovative activities. Schumpeter Mark II sectors are characterized by "creative accumulation" (in Keith Pavitt's words) with the prevalence of large established firms and the presence of relevant barriers to entry for new innovators. This regime is characterized by the dominance of a stable core of a few large firms, with limited entry. The distinction refers to the early Schumpeter of *Theory of Economic Development* (1911, "Schumpeter Mark I") and to the later one of *Capitalism, Socialism and Democracy* (1942, "Schumpeter Mark II"). Machinery or biotechnology are examples of Schumpeter Mark I sectors, while the semiconductor industry of the 1990s (think of microprocessors and dynamic memories) or mainframe computers in the period 1950s–1990s are examples of Schumpeter Mark II sectors.

Other differences across sectors have been related to technological regimes, a notion introduced by Nelson and Winter (1982), referring to the learning and knowledge environment in which firms operate. A specific technological regime defines the nature of the problem firms have to solve in their innovative activities, affects the model form of technological learning, shapes the incentives and constraints to particular behavior and organization, and influences the basic processes of variety generation and selection (and therefore the dynamics and evolution of firms). More generally, Malerba and Orsenigo (1996 and 1997) have proposed that a technological regime is composed by opportunity and appropriability conditions, degrees of cumulativeness of technological knowledge, and characteristics of the relevant knowledge base. More specifically, technological opportunities reflect the likelihood of innovating for any given amount of money invested in search. High opportunities provide powerful incentives to the undertaking of innovative activities and denote an economic environment that is not functionally constrained by scarcity. In this case, potential innovators may come up with frequent and important technological innovations. Appropriability of innovations summarizes the possibilities of protecting innovations from imitation and of reaping profits from innovative activities. High appropriability means the existence of ways of successfully protecting innovation from imitation. Low appropriability conditions denote an economic environment characterized by the widespread existence of externalities (Levin et al. 1987). Cumulativeness conditions capture the properties that today's innovations and innovative activities form the starting point for tomorrow innovations. More broadly, one may say that high cumulativeness means that today's innovative firms are more likely to innovate in the future in specific technologies and along specific trajectories than non-innovative firms. Cumulativeness may be due to knowledge/cognitive factors, organizational factors, or

market factors of the "success breeds ↳ success" type. The properties of the knowledge base relate to the nature of knowledge underpinning firms' innovative activities. Technological knowledge involves various degrees of specificity, tacitness, complementarity, and independence and may greatly differ across sectors and technologies (Winter 1987). Differences in technological regimes affect the organization of innovative activities at the sectoral level and may lead to a fundamental distinction between Schumpeter Mark I and Schumpeter Mark II models. High technological opportunities, low appropriability, and low cumulativeness (at the firm level) conditions lead to a Schumpeter Mark I pattern. By contrast, high appropriability and high cumulativeness (at the firm level) conditions lead to a Schumpeter Mark II pattern: think again of the semiconductor industry of the 1990s (i.e. microprocessors and dynamic memories) and mainframe computers in the period 1950s–1990s.

Technological regimes and Schumpeterian patterns of innovation change over time (Klepper 1996). According to an industry life-cycle view, a Schumpeter Mark I pattern of innovative activities may turn into a Schumpeter Mark II. Early in the history of an industry—when knowledge is changing very rapidly, uncertainty is very high, and barriers to entry very low—new firms are the major innovators and are the key elements in industrial dynamics. When the industry develops and eventually matures and technological change follows well-defined trajectories, economies of scale, learning curves, barriers to entry, and financial resources become important in the competitive process. Thus, large firms with monopolistic power come to the forefront of the innovation process (Utterback 1994; Gort and Klepper 1982; Klepper 1996). In the presence of major knowledge, technological, and market discontinuities, a Schumpeter Mark II pattern of innovative activities may be replaced by a Schumpeter Mark I. In this case, a rather stable organization characterized by incumbents with monopolistic power is displaced by a more turbulent one with new firms using the new technology or focusing on the new demand (Henderson and Clark 1990; Christensen and Rosenbloom 1995). Although rather archetypical, these analyses point to the direction of placing a lot of attention to differences across sectors in some key factors related to knowledge and learning regimes. As the examples discussed above suggest, change over time also reflects institutional change and the coevolution of industries and institutions.

Other distinctions refer to sectors that are net suppliers of technology and sectors that are users of technology. On the bases of the R&D done by 400 American firms and of intersectoral flows in the American economy, Scherer (1982) identifies sectors that are net sources of R&D for other sectors (such as computers and instruments), and sectors that are net users of technology (such as textiles and metallurgy). A similar analysis is done by Robson et al. (1988) who, on the basis of 4,378 innovations in the UK between 1945 and 1983, identify (*a*) "core sectors" (such as electronics, machinery, instruments, and chemicals) which generate most of innovations in the economy and are net sources of technology, (*b*) secondary sectors (such
p. 384 as auto and metallurgy) which play a secondary role in ↳ terms of sources of innovation for the economy, and (*c*) user sectors such as services which mainly absorb technology.

A key difference among sectors refers to the sources of innovation and the appropriability mechanisms. Pavitt (1984) proposes four types of sectoral pattern for innovative activities. In supplier-dominated (e.g. textile, services) sectors, new technologies are embodied in new components and equipment, and the diffusion of new technologies and learning takes place through learning-by-doing and by-using. In scale-intensive sectors (e.g. autos, steel), process innovation is relevant and the sources of innovation are both internal (R&D and learning-by-doing) and external (equipment producers), while appropriability is obtained through secrecy and patents. In specialized suppliers (e.g. equipment producers), innovation is focused on performance improvement, reliability, and customization, with the sources of innovation being both internal (tacit knowledge and experience of skilled technicians) and external (user–producer interaction); appropriability comes mainly from the localized and interactive nature of knowledge. Finally, science-based sectors (e.g. pharmaceuticals, electronics) are characterized by a high rate of product and process innovations, by internal R&D, and by scientific research done at universities and public research laboratories; science is a source of innovation, and appropriability means are of various types, ranging from patents, to lead-times and learning curves, and to secrecy. The Pavitt taxonomy has been tremendously successful in empirical research and has guided the identification of firms and country advantages. Refinements and enrichments of the taxonomy have been proposed in the following decades. A very interesting and relevant work in this direction is the one by Marsili (2001).

Differences across sectors in appropriability conditions have been examined by Levin et al. (1987), PACE (1996) and Cohen et al. (2002) using survey questionnaires for R&D managers in the United States, Europe, and Japan, following the pioneering Yale survey. Here, major differences across sectors have been identified in terms of appropriability means—patents, secrecy, lead-times, learning curves, and complementary assets. All these surveys have found major differences across sectors in the use of patents.

14.3 Sectoral Systems of Innovation

The contributions examined above focus on a specific difference among sectors. In this and the following sections, a multidimensional, integrated, and dynamic view of innovation in sectors is proposed, related to
p. 385 the framework of sectoral systems of ↳ innovation, which provides a methodology for the analysis and comparison of sectors.

A sector is a set of activities that are unified by some linked product groups for a given or emerging demand and which share some common knowledge. Firms in a sector have some commonalities and at the same time are heterogeneous. A sectoral system framework focuses on three main dimensions of sectors:

(a) Knowledge and technological domain

(b) Actors and networks

(c) Institutions

(a) Knowledge and technological domain. Any sector may be characterized by a specific knowledge base, technologies and inputs. In a dynamic way, the focus on knowledge and the technological domain places at the centre of the analysis the issue of sectoral boundaries, which usually are not fixed, but change over time.

(b) Actors and networks. A sector is composed of heterogeneous agents that are organizations or individuals (e.g. consumers, entrepreneurs, scientists). Organizations may be firms (e.g. users, producers, and input suppliers) or non-firms (e.g. universities, financial institutions, government agencies, trade-unions, or technical associations), and include subunits of larger organizations (e.g. R&D or production departments) and groups of organizations (e.g. industry associations). Agents are characterized by specific learning processes, competencies, beliefs, objectives, organizational structures, and behaviors, which interact through processes of communication, exchange, cooperation, competition, and command.

Thus, in a sectoral system framework, innovation is considered to be a process that involves systematic interactions among a wide variety of actors for the generation and exchange of knowledge relevant to innovation and its commercialization. Interactions include market and non-market relations that are broader than the market for technological licensing and knowledge, interfirm alliances, and formal networks of firms, and often their outcome is not adequately captured by our existing systems of measuring economic output.

(c) Institutions. Agents' cognition, actions, and interactions are shaped by institutions, which include norms, routines, common habits, established practices, rules, laws, standards, and so on. Institutions may range from ones that bind or impose enforcements on agents to ones that are created by the interaction among agents (such as contracts); from more binding to less binding; from formal to informal (such as patent laws or specific regulations vs. traditions and conventions). A lot of institutions are national (such as the patent system), while others are specific to sectors (such as sectoral labor markets or sector specific financial institutions).

Over time, a sectoral system undergoes processes of change and transformation through the coevolution of its various elements.

p. 386 The notion of sectoral system of innovation and production complements other concepts within the innovation system literature (Edquist 1997) such as national systems of innovation delimited by national boundaries and focused on the role of non-firm organizations and institutions (Freeman 1987; Nelson 1993; Lundvall 1993), regional/local innovation systems in which the boundary is the region (Cooke et al. 1997), technological systems, in which the focus is on technologies and not on sectors[1] (Carlsson and Stankiewitz

1995; Hughes 1984; Callon 1992), and distributed innovation system (in which the focus is on specific innovations—Andersen et al. 2002).

What are the main differences between a sectoral innovation system and a national innovation system perspective? While national innovation systems take innovation systems as delimited more or less clearly by national boundaries, a sectoral system approach would claim that sectoral systems may have local, national, and/or global dimensions. Often these three different dimensions coexist in a sector. In addition, national innovation systems result from the different composition of sectors, some of which are so important that they drive the growth of the national economy. For example, Japanese growth in the 1970s and 1980s was driven by specific sectors, which were different from the sectors behind the American "resurgence" during the 1990s. Similarly, Italian economic growth is driven by specific sectors. Thus, understanding the key driving sectors of an economy with their specificities greatly helps in understanding national growth and national patterns of innovative activities.

The theoretical and analytical approach of sectoral systems is grounded in the evolutionary theory. Evolutionary theory places a key emphasis on dynamics, innovation processes, and economic transformation. Learning and knowledge are key elements in the change of the economic system. "Boundedly rational" agents act, learn, and search in uncertain and changing environments. Agents know how to do different things in different ways. Thus learning, knowledge, and behavior entail agents' heterogeneity in experience and organization. Their different competences affect their persistent differential performance. In addition, evolutionary theory places emphasis on cognitive aspects such as beliefs, objectives, and expectations, which are in turn affected by previous learning and experience and by the environment in which agents act. A central place in the evolutionary approach is occupied by the processes of variety creation (in technologies, products, firms, and organizations), replication (that generates inertia and continuity in the system), and selection (that reduces variety in the economic system and discourages the inefficient or ineffective utilization of resources). Finally, for evolutionary theory, aggregate phenomena are emergent properties of far-from-equilibrium interactions and have a metastable nature (Nelson 1995; Dosi 1997; Metcalfe 1998). Here, the environment and conditions in which agents operate may drastically differ. Evolutionary theory stresses major differences in opportunities related to
p. 387
science and technologies. The same holds for the knowledge base underpinning innovative activities, as ↳ well as for the institutional context. Thus the learning, behavior, and capabilities of agents are constrained and "bounded" by the technology, knowledge base, and institutional context. Heterogeneous firms facing similar technologies, searching around similar knowledge bases, undertaking similar production activities, and "embedded" in the same institutional setting, share some common behavioral and organizational traits and develop a similar range of learning patterns, behavior, and organizational forms.

One last remark regards the aggregation issue regarding products, agents or functions. For example, sectoral systems may be examined broadly or narrowly (in terms of a small set of product groups).[2] A broad definition allows us to capture all the interdependencies and linkages in the transformation of sectors, while a narrow definition identifies more clearly specific relationships. Of course, within broad sectoral systems, different innovation systems related to different product groups may exist. The choice of the level of aggregation depends on the goal of the analysis.

In the following pages we will concentrate on each block of a sectoral system of innovation and production:

- Knowledge, technological domain, and boundaries
- Agents, interaction and networks
- Institutions

14.4 Knowledge, Technological Domain, and Sectoral Boundaries

Knowledge plays a central role in innovation. Knowledge is highly idiosyncratic at the firm level, does not diffuse automatically and freely among firms, and has to be absorbed by firms through their differential abilities accumulated over time. The evolutionary literature has proposed that sectors and technologies differ greatly in terms of the knowledge base and learning processes related to innovation. Knowledge differs across sectors in terms of domains. One knowledge domain refers to the specific scientific and technological fields at the base of innovative activities in a sector (Dosi 1988; Nelson and Rosenberg 1993), while another comprises applications, users, and the demand for sectoral products. Recently a major discontinuity has taken place in the processes of knowledge accumulation and distribution with the emergence of the knowledge-based economy which has redefined existing sectoral boundaries, affected relationships among actors, reshaped the innovation process, and modified the links among sectors (Nelson 1995; Dosi 1997; Metcalfe 1998; Lundvall 1993; Lundvall and Johnson 1994).

 What do we know about the main dimensions of knowledge? First, knowledge may have different degrees of accessibility (Malerba and Orsenigo 2000), i.e. opportunities of gaining knowledge external to firms, which in turn may be internal or external to the sector. In both cases, greater accessibility of knowledge may decrease industrial concentration. Greater accessibility internal to the sector implies lower appropriability: competitors may gain knowledge about new products and processes and, if competent, imitate those new products and processes. Accessibility of knowledge that is external to the sector may be related to the levels and sources of scientific and technological opportunities. Here, the external environment may affect firms through human capital with a certain level and type of knowledge or through scientific and technological knowledge developed in firms or non-firm organizations, such as universities or research laboratories (Malerba and Orsenigo 2000).

The sources of technological opportunities differ markedly among sectors. As Freeman (1982) and Rosenberg (1982), among others, have shown, in some sectors opportunity conditions are related to major scientific breakthroughs in universities; in others, opportunities to innovate may often come from advancements in R&D, equipment, and instrumentation; while in still other sectors, external sources of knowledge in terms of suppliers or users may play a crucial role. Not all external knowledge may be easily used and transformed into new artifacts. If external knowledge is easily accessible, transformable into new artifacts and exposed to a lot of actors (such as customers or suppliers), then innovative entry may take place (Winter 1984). If advanced integration capabilities are necessary (Cohen and Levinthal 1989), the industry may be concentrated and formed by large, established firms.

Second, knowledge may be more or less cumulative, i.e. the degree by which the generation of new knowledge builds upon current knowledge. One can identify three different sources of cumulativeness.

(1) Cognitive. The learning processes and past knowledge constrain current research, but also generate new questions and new knowledge.

(2) The firm and its organizational capabilities. Organizational capabilities are firm-specific and generate knowledge which is highly path-dependent. They implicitly define what a firm learns and what it can hope to achieve in the future.

(3) Feedbacks from the market, such as in the "success-breeds-success" process. Innovative success yields profits that can be reinvested in R&D, thereby increasing the probability to innovate again.

High cumulativeness implies an implicit mechanism leading to high appropriability of innovations. In the case of knowledge spillovers within an industry, however, it is also possible to observe cumulativeness at the sectoral level. Cumulativeness may also be present at the local level. In this case, high cumulativeness

p. 389 within specific locations is more likely to be associated with low appropriability conditions and spatially ↳ localized knowledge spillovers. Finally, cumulativeness at the technological and firm levels createsfirstmover advantages and generates high concentration. Firms that have a head start develop a new knowledge based on the current one and introduce continuous innovations of the incremental type.

Accessibility, opportunity, and cumulativeness are key dimensions of knowledge related to the notion of technological and learning regimes (Nelson and Winter 1982; Malerba and Orsenigo 1997), which, as seen above, may differ across sectors. Other dimensions of knowledge could be related to its tacitness, codificability, complexity, systemic features, scientific base, and so on (Winter 1987; Cowan, David, and Foray 2000).

The boundaries of sectoral systems are affected by the knowledge base and technologies. However, the type and dynamics of demand represent a major factor in the processes of transformation of sectoral systems. The same holds for links and complementarities among artifacts and activities. These links and complementarities are, first of all, of the static type, as are input–output links. Then there are dynamic complementarities, which take into account interdependencies and feedbacks, both at the demand and at the production levels. Dynamic complementarities among artifacts and activities are major sources of transformation and growth of sectoral systems, and may set in motion virtuous cycles of innovation and change. This could be related to the concept of filiere and the notion of development blocks (Dahmen 1989). Links and complementarities change over time and greatly affect a wide variety of variables of a sectoral system: firms' strategies, organization, and performance; the rate and direction of technological change; the type of competition; and the networks among agents. Thus the boundaries of sectoral systems may change more or less rapidly over time, as a consequence of dynamic processes related to the transformation of knowledge, the evolution and convergence in demand, and changes in competition and learning by firms.

In general, the features and sources of knowledge affect the rate and direction of technological change, the organization of innovative and production activities, and the factors at the base of firms' successful performance.

Great differences among sectors in the dimensions discussed above exist. Let us compare, for example, pharmaceuticals and machine tools. In the pharmaceutical industry, the knowledge base and the learning processes have greatly affected innovation and the organization of innovative activities. In the early stages (1850–1945), the industry was close to chemicals, with little formal research until the 1930s and a major use of licenses. The following period (1945–early 1980s) was characterized by the introduction of random screening of natural and chemically derived compounds. This led to an explosion of R&D and, although few blockbusters were discovered in each period, nevertheless, each period enjoyed high growth. The advent of molecular biology since the 1980s led to a new learning regime based on molecular genetics and rDNA technology, with two search regimes: one regarding specialized technologies, the other generic
p. 390 technologies. Nowadays, no individual ↳ firm can gain control on more than a subset of the search space. Innovation increasingly depends on strong scientific capabilities and on the ability to interact with science and scientific institutions in order to explore the search space (McKelvey, Orsenigo, and Pammolli 2004; Henderson, Orsenigo, and Pisano 1999).

In machine tools, innovation has been mainly incremental and now is increasingly systemic. Knowledge about applications is very important, and therefore user– producer relationships as well as partnerships with customers are common. The knowledge base has been embodied in skilled personnel on the shop floor level (with applied technical qualification) and in design engineers (not necessarily with a university degree but with long-term employment in the company). Internal training (particularly apprenticeships) is quite relevant. In small firms, R&D is not done extensively and R&D cooperation is not common. Recently, the knowledge base has shifted from purely mechanical to mechanic, microelectronic and information intensive, with an increasing codification and an increasing use of formal R&D. Products have increasingly being modularized and standardized. A key role is also played by information flows about components coming from producers of different technologies, such as lasers, materials, measurement, and control devices. Nowadays, many large machine tool companies operate already on an international basis making use of specific knowledge sources at their different firm sites (Wengel and Shapira 2004; Mazzoleni 1999).

14.5 Actors, Relationships, and Networks

Sectoral systems are composed of heterogeneous actors. In general, a rich, multidisciplinary, and multisource knowledge base and rapid technological change implies a great heterogeneity of actors in most sectors.

Firms are the key actors in the generation, adoption, and use of new technologies, are characterized by specific beliefs, expectations, goals, competences, and organization, and are continuously engaged in processes of learning and knowledge accumulation (Nelson and Winter 1982; Malerba 1992, Teece and Pisano 1994, Dosi, Marengo, and Fagiolo 1998, Metcalfe 1998). The extent of firm heterogeneity is the result of the opposing forces of variety creation, replication, and selection (Nelson 1995; Metcalfe 1998). Selection increases homogeneity, while entry and technological and organizational innovations are fundamental sources of heterogeneity. Firm heterogeneity is also affected by the characteristics of the knowledge base, specific experience and learning processes, and the working of dynamic complementarities.

p. 391 Actors also include users and suppliers who have different types of relationships with the innovating, producing, or selling firms. Users and suppliers are characterized by specific attributes, knowledge, and competencies, with more or less close relationships with producers (Von Hippel 1988, Lundvall 1993). As previously mentioned, in a dynamic and innovative setting, suppliers and users greatly affect and continuously redefine the boundaries of a sectoral system.

Other types of agents in a sectoral system are non-firm organizations such as universities, financial organizations, government agencies, local authorities, and so on. In various ways, they support innovation, technological diffusion, and production by firms, but again their role greatly differs among sectoral systems. In several high technology sectors, universities play a key role in basic research and human capital formation, and in some sectors (such as biotechnology and software) they are also a source of start-ups and even innovation. In sectoral systems such as software or biotechnology–pharmaceuticals, new actors such as venture capital companies have emerged over time. These financial organizations have played a different role according to the stage of the industry life-cycle. When industry matures or large firms are relevant, capital constraints become lighter and much investment is self-financed. By contrast, for start-ups in emerging or new high-tech sectors, capital constraints are very high and specific financial intermediaries such as venture capital firms are important (Rivaud-Danset 2001; Dubocage 2002).

Often the most appropriate units of analysis in specific sectoral systems are not necessarily firms but individuals (such as the scientist who opens up a new biotechnology firm), firms' subunits (such as the R&D or the production department), and groups of firms (such as industry consortia).

The focus on users, government agencies, and consumers puts a different emphasis on the role of demand. In a sectoral system, demand is not seen as an aggregate set of similar buyers or atomistic undifferentiated customers, but as composed of heterogeneous agents who interact in various ways with producers. Demand then becomes composed by individual consumers, firms, and public agencies, which are in turn characterized by knowledge, learning processes, and competences, and which are affected by social factors and institutions. The emergence and transformation of demand become then a very important part in the dynamics and evolution of sectoral systems. In addition, demand has often proven to be a major factor in the redefinition of the boundaries of a sectoral system, a stimulus for innovation, and a key factor shaping the organization of innovative and production activities.

Within sectoral systems, heterogeneous agents are connected in various ways through market and non-market relationships. It is possible to identify different types of relations, linked to different analytical cuts. First, traditional analyses of industrial organizations have examined agents as involved in processes of exchange, competition, and command (such as vertical integration). Second, in more recent analyses, p. 392 processes of formal cooperation or informal interaction among firms or ↳ among firms and non-firm organizations have been examined in depth (as one may see from the literature on tacit or explicit collusion, or hybrid governance forms, or formal R&D cooperation). This literature has analyzed firms with certain market power, suppliers or users facing opportunistic behavior or asset specificities in transaction, and firms with similar knowledge having appropriability and indivisibility problems in R&D. Finally, the evolutionary approach and the innovation systems literature have also paid a lot of attention to the wide range of formal and informal cooperation and interaction among firms. However, according to this perspective, in uncertain and changing environments networks emerge not because agents are similar, but because they are different. Thus, networks integrate complementarities in knowledge, capabilities, and specialization (see Lundvall 1993; Edquist 1997; Nelson 1995; Teubal et al. 1991). Relationships between firms and non-firm organizations (such as universities and public research centers) have been a source of innovation and change in several sectoral systems: pharmaceuticals and biotechnology, information technology, and telecommunications have been relevant (Nelson and Rosenberg 1993).

One final observation needs to be made: the key role played by networks in a sectoral system leads to a meaning of the term "sectoral structure" different from the one used in industrial economics. In industrial economics, structure is related mainly to the concept of market structure and of vertical integration and diversification. In a sectoral system perspective, on the contrary, structure refers to links among artifacts and to relationships among agents: it is therefore far broader than the one based on exchange–competition–command. Thus we can say that a sectoral system is composed of webs of relationships among heterogeneous agents with different beliefs, goals, competencies, and behavior, and that these relationships affect agents' actions. They are rather stable over time.

In summary, the types and structures of relationships and networks differ greatly from sectoral system to sectoral system, as a consequence of the features of the knowledge base, the relevant learning processes, the basic technologies, the characteristics of demand, the key links, and the dynamic complementarities. Again, let's provide some examples.

Again, the comparison of four quite different sectoral systems, such as chemicals, computers, semiconductors, and software, illustrates this point. In chemicals, the structure of the sectoral system has been centered around large firms, which have been the major source of innovation over a long period of time. Large R&D expenditures, economies of scale and scope (Chandler 1990), cumulativeness of technical advance, and commercialization capabilities have given these firms major innovative and commercial advantages (Arora, et al. 1998). With the diffusion of the synthetic dyestuff model, firms scaled up their R&D departments and the role of universities increased. The introduction of polymer chemistry (1920s) affected the structure of the industry because knowledge about the characteristics of different market segments p. 393 became important, so that firms had to ↳ develop extensive linkages with downstream markets. The other major change related to the development of chemical engineering and the concept of unit of operation led to an increasing division of labor between chemical companies and technology suppliers, with the rise of the specialized engineering firms (SEFs), which developed vertical links with chemical companies. In this period, university research continued to be important for the development of innovations, and links between universities and industry increased. In addition, advances in chemical disciplines and the separability of knowledge increased the transferability of chemical technologies. Thus, there has been a greater role of licensing also by large firms, which in turn increased knowledge diffusion.

In computers, the different stages of the evolution of the industry (related to different products) have been characterized by different actors and networks. Having been a typical Schumpeter Mark II sector for most of its history (until very recently), mainframe computers have always been dominated by large firms, with high cumulativeness of technical advance. In particular, during the 1960s and 1970s, mainframes were produced and integrated by vertically integrated firms, and IBM was the typical example. IBM was producing both components and systems and was active in the development, manufacturing, marketing, and distribution of large systems and of the key components. When minicomputers were introduced, the computers sector experienced the entry and growth of firms specialized in components or in systems (with the early years characterized by a Schumpeter Mark I pattern). The same holds for the early years of microcomputers. Later on, however, competition became characterized by groups of specialized firms related to different platforms. Each platform was characterized by divided technical leadership of several disintegrated firms. Innovation became decentralized, and the control over the direction by a single firm became very difficult. Recently, in computer networks, modularity and connectedness increased the role of networks of firms with local development and local feedbacks (Bresnahan and Greenstein 1999; Bresnahan and Malerba, 1999).

In semiconductors, the industry has been characterized by a quite different set of actors, ranging from merchant semiconductor manufacturers to vertically integrated producers. The types of actors have been quite different from period to period and from country to country during the evolution of the industry. New entrants and specialized producers were quite relevant in the United States, with entrants particularly high either early on in the history of the industry or during phases of technological discontinuities (and giving the industry a typical Schumpeter Mark I fashion in these periods of rapid and radical change). Large, vertically integrated producers were more common in Japan and Europe (Malerba 1985; Langlois and Steinmueller 1999). Thus, in these countries a Schumpeter Mark II mode characterized the industry. In semiconductors, other main actors have played a major role. The military was one of the major factors responsible for the growth of the American industry, compared to Europe and Japan, because it supported
 the entry of new firms and provided competent firms with a large and ↳ innovative demand. During the 1970s in Japan, MITI was a major factor in allowing the Japanese industry (composed of large producers) to close the gap with American producers in some product ranges (such as memory devices).

In software, specialization of both global players and local producers is present. In addition, the changing knowledge base has created an evolving division of labor among users, "platform" developers, and specialized software vendors (Bresnahan and Greenstein 1998). The sectoral system of innovation in software, however, is incomplete without the addition of companies that utilize these platforms to deliver enterprise-critical applications. Many of these applications continue to be produced in-house by organizations using the tools provided as part of the platform or available from the development tools markets (Steinmueller 2004).

14.6 Institutions

In all sectoral systems, institutions play a major role in affecting the rate of technological change, the organization of innovative activity, and performance. They may emerge either as a result of deliberated planned decision by firms or other organizations, or as the unpredicted consequence of agents' interaction.

Some institutions are sectoral, i.e. specific to a sector, while others are national. The relationship between national institutions and sectoral systems is quite important in most sectors. National institutions have different effects on sectors. For example, the patent system, property rights, or antitrust regulations have different effects as a consequence of the different features of the systems, as surveys and empirical analyses have shown (see for example Levin et al. 1987). However, the same institution may take different features in different countries, and thus may affect the same sectoral system differently. For example, the well-known diversity between the first-to-invent and the first-to-file rules in the patent systems in the United States and in Japan had major consequences on the behavior of firms in these two countries. Often, the characteristics of national institutions favor specific sectors that fit better the specificities of the national institutions. Thus, in certain cases, some sectoral systems become predominant in a country because the existing institutions of that country provide an environment more suitable for certain types of sectors and not for others. For example, in France, sectors related to public demand have grown considerably (Chesnais 1993). In other cases, national institutions may constrain development or innovation in specific sectors, or mismatches between national and sectoral institutions and agents may take place. The examples of the different types of interaction between national institutions and sectoral evolution in various advanced countries in Dosi and Malerba (1996) are cases in point.

p. 395 The relationship between national institutions and sectoral systems is not always one-way, as it is in the case of the effects of national institutions on sectoral variables. Sometimes, the direction is reversed, and goes from the sectoral to the national level. In fact, it may occur that the institutions of a sector, which are extremely important for a country in terms of employment, competitiveness, or strategic relevance, end up emerging as national, thus becoming relevant for other sectors. But in the process of becoming national, they may change some of their original distinctive features.

Again, major differences emerge across sectors, as in the case of pharmaceuticals, software, machine tools, and telecommunications, for example. In pharmaceuticals, national health systems and regulations have played a major role in affecting the direction of technical change, in some cases even blocking or retarding innovation. In addition, patents have played a major role in the appropriability of the returns from innovations. In software, standards and standard setting organizations are important, and IPR play a major role in strengthening appropriability. However, the emerging open source movement aims to create a new segment of the software industry which is characterized by new distribution methods and by cooperative production activities based on voluntary association. This has reduced the possibility of maintaining proprietary control over data structure, thus inducing entry and more competition (Steinmueller 2004). In machine tools, internal and regional labor markets and local institutions (e.g. local banks) have played a major role in influencing international advantages of specific areas. Trust-based, close relationships at the regional level have over a long time ensured a sufficient financing of the innovation and of the expansion plans of family businesses in Germany and Italy (Wengel and Shapira 2004). Finally, in telecommunications, the roles of regulation, liberalization/privatization, and standards have been of major importance in the organization and performance of the sector. As discussed in Dalum and Villumsen (2001), liberalization and privatization have had major effects on the behavior and performance of incumbents and have transformed the structure of the industry. An example of the role of institutions is given by GSM in Europe.

14.7 The Dynamics and Transformation of Sectoral Systems

As mentioned above, at the base of the dynamics and transformation of sectoral systems lies the interplay among evolutionary processes (such as variety creation, replication, and selection) that differ from sector to p. 396 sector (Nelson 1995; Metcalfe ↳ 1998). Processes of variety creation may refer to products, technologies, firms, and institutions, as well as firm strategies and behavior and could take place through entry, R&D, innovation, and so on (Cohen and Malerba 2002). Sectoral systems differ extensively in the processes of variety creation and of heterogeneity among agents. The creation of new agents—both new firms and non-firm organizations—is particularly important for the dynamics of sectoral systems. As examined by Audretsch (1996) and Geroski (1995), among others, the role of new firms differs drastically from sector to sector (in terms of entry rates, composition, and origin), and thus has quite different effects on the features of sectoral systems and their degree of change. Sectoral differences in the level and type of entry seem to be closely related to differences in the knowledge base; level, diffusion and distribution of competences; the presence of non-firm organizations (such as universities and venture capital); and the working of sectoral institutions (such as regulations or labor markets) (Audretsch 1996; Malerba and Orsenigo 1999; McKelvey 1997; Geroski 1995). Processes of selection play the key role of reducing heterogeneity among firms and may drive out inefficient or less progressive firms. They may refer to products, activities, technologies, and so on. In addition to market selection, in several sectoral systems non-market selection processes are at work, as in the cases of the involvement of the military, the health system, and so on. In general, selection affects the growth and decline of the various groups of agents and the range of viable behaviors and organizations. Selection may greatly differ across sectoral systems in terms of intensity and frequency. Theoretical work (see Metcalfe 1998) and empirical work on "competence destroying" innovation, industrial dynamics, firms' entry and exit, and mergers and acquisitions have shed light on several aspects of selection.

Changes in sectoral systems are the result of coevolutionary processes of their various elements, involving knowledge, technology, actors, and institutions. Nelson (1994) and Metcalfe (1998) have discussed these processes at the general level by focusing on the interaction between technology, industrial structure, institutions, and demand. These processes are sector-specific and often path-dependent. Here, local learning, interactions among agents, and networks may generate increasing returns and irreversibilities that may lock sectoral systems into inferior technologies.[3] In addition, the interaction between knowledge, technology firms, and institutions are also shaped by country-specific factors.

In general, one could say that changes in the knowledge base and in the relevant learning processes of firms induce deep transformations in the behavior and structure of the agents and in their relationships between one another. Overall market competition and market structure depend on the strategies and fortunes of individual companies, which are linked to different national contexts or to the international scene. Firms have diverse reactions in order to try to increase their fit and to survive in their particular environment. These environments keep changing, not least due to innovations and choices made by all the constituent competitors: some of these environments are national, others increasingly international.

p. 397 Over the past decades, computers have had major coevolutionary processes, quite different from one another. In mainframes, coevolution has been characterized by large systems requiring user–producer relationships, centralization of user information systems, and extensive sales and service efforts by large vendors. Market structure was highly concentrated and suppliers were vertically integrated. A dominant design (IBM/360) emerged in the growth phase of the segment and a market leader (IBM) dominated the industry early on, with a coordinating role over the platform and the ability to steer the direction of technical change. The US government played a role in early support for technological exploration and was a major buyer of early computers. In minicomputers and microcomputers, coevolution has been characterized by technological change focused on dedicated applications in the case of minicomputers or on systems that increased ease of use and a lower price/performance ratio (in the case of microcomputers). The relationships with customers have required much less post-sales effort and service. Market structure was characterized by high entry early on, and then by increasing concentration in platforms in both minicomputers and microcomputers. In computer networks, connectivity and compatibility led to modular, open, and multiform client/server platforms. Technical change follows a variety of directions with an upsurge in the number of potential technologies associated with the relevant platforms. Interdependencies and externalities have increased. Divided technical leadership has emerged, in that no single firm has been able to govern change and coordinate platform standards.

This example is quite different from coevolution in other sectoral systems. In pharmaceuticals, the nature of the process of drug discovery (discussed in Section 14.4) had important consequences on the patterns of competition and on market structure. Until the molecular biology revolution, dominant firms persisted as leaders. The molecular biology revolution induced deep changes in the incentive structures within firms and universities, with the advent of university spin-offs and the emergence of the specialized new biotechnology firms. In this process of adaptation and change, different dynamic processes led to different patterns of competition and performances (McKelvey, Orsenigo, and Pammolli 2004). In telecom equipment and services, the early separation of the radio spectrum for use in one-way broadcasting and two-way telephony gave rise to an oligopolistic structure that persisted for quite a long time (Dalum and Villumsen 2001). The convergence within ICT and between ICT and broadcasting-audio-visual and the emergence of the Internet originated a more fluid market structure with a lot of different actors with different specializations and capabilities, and new types of users. This in turn greatly expanded the boundaries of the sector by creating new segments and new opportunities, and also by creating national differences in the organization of innovation. Moreover, the emergence of the Internet has generated more pressure in favor of open standards and has led to the rise of new actors (such as ISP and content providers). p. 398 In software, since the early 1980s, the spread of ↳ networked computing, embedded software, the Internet, the development of opensystem architecture and open source, and the growth of web-based network computing has led to the decline of large computer producers as developers of integrated hardware and software systems and to the emergence of a lot of specialized software companies. Also, software distribution has greatly changed, from licensing agreements in the early days, to the rise of independent software vendors, to price discounts for package software, and, with the diffusion of the CD-ROM and the Internet, to shareware and freeware (this last one particularly relevant with Linux) (D'Adderio 2001). In machine tools, a major driving force for coevolutionary processes is the demand from advanced customer sectors, namely the automotive, aeronautics, and defense industries, and the increasing use of electronic devices.

The emergence of new clusters that span several sectors, such as internet–software–telecom, biotechnology–pharmaceuticals, and new materials, is one of the most relevant current transformation processes in sectoral systems. Here a great role is played by the integration and fusion of previously separated knowledge and technologies and by the new relations involving users, consumers, firms with different specializations and competences, and non-firm organizations and institutions grounded in previously separated sectors.

14.8 Policy Implications

A sectoral system of innovation approach provides a design for innovation and technology policies. Within a system of innovation framework, identifying deficiencies in the functioning of a system is the same as identifying those systemic dimensions that are missing or inappropriate or not working and which lead to a "problem" in terms of comparative performance. When we know the causes behind a certain "problem"—for example, weak technological transfer between universities and industry—we have identified a "system failure." Not until they know the character of the system failure can policy makers know whether to influence or to change organizations or institutions or the interactions between them. Therefore, an identification of a problem should be supplemented with an analysis of its causes as part of the analytical basis for the design of an innovation policy. Benchmarking is not enough.

Thus a sectoral system approach provides the identification of "system failures" and the related variables which should be policy targets. Sectoral analyses should focus on systemic features in relation to knowledge and boundaries, heterogeneity of actors and networks, institutions and transformation (through
p. 399 coevolutionary ↳ processes). As a consequence, the understanding of these dimensions becomes a prerequisite for any policy addressed to a specific sector.

Given the major differences among sectoral systems examined in this chapter, the impact of general or horizontal policies may drastically differ across sectors, because the channels and ways policies have their effects differ from sector to sector. For example, cooperation and networks or non-firm organizations and institutions could have different relevance in different sectors. Therefore, policies affecting networks or non-firm organizations, such as transfer agencies, have to take these differences into account.

In addition, a sectoral system approach emphasizes that, for fostering innovation and diffusion in a sector, technology and innovation policies may not be enough. A wide range of other policies may be necessary. Innovation and technology policy could be supplemented by other types of policies, such as science policy, industrial policy, policies related to standards and IPR, and competition policy. This point highlights the importance of the interdependencies, links, and feedbacks among all of these policies, and their combined effects on the dynamics and transformation of sectors.

Relatedly, a sectoral system approach emphasizes that policy makers being within a variety of networks are an active internal (part) of sectoral systems at different levels. In fact, the policy makers intervene actively in knowledge creation, IPR, corporate governance rules, technology transfer, financial institutions, skill formation, and public procurement. As a consequence, they have to develop advanced competences and create an institutional setting in order to be effective and consistent at the various different levels.

Finally, policy has to consider the coexistence of different geographical dimensions of sectoral systems. Developments in the local, national, regional, and global levels influence the articulation of technological capabilities. Policies that focus on only one level are likely to miss constraints or opportunities that are influential in the innovative behavior of individual organizations.

The emphasis on the diversity of sectoral systems highlights also different policy measures for different sectors. In fact, policy needs are closely related to the problems faced by the various actors operating in the sectoral contexts and to the sectoral specificity of knowledge, boundaries, actors, and networks.

In sum, traditional innovation policies have been formulated as providing public resources for R&D and changing the incentives for firms to innovate. Tax breaks for R&D, innovation subsidies, and patents are typical examples of these policies. A sectoral system perspective does not deny the significance of this approach. It recognizes, however, that the effects may run rapidly into diminishing returns. To offset this, it is necessary that innovation opportunities be enhanced. Improving the organization of an innovation

p. 400 system within a sector is an almost certain route to improving the complementary payoffs from public and private R&D. The sectoral perspective provides a tool for policy makers to comprehend the differences in ↳ innovation systems and for identifying the specific actors that should be influenced by policy. The quid pro quo, however, is that policy makers need to invest much more effort in understanding the idiosyncrasies of the specific sectors that they use to channel the influence of policy (Edquist et al. 2004).

14.9 The Challenges Ahead

This chapter has claimed that innovation greatly differs across sectors in terms of sources, actors, features, boundaries and organization. It has proposed an integrated and comparative way to look at sectors based on the sectoral systems framework.

Some remarks have to be advanced here in way of conclusion. The discussion of sectoral systems has shown that there could be several levels of sectoral aggregation, and that the choice of one depends on the goal of the analysis. While the discussion here has been very broad in terms of sectors in order to emphasize linkages, interdependencies, and transformation, for different research goals the level of disaggregation could be much higher, at the level of product groups. Still, we may talk about systems of innovation in this respect.

Geographical boundaries are a key dimension to be considered in analyses of sectoral systems. National boundaries are not always the most appropriate ones for an examination of structure, agents, and coevolution. Often, sectoral systems are highly localized and frequently define the specialization of local areas (as in the case of machinery, some traditional industries, and even information technology). For example, machinery is concentrated in specialized regional areas. Similarly, sectoral specialization and local agglomeration have overlapped in Route 128 (for minicomputers) and in Silicon Valley (for personal computers, software, and microelectronics) (Saxenian 1994). Moreover, in the context of transnational economic integration, the sector may matter as much or more than the national system.

Differences across countries in sectoral systems have been relevant and have affected countries' international performance. In general, one could claim that those countries that did not have effective sectoral system characteristics did not perform well in international markets. The same holds for those countries that tried to replicate the success of world leaders by mimicking some of the features of the sectoral systems of the leading countries, without having the appropriate set of actors, linkages, and institutions. By contrast, those countries that have tried to specialize in subsectors with products, knowledge, and institutional requirements ↳ that match their specific institutional framework have been
p. 401 successful (Coriat, Malerba, and Montobbio 2004).

Finally, this chapter has tried to show how relevant a sectoral system approach is for an understanding of the features, determinants, and effects of innovation, in terms of research and policy. The policy aspect has been discussed in the previous section and will not be repeated here, but research on sectoral systems may prove very fruitful and has to move along several lines of advancement.

(1) A sectoral system framework may allow for detailed analyses of innovation in sectors in terms of knowledge and learning processes, structure (where structure is seen here as a network of relationships), and institutions. In addition, a sectoral system approach provides a way to examine the dynamics of sectors due to innovation and technological change and the coevolutionary processes taking place among knowledge, technology, actors, and institutions. Different sectoral systems may be compared along similar dimensions (in order to try to identify similarities across sectors), and the same sectoral system may be examined across different countries (in order to focus on the interplay between sectoral and national variables).

(2) The specific mechanisms, causal relationships, and interactions among the variables composing a sectoral system have to be studied in great depth both empirically and theoretically. This requires the development of quantitative analyses, econometric studies, and formal models. Driven by empirical analyses, appreciative and formal theoretical work has to be carried out regarding the basic relationships among the elements of a sectoral system, the emergence and persistence of networks, the basic processes of variety creation and selection, and coevolution. Here, both theoretical models of industry dynamics and history-friendly models can be useful. In the best evolutionary and innovation system traditions, this work should go hand in hand with, and be continuously confronted by, empirical work.

(3) Research should focus on some key variables that are still rather unexplored. In particular:

- the extent and features of within-sector firms heterogeneity and the related processes of variety creation and selection;
- demand, in terms of emergence, structure, and role in the innovation process;
- networks, in terms of emergence, composition, structure, and evolution;
- coevolution of the various elements of a sectoral system;
- institutions, both in terms of emergence and role of sectoral institutions and in terms of the sectoral effects of national institutions.

(4) Taxonomies of sectoral systems have to be constructed. Here, comparative work is particularly relevant. These taxonomies should group sectoral systems in terms of elements, structure, and
p. 402
dynamics, so that regularities ↳ may be identified among sectors. Pavitt's taxonomy (Pavitt 1984) and the Schumpeter Mark I and Schumpeter Mark II distinction could be useful starting points.

(5) Analyses of the relationship between the presence and strength of elements of sectoral systems and the international performance of countries have to be developed (see e.g. Coriat, Malerba, and Montobbio 2004).

In conclusion, as stressed above, a full understanding of the determinants, features, and effects of innovation in sectoral systems requires the integration of various types of complementary analyses: descriptive, quantitative, econometric, and theoretical.

Notes

1. In fact sectoral systems often have more than one technology, while the same technology (as in the general purpose technology case) may be used by many different sectors.

2. Similarly, in addition to firm and non-firms organizations, also agents at lower and higher levels of aggregation such as individuals or consortia of firms may be the key actors in a sectoral system.

3. For example, sectors with competing technologies such as nuclear energy (Cowan 1990), cars (and their power sources—Foreman-Peck 1996), metallurgy (ferrous casting—Foray and Grubler 1990) and multimedia (VCR—Cusumano et al. 1992) show interesting examples of path-dependent processes.

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