Introduction

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Innovation and technological change are highly affected by the sector in which they take place. The agents, the relationships among actors and the institutions of a sector all exert a major and profound influence on the differences in innovation across sectors. How to consider these effects on innovation? And how to take into account differences across sectors?

This book examines innovation in six major sectors in Europe and in other advanced countries: pharmaceuticals and biotechnology, telecommunications equipment and services, chemicals, software, machine tools and services (airports, medical and retailing). These sectors have been chosen because, in them, technological change is quite rapid, and innovation plays a major role in fostering growth and in affecting the competitiveness of firms and countries.

This volume proposes a novel approach to looking at innovation in sectors. It provides a *sectoral systems of innovation* framework, which uses a multidimensional, integrated and dynamic view of sectors in order to analyze innovation. Although this book focuses on innovation, the concept of sectoral systems can also be applied to *production*. The notion of SSIs departs from the traditional concept of sector used in industrial economics because it examines other agents in addition to firms, places great emphasis on knowledge, learning and sectoral boundaries, focuses on non-market as well as on market interactions, and pays much attention to institutions. In an SSI perspective, firms are active actors that shape their technological and market environments. Innovation is considered a process that involves continuous and systematic interactions among a wide variety of actors.

In this book innovation in a sector is considered to be affected by three main factors:

a. Knowledge and technologies;
b. Actors and networks;
c. Institutions.

a. Knowledge and technologies. Any sector can be characterized by a specific knowledge base, technologies and inputs. In a dynamic way, the focus on knowledge and technology places the issue of sectoral boundaries at the centre of analysis. In sectors in which innovation is quite rapid, sectoral boundaries are not fixed but change over time. Knowledge and basic technologies constitute major constraints on the full range of diversity of the behaviors and organizations of firms. Links and complementarities among artifacts and activities also play a major role in defining the real boundaries of a sectoral system. These links and complementarities can be static (as input-output links are) or dynamic. Dynamic complementarities take into account interdependencies and feedback, both at the demand and at the production levels. They are major sources of the transformation and growth of sectoral systems, and may set in motion virtuous cycles of innovation and change.

b. Actors and networks. A sector consists 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-firm organizations (e.g. universities, financial organizations, government agencies, trade unions or technical associations), including subunits of larger organizations (e.g. research and development – R&D – or production departments) or groups of organizations (e.g. industry associations). Agents are characterized by specific learning processes, competencies, beliefs, objectives, organizational structures and behaviors. They interact through processes of communication, exchange, cooperation, competition and command. Within sectoral systems, heterogeneous agents are connected in various ways through market and non-market relationships. The types and structures of relationships and networks differ 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, key links and dynamic complementarities.

Thus, in a sectoral system perspective, innovation and production are considered to be processes that involve 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, inter-firm alliances, and formal networks of firms. Often their outcome is not adequately captured by our existing ways 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. They may range from the ones that bind or impose enforcements on agents to the ones that are created by the interaction among agents (such as contracts); from more binding to less binding; and from formal to informal (such as patent laws or specific regulations versus traditions and conventions). Many institutions are national (such as the patent system), while others may be specific to sectoral systems, such as sectoral labor markets or sector-specific financial institutions.

The relationships between *national institutions* and *sectoral systems* are quite important. First, national institutions – such as the patent system, property rights or antitrust regulations – have different effects on innovation in different sectors. Second, the same institution may take on different features in different countries, and thus may affect innovation differently. Third, the characteristics of national institutions often favor specific sectors that fit them better. In some cases national institutions may constrain the development of innovations in specific sectors, with the result that mismatches between national institutions on one side and sectoral institutions and agents on the other side may take place. Fourth, the relationship between national institutions and sectoral systems may sometimes go from the sector to the national level: the institutions of a sector, extremely important for a country in terms of employment, competitiveness or strategic relevance, may end up emerging as national (thus also becoming relevant for other sectors). But, in the process of becoming national, they may change some of their original distinctive features.

Demand is a key part of a sectoral system. However, the focus on users and on institutions puts a different emphasis on the role of demand. Demand is made up of individual consumers, of firms and of public agencies, each characterized by knowledge, learning processes, competencies and goals, and affected by social factors and institutions. Thus, in a sectoral system, demand is not seen as an aggregate set of similar buyers, but as consisting of heterogeneous agents the interactions of which with producers are shaped by institutions. In general, the emergence and transformation of demand play a major role in the dynamics and evolution of sectoral systems.

In sum, the framework of a sectoral system may prove a useful tool in analyzing innovation, for various reasons:

- a descriptive analysis of the innovation process in sectors;
- the recognition of the factors affecting innovation;
- the analysis of the relationship between innovation and the changing boundaries of sectors;

- a full understanding of the short-term and long-term dynamics and transformation of sectors;
- the identification of the factors affecting the international performance of firms and countries in the different sectors;
- the development of new public policy indications.

This volume is unique in examining in a consistent and comparative way pharmaceuticals and biotechnology; chemicals; telecommunication equipment and services; software; machine tools; and medical, airport and retailing services along the various dimensions discussed above. It tries to answer questions such as:

- What affects the specific organization of the innovative activity of a sector? Why is this organization so different across sectors (for example, between chemicals and software, or between biotechnology and machine tools)?
- What are the main characteristics of the networks of innovators in a sector? Do these networks differ significantly among sectors, and, if so, why?
- What are the factors responsible for the changing boundaries and major transformation of sectors such as telecommunications or software?
- What is the role of institutions in affecting innovation in a sector?
- How relevant is the role of different national institutional frameworks across European countries for innovation in a sector?
- What are the factors at the base of the international competitiveness of Europe in each sector?
- Should national and European public policies pay attention to sectoral specificities and sectoral differences?

The organization of the volume is as follows. The first part of the book presents concepts and issues related to the sectoral system of innovation: chapter 1 discusses sectoral systems of innovation and production and their main building blocks, while chapter 2 introduces some basic data and contains a discussion of the link between sectoral systems and innovation systems. The second part of the book contains analyses of sectoral systems in Europe: pharmaceuticals and biotechnology (chapter 3), chemicals (chapter 4), telecommunications equipment and services (chapter 5), software (chapter 6), machine tools (chapter 7) and services (chapter 8). In the third part some major themes are addressed: the role of institutions in sectoral systems (chapter 9), the interplay between national institutional frameworks and sectoral specialization (chapter 10), the factors affecting international performance of sectoral systems (chapter 11) and the new dimensions of public policy deriving from this book (chapter 12). Finally, a summing up and concluding chapter (chapter 13) closes the book.

One note has to be advanced here. When a sectoral system is examined, different levels of aggregation and large or narrow sectoral boundaries may be chosen. This depends on the goal of the analysis. So, in this book in the chapters about specific sectoral systems of innovation, sectors have been defined broadly: pharmaceuticals, chemicals, telecommunications, software, machine tools. This broad definition allows us to emphasize interdependencies, linkages and transformations spanning a large set of products, actors and functions. However in some chapters a more disaggregated level is also used in order to show that within the broadly defined sectors different innovation systems may coexist. Also in these cases we can talk about systems of innovation, only that the level of disaggregation is much higher. In order to make this distinction clear, in this book authors have used the term "sector" for the broad aggregations mentioned above, and the terms "subsectors," "product groups" and "product segments" for more narrowly defined aggregations within broad sectors.

Part I

Sectoral systems: concepts and issues

1 Sectoral systems of innovation: basic concepts

Franco Malerba

1 Introduction

Innovation takes place in quite different sectoral environments, in terms of sources, actors and institutions. These differences are striking.

Let us take, for example, pharmaceuticals and biotechnology. Here science plays a major role, and several different types of firms are the protagonists of innovation, from large corporations to new biotechnology firms. Interaction between universities and venture capital is relevant. In this sector, regulation, intellectual property rights (IPR) and patents, national health systems and demand all play a major role in the innovation process. Quite a different set of actors, networks and institutions characterize innovation in telecommunications equipment and services, as a result of the convergence of previously separated sectors such as telecommunications, computers, the media and so on, and of the rapid growth of the Internet. In chemicals we see a different scenario: large innovators have shown great continuity in their innovativeness, and the scale of internal R&D has always been a major source of innovative advantage. In software, on the other hand, the context of application is relevant for innovation, and a vertical and horizontal division of labor among different actors has recently taken place. Finally, in machine tools incremental innovation is quite common, and R&D plays a less relevant role than in other sectors. Links with users and the on-the-job activity of skilled personnel is quite relevant. Differences in innovation across sectors also involve services, where products are closely related to processes, and knowledge embodied in equipment and in people is very important.

How to take account of and analyze these differences? The analysis of innovation in sectors developed in this book is centered around the concept of *sectoral systems of innovation*. By way of introduction, the definition that will be presented in section 3 and discussed in sections 4 and 5 is anticipated here.

A sector is a set of activities that are unified by some related product group for a given or emerging demand and that share some basic

knowledge. Firms in sectors have commonalities and at the same time are heterogeneous. Innovation in sectors has relevant systemic features. In this book it is proposed that a sectoral system of innovation (and production) is composed of a set of agents carrying out market and non-market interactions for the creation, production and sale of sectoral products. Sectoral systems have a knowledge base, technologies, inputs and (potential or existing) demand. The agents are individuals and organizations at various levels of aggregation, with specific learning processes, competencies, organizational structure, beliefs, objectives and behaviors. They interact through the processes of communication, exchange, cooperation, competition and command, and their interaction is shaped by institutions. A sectoral system undergoes processes of change and transformation through the coevolution of its various elements.

Thus a sectoral system has three building blocks:

- *knowledge and technology;*
- *actors and networks;*
- *institutions.*

What are the advantages of using a sectoral system perspective in the analysis of innovation? The main advantages of a sectoral system view are a better understanding of: the structure and boundaries of sectors; agents and their interaction; the learning and innovation processes specific to a sector; the types of sectoral transformations; and the factors at the base of the differential performance of firms and countries in a sector.

The theoretical and analytical approaches on which this book draws come from evolutionary theory and the system of innovation studies. It is in the evolutionary field that key concepts such as learning, knowledge and competencies and a major focus on dynamics are present. And it is in the innovation system literature that one may find relationships and networks as key elements of the innovative and production processes (Edquist, 1997). In particular, the notion of *sectoral systems of innovation* complements other concepts such as *national systems of innovation* (NSIs), which have a focus on national boundaries and on non-firm organizations and institutions (Freeman, 1987; Nelson, 1993; and Lundvall, 1992), *regional/local innovation systems*, in which the focus is on the region (Cooke, Gomez Uranga and Extebarria, 1998), and *technological systems*, in which the focus is mainly on networks of agents for the generation, diffusion and utilization of specific technologies (Carlsson and Stankiewitz, 1995; Hughes, 1984; and Callon, 1992).

This chapter is conceptual and methodological. It aims to discuss the theoretical foundations of the notion of a sectoral system of innovation, to propose a definition of a sectoral system, to identify the major dimensions

and the main variables, to analyze the main factors affecting structure, agents' heterogeneity and change, and to set out the main research questions and the key challenges that lie ahead.

The chapter is organized in the following way. In section 2 the theoretical foundations of the notion of sectoral systems are presented, and in section 3 a definition and a framework is proposed. In section 4 the main building blocks of a sectoral system are examined: knowledge, learning processes, technologies and demand; the structure of interaction among heterogeneous firms and non-firm organizations and institutions. Then, in section 5, the dynamics and transformation of sectoral systems are discussed, while in section 6 the geographical boundaries are analyzed.

2 Antecedents and theoretical bases

In innovation studies, sectors provide a key level of analysis for economists, business scholars, technologists and economic historians. When sectors are examined, however, two different traditions are encountered.

The first is related to the industrial economics literature. The structure-conduct-performance tradition, the transaction costs approach, sunk cost models, game theoretical models of strategic interaction and cooperation, and econometric industry studies have emphasized differences across industries. Most of these approaches have considered the sectoral boundaries to be static and delimited in terms of similarity of techniques or similarity of demand. Sometimes strategic interdependence has been added as another criterion for delimiting sectors. Differences in the equilibrium structure of sectors have been identified as being determined by the underlying patterns of technology and demand, in addition to the type of sunk costs. These studies in the industrial economics tradition have examined the structure of sectors in terms of concentration, vertical integration, diversification and so on; the dynamics of sectors in terms of technical progress, entry, firms' growth and so on; and the interaction among firms in terms of strategic behavior (Bain, 1956; Scherer, 1990; Tirole, 1988; and Sutton, 1991, 1998). This tradition has obtained tremendous progress and major results in all the above-mentioned topics. In most of these studies, however, not much emphasis has been placed on the role of non-firm organizations, on the knowledge and learning processes by firms, on the wide range of relations among the agents, or on the transformation of sectors in their boundaries, actors, products and structure. These remarks could be coupled with the complementary observations by Geroski (1998), who discusses market boundaries and emphasizes the concept of the strategic market.

The second tradition dealing with sectors is much richer empirically but much more heterogeneous, eclectic and dispersed. Here one finds very rich empirical evidence on the features and working of sectors, on their technologies, production, innovation and demand, and on the type and degree of change. But most of the sector case studies focus on a single dimension (such as innovation, firms' competencies, structure of production and so on), ask different research questions, are undertaken with different methodologies and have a different level of aggregation in terms of unit of analysis. As a consequence, the possibility of having integrated and consistent analyses of sectors in their interrelated dimensions, understanding fully their working and transformation or comparing different sectors with respect to several dimensions (such as the type and role of agents, the structure and dynamics of production, the rate and direction of innovation and the effects of these variables on the performance of firms and countries) is still very limited.

In innovation studies, an intermediate level between the industrial organization tradition and the case studies approach is represented by empirical taxonomies concerning differences across sectors in innovative activities. The simplest one, widely used in international studies by the Organization for Economic Co-operation and Development (OECD), European Union and other international organizations, refers to sectors that are "high R&D-intensive" (such as electronics and drugs) and "low R&D-intensive" (such as textiles and 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 cumulative technological advancements, 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. A third distinction refers to sectors that are *net suppliers* of technology and sectors that are *users* of technology. On the bases of the R&D carried out by 400 American firms and of inter-sectoral flows in the American economy, Scherer (1982) identifies sectors that are net sources of R&D (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, Townsend and Pavitt (1988), who – on the basis of 4,378 innovations in the United Kingdom between 1945 and 1983 – identify "core sectors" (such as electronics, machinery, instruments and chemicals), which generate most of the innovations in the economy and