5 Innovation systems

This chapter examines a series of contributions that share a systemic-relational approach to the study of innovation: a perspective based on the relationships between a plurality of actors and institutions, both economic and otherwise. After a presentation of the conditions that lead to the emergence of the approach, the chapter reviews the features of different, but complementary, innovation systems – national, sectoral and technological. Finally, there is a discussion of the triple helix model, focused on the interactions between three distinct institutional spheres: university, industry and government.

5.1 An integrated approach

From the second half of the eighties, more integrated analytical perspectives began to appear in Innovation Studies. Despite substantial differences, certain basic elements are common to these 'new' approaches to innovation. First, the generalisation of the idea that knowledge is one of the key drivers of development (*knowledge economy*) and that learning processes are therefore essential to increase the competitiveness of companies, regions and nations (*learning economy*). Second, the definitive abandonment of a strictly economistic view of innovation, with the realisation that: (1) innovation requires the contribution of a heterogeneous plurality of actors, both economic and otherwise (companies, universities, governments, etc.); and (2) *institutions* play an important role in shaping the context in which these actors operate. Third, the recognition that these processes are inherently social and relational in character, and for this reason the production and dissemination of knowledge and innovation are embedded in networks of relationships between people and between organisations. Finally, all the approaches assume a *systemic perspective*: innovation, in other words, is interpreted as an emergent – only partially intentional – property of a system of elements and relations, with results that, for the actors involved, may be desired or involuntary, positive or negative. In brief, the idea that real *innovation systems* exist constitutes the lowest common denominator of the theoretical and empirical contributions that will be presented in this chapter.

5.2 Assumptions

The systemic approaches that have developed over the last 25 years have made use of much of the research work carried out in previous decades on innovation and factors of competitiveness at the micro (company), meso (sectoral and regional) and macro (national and international) levels. Their formulation is also a response to the emergence of certain economic phenomena, which demonstrate the increasingly complex and interactive character of innovation processes.

The *first of these phenomena* concerns the change which has occurred in the models of production (micro level) and regulation of the economy (meso and macro levels). With the crisis of Fordism, in fact, companies experiment with alternative models of production organisation that, on the one hand, show the increasingly relational character of the economy (Trigilia 2007b); and, on the other hand, the importance of the socio-institutional context and its territorial articulation. For example, studies on the industrial districts and regions of the 'Third Italy' (Becattini 1975, 2000; Bagnasco 1977, 1988; Paci 1980; Trigilia 1986) demonstrate the existence of an alternative development model to Fordism, one that is characterised by flexible specialisation (Piore and Sabel 1984) and is based on local systems of small- and medium-sized companies operating in traditional industries and linked to each other by specialised division of labour. The small business areas – and in particular the 'industrial districts'[1] – show how production efficiency and competitiveness are based on the social construction of the market. Studying them, therefore, requires a complex, interdisciplinary analytical approach, that takes into account the history of the territories as well as the existence of a plurality of actors and of modes of regulation. This approach, initially used to study the traditional manufacturing sectors, based on a diffuse, incremental kind of innovation (Bellandi 1989), subsequently also proved to be useful for understanding the processes of radical innovation, such as those taking place in Silicon Valley (Saxenian 1994).

The *second phenomenon* is the development of high-tech sectors, something that highlights a growing 'scientification' process in relation to technology (Carlsson and Stankiewicz 1991, 112). This is particularly evident in the so-called *science-based* sectors; that is, in the industries that make most use of knowledge coming from the scientific community (biotechnology, pharmaceuticals, etc.). In the US, for example, in just a few years there was an exponential growth in the number of patents that based their findings on scientific research financed with public funds. Patents citing publications of this type tripled in the space of five years, rising from 17,000 in 1987–88 to about 50,000 in 1993–94, and three-quarters of these refer to articles or papers produced by universities or other public research centres (Narin *et al.* 1997). This trend is concentrated in specific scientific-technological fields, especially in biomedical and clinical research: in 1988, scientific articles cited in American industrial patents from these disciplines accounted for about 54 per cent of the total, while in 1996 this figure rose to 73 per cent (OECD 1999, 16).

A *third phenomenon* is the growth of inter-company partnerships – especially in the field of R&D, due to the increasingly diverse and interdependent nature of the specialised knowledge necessary for innovation.[2] And, last, a *fourth phenomenon* is related to economic globalisation and the consequent reorientation of public policies. The emergence of new international competition from recently industrialised countries makes it clear that: (1) innovation is the winning strategy to compete with countries with low labour costs; (2) the role of public policies is crucial to support innovation; and (3) the policies must, however, be rethought within a more integrated and systemic framework (OECD 2005).

In short, all of these phenomena prompt a reconsideration of innovation in the light of the fact that the production of goods and services is becoming increasingly *knowledge-intensive* and involves a plurality of actors and institutions. The new approach of *innovation systems* is designed to respond to this requirement. The contributions presented in this chapter do not amount to a formal theory, in the sense of a shared, coherent set of concepts and propositions regarding precise relationships between variables. Rather, they develop an analytical and conceptual framework that guides the analysis towards one single object of research, albeit articulated on different levels. To employ an expression utilised by Lundvall (1992a, 1) in the introduction to his book on *National Systems of Innovation*, innovation systems represent a *focusing device* that places interactive learning and innovation at the centre of analysis. It is, in the words of Nelson and Winter (1982), an '*appreciative theorising*' that 'tends to be close to empirical work and provides both interpretation and guidance for further exploration' (Nelson 1998, 500). Analytical reasoning, in other words, which provides abstract causal models that are, however, empirically grounded and historically friendly; models which, to sociologists, will be reminiscent of Merton's middle-range theories and Weber's ideal-types.

As we shall see, there are certain shared assumptions that underlie these systemic approaches. But there are also differences that should not be overlooked, starting from those relating to the foundational dimensions of innovation systems. The latter, in fact, were defined by using *spatial/geographical criteria*, distinguishing between national, regional and local systems; or by using *industrial-technological criteria*, classifying them according to production or technological sectors; or, finally, by identifying them on the basis of the *types of actors and relationships* (as in the case of the triple helix model). In the next section, national systems and then other models will be analysed – with the exception of regional and local systems, which will be discussed in Chapter 6, which is dedicated to the territorial dimension of innovation.

5.3 National systems

The first formulations that refer to *national innovation systems (NIS)* appeared in the eighties in the work of some of the most important IS scholars. The term is used for the first time in an unpublished document written by Charles Freeman for the OECD, in which the English academic stresses the importance of an active role for governments in promoting technological infrastructure to support economic development (Johnson *et al*. 2003, 3). In the same period, other research groups underlined the need to take a variety of factors into account in order to understand innovation, while the idea of an innovation system appeared in an essay by Bengt-Åke Lundvall (1985). The term was then formalised in a study by Freeman (1987) on Japan, and a section was dedicated to NIS in a collective volume edited by some of the foremost experts on innovation (Dosi *et al.* 1988). Thereafter, in the nineties, certain important books came out that consecrated the relevance and centrality of the argument within IS (Lundvall 1992b; Nelson 1993; Edquist 1997).

In addition to the academic world, the concept became widespread throughout the political arena due to its use by certain international organisations. The OECD was the first to employ it in a series of studies and research that emphasised its potential to support innovation at both an analytical and political level. The concept was also accepted by the European Commission, the United Nations Conference on Trade and Development (UNCTAD), the Academy of Sciences of the United States and several other national governments (Lundvall *et al.* 2002). What can explain this success, amongst both scholars and policy-makers?

The first reason for such a positive reaction in the academic world is that it was an approach that developed a number of contributions made in previous years. These included the results of some important research, such as the Sappho investigation carried out by Freeman along with other SPRU (Science Policy Research Unit) colleagues – which highlighted the importance to innovation of long-term ties and relationships with actors external to the companies. Other research had emphasised the role of *non-market* relations in the transmission of knowledge and the role of the institutional context in regulating the economy, as was emerging from the first studies on Japan and on the ‘variety of capitalisms’ approach. In addition, the systemic approach was a confluence point for new reflections of a theoretical nature. A distancing was in fact taking place from neo-classical economics both at an analytical level, due to the lack of emphasis given to technological change in the explanation of economic growth, and at a political level, because of its neo-liberalist implications in terms of policy-making (Sharif 2006). The ‘crisis’ of the linear conception of innovation and the emergence of the evolutionary economy stimulated, therefore, the search for new conceptual coordinates. Innovation was placed at the centre of a new theory of development that integrated analysis of the *economic structure* and *institutional context*, both to explain the various trends and specialisations of advanced economies and to provide advice to national governments (Lundvall and Maskell 2000, 354).

This introduces the second reason for the rapid success of the new systemic approach. NIS established itself as a *policy concept*, as a useful idea to guide not only research but also public policies (Sharif 2006, 750). From the very beginning, in fact, NIS existed on the frontier between two communities – the scientific and the policy-making – by virtue of the role played by certain leading scholars in both fields (consider, for example, the involvement with the OECD of figures such as Freeman and Lundvall).

But what exactly are NIS? There are various definitions. For Nelson and Rosenberg the concept refers to 'a set of institutions whose interactions determine the innovative performance … of national firms' (1993, 4; Nelson 1993, 349). Lundvall indicates the 'elements and relationships which interact in the production, diffusion and use of new, and economically useful, knowledge … and are either located within or rooted inside the borders of a nation state' (1992a, 2). Edquist, finally, believes that NIS include 'all important economic, social, political, organizational, institutional and other factors that influence the development, diffusion and use of innovation' (1997, 14). These, as can be seen, are definitions that differ in part, yet behind which there lie certain shared theoretical assumptions (Johnson *et al*. 2003).

1 The first assumption is that national economies present a variety of specialisations which regard productive, commercial and also cognitive structures. These productive and cognitive specialisations are interdependent and co-evolve in a path-dependent manner: they follow trajectories shaped by history and previous experience, slowly transforming themselves as a result not only of economic change but also of learning processes developed by the actors.
2 The second assumption is that knowledge is *sticky*: it does not circulate easily from one place to another, is 'embodied' in the minds and bodies of people, in routine business, and in interpersonal and inter-organisational relationships.
3 The third assumption is that individuals, companies and other organisations never innovate in complete isolation; and to study their relations an 'interactionist' perspective is needed.
4 The fourth assumption is that the (heterogeneous) plurality of actors and institutions involved in innovation processes requires an analytical approach of a holistic, interdisciplinary and historico-evolutionary kind.

For all these reasons, scholars who follow this particular line take a systemic approach and focus on the social and political, as well as economic aspects, looking carefully at the origins and transformations of the institutional context in which innovation occurs (Edquist 2005). A qualifying concept for this approach is *system*, which is seen as an interconnected set of elements that work towards a common goal (Carlsson *et al.* 2002, 234). A system essentially consists of two parts – components and relationships – and possesses different and distinct properties from those of its constituent elements (Edquist 2005, 187).

The *components of the system* are organisations and institutions (Figure 5.1). The former refers to the set of actors who act and interact in the system, the latter to the rules – both formal and informal – that guide action and regulate interaction. Edquist and Johnson provide a precise definition of these two concepts: '*Organizations* are formal structures that are consciously created and have

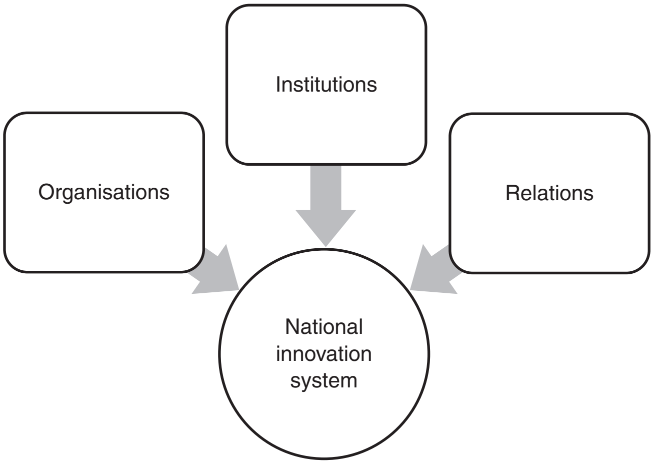

Figure 5.1 The national innovation system: a schematic representation.

an explicit purpose' (1997, 46). Examples are companies, universities, public and private research centres, credit agencies that finance innovation, government agencies that deal with research and innovation policies, and so on. '*Institutions* are sets of common habits, norms, routines, established practices, rules, or laws that regulate the relations and interactions between individuals, groups and organizations' (ibid.).[3] Examples are the laws on intellectual property rights (patents, trademarks, etc.), habits of cooperation and competition between companies, collaboration practices between companies and universities, the rules that govern scientific research, innovation funding, etc.

Relations, finally, refers to the relationships that link the various components of the system. This aspect therefore regards the ties that are created between organisations within a specific institutional context. As previously touched upon, the NIS approach places a strong emphasis on the interactive dimension, taking into consideration both market and non-market relations between the actors involved.

Defining the boundaries of the system is crucial in order to identify which components and relationships are taken into account. NIS studies adopt a geopolitical criterion of definition, employing nation states as units of analysis. This is for two reasons. The first lies in the awareness that there exist marked economic, political, social and cultural differences at a national level that affect the institutional and organisational configuration of the various innovation systems: the resources that they invest in scientific research; the prevailing specialisations; the methods of innovation and the results that are achieved. The second is that the policies that support – directly or indirectly – the innovative capacity of companies and territories are to a significant extent determined at state level. This does not mean to exclude other aspects of analysis involving different spatial scales (local, regional, international and global) nor to deny that other regulatory bodies (international institutions, supranational and sub-national governments, multinationals, etc.) play a major role, all the more so in an era of increasing globalisation (Lundvall 1992a, 13; Nelson 1992, 367–9; Nelson and Rosenberg 1993, 19–20; Edquist 1999, 2005; Lundvall *et al.* 2002, 215).

In recent years, attention has also been devoted to the functions and activities of innovation systems. The main *function* of NIS is to 'develop, diffuse and use innovations' (Edquist 2005, 190). The *activities* are carried out by various organisations and represent their specific contribution to innovation. No univocal relationship exists, however, between organisations and activities. Organisations can, in fact, carry out more than one activity: universities, for example – as we shall see later in our discussions of the triple helix model – can perform activities regarding human capital training, R&D, and innovation and development at the local level. Conversely, the same activity can be carried out by different organisations: for example, the training of human capital can be performed by the school and university system but also by companies and other public and private institutions.

On the basis of the various contributions that appeared in the international literature, Edquist (ibid., 190–1) developed a list of the ten main activities carried out by NIS:

1. to produce new *knowledge* through R&D;
2. to build *skills* for human capital through the school-university education system, vocational training, etc.;
3. to establish new *markets* for products;
4. to define *qualitative requirements* for new products based on the needs of the demand;
5. to create and modify *organisations* necessary for the development of new fields of innovation;
6. to generate (market and non-market) *networks* to facilitate the circulation of knowledge;
7. to create and modify *institutions* that are able to provide useful ties and incentives for innovation;
8. to carry out *incubation activities* in support of new initiatives;
9. to ensure *funding* for innovation;
10. to provide qualified *consultancy services* (technology transfer, commercial and legal information, etc.).

Many of these activities take on a different significance depending on the regional and sectoral systems considered, and are only partially created in an intentional manner: innovation systems evolve over time with little in the way of organised planning.

In the NIS approach, institutions play an important role and this creates an interesting area of discussion with comparative political economy; that is, with sociological and political science approaches of an institutional kind. Indeed, in contrast to what is observed with the mainstream, neo-classical economy, which tends to accept only one rule of behaviour – a maximising and utilitarian rationale – the NIS approach views history and institutional contexts as important in order to understand the concrete modalities of behaviour, interaction and learning of economic actors (Johnson *et al*. 2003, 5). That said, it should also be noted that there is no shared definition of this concept. Some authors, in fact, following Douglas North's suggestion (1990), differentiate sharply between *organisations* and *institutions*. Others, such as Nelson and Rosenberg (1993, 5; Nelson 1993, 351), do not employ this distinction and interchangeably make use of the terms 'institutions' and 'institutional actors' to include all the organisations involved in innovation.[4] They believe, in fact, that it is difficult to draw a clear boundary between the first and second, as it is to make a distinction between the rules and principles that establish patterns of behaviour and the behaviour itself (Nelson 2008, 4).

Further differences exist in the NIS approach. A second difference concerns the more or less broad definition which is given to the object of analysis. Some scholars – especially those hailing from the American tradition of scientific and technological studies – tend to adopt a rather narrow analytical focus, concentrating on R&D and related policies to identify the specialisations of national scientific and innovation systems. Other scholars, in contrast – especially those in Europe – take a broader perspective, giving importance not only to more formalised research activity, but also to forms of tacit knowledge and modalities of learning based on productive routines and interaction (Lundvall and Maskell 2000, 362). The former, in other words, focus on the principal organisations (companies, universities, etc.) that promote and disseminate scientific knowledge and innovation; while the latter believe that these activities should be seen in a wider context, since economic, political and cultural factors influence the intensity and the results of innovative activities (Freeman 2002, 194).

A third difference relates to the degree of theorisation required within this field of study. Here the line of distinction lies between those who discern a deficit of theory and the need for greater rigour in the definition and operationalisation of concepts (e.g. Charles Edquist, Jan Fagerberg and Stanley Metcalfe), and those who instead consider the theoretical and analytical flexibility of this approach to be an advantage (e.g. Maureen McKelvey, Richard Nelson and Keith Smith) (Sharif 2006, 757–9). Substantial traces of these differing perspectives can already be seen in two major works that appeared in the early nineties: Nelson's book (1993), in fact, is based on a comparison of different national cases and deals mainly with actors in scientific-technological innovation; Lundvall (1992b), on the other hand, assumes a broader focus and is more theoretically oriented.[5]

The book edited by Richard Nelson is a study of 15 national economies and is aimed at highlighting the similarities and differences in the institutions and mechanisms that support innovation (Nelson and Rosenberg 1993, 3). The cases examined include the most industrialised economies (US, Japan, Germany, France, Italy and Great Britain), several small high-income states (Denmark, Sweden, Canada and Australia) and some newly industrialised countries (South Korea, Taiwan, Argentina, Brazil and Israel). The case studies, although carried out in a different manner, pay particular attention to R&D and its funding, focusing on three main actors: companies, universities and governments. The contribution offered by these institutions and the different combinations present in the various countries – that is, the different institutional mix – define the distinctive features of the national innovation systems and condition their performance.

A good example of this approach is represented by the analysis carried out on the *US innovation system* (Mowery 1992, 1998; Mowery and Rosenberg 1993). What are its distinctive features, compared to those of other industrialised countries?

- The matter of scale – following World War Two, and for several decades, the volume of American investment in R&D far exceeded that of all other advanced economies.
- The prominent role of small start-ups in the commercialisation of new technologies, especially in high-tech areas: microelectronics, computers, software, robotics and biotechnology.
- Two other distinctive traits have to do with the policies promoted by the US government.
- The impact of the antitrust law on the innovative performance of companies.
- The high incidence of federal government spending on R&D activities, with particular reference to those related to defence programmes.

It is worthwhile to look at the latter two aspects in more detail. As noted in Chapter 2, in the second half of the nineteenth century the innovative system present in the US was largely based on a combination of mechanical skills and manufacturing firms that placed little reliance on scientific knowledge. Towards the end of the century the birth of large-scale industrial research redefined the profile of the American innovative system. This was a change linked to the introduction of antitrust laws, which prohibited cartel agreements between competing companies: those agreements, in other words, aimed at exerting collusive control over prices and markets. Starting in 1895, these norms generated a strong wave of mergers, with the emergence of giant corporations that in turn gave rise to the first large industrial research laboratories: the strategy was to beat the competition by focusing on innovative discoveries. Throughout the whole of the next century, the more or less stringent application of the antitrust laws profoundly affected the innovation behaviour of companies – in particular, the propensity to invest directly in in-house research activities or to monitor the external market to buy patents and technologies from other companies (Mowery 1992, 127–8).

In the early eighties, for example, the relaxing of antitrust restrictions – in relation to cooperation between companies on research and innovation – resulted in a massive proliferation of inter-company agreements. This factor, along with other ‘politico-regulative’ interventions (such as the Bayh-Dole law on university patents and more vigorous action at an international level for the protection of intellectual property rights), accompanied and facilitated structural change in the American innovation system. The large industrial laboratories were severely reduced in size and a process of research outsourcing saw the growth of inter-company partnerships and relationships with universities, and a trend towards R&D internationalisation.

Another item of great interest is the variable role played by public spending in American history. The American system of innovation was long dominated by private industry and in the first half of the twentieth century the great laboratories of the chemical, oil and electrical companies dominated industrial research. In 1946 these three industries provided employment for about 26,000 engineers and scientists – representing roughly 70 per cent of the total number of people working in the research laboratories of manufacturing firms (Mowery 1992, 130, Table 1). Federal government funding for R&D was rather limited: in the thirties it ranged between 12 per cent and 20 per cent of the national total. In contrast, the industrial sector contributed about two-thirds of the total expenditure. Moreover, state (rather than federal) funding of universities – encouraging the latter's sense of responsibility towards local communities – fostered an early intertwining of relationships between universities and businesses at a regional level. This was something that did not take place in Europe. Already in the first half of the twentieth century, then, the contribution of American universities to industrial research – through courses of study tailored to the needs of regional economies – was particularly relevant, as was their contribution to the technological performance of companies. And this was all despite the fact that there were few scientific fields in which the US excelled over Europe. To sum up, the pre-war system of innovation was guided and dominated by large private companies.

The post-war system, however, underwent radical change as a result of the Cold War and America's new role as a world superpower. The federal government began to take a central position in the financing of research, both in industry and the universities. During the fifties and sixties the share of federal funding amounted on average to 62 per cent of national expenditure on R&D (Figure 5.2). Much of the research, although being conducted by non-governmental laboratories, was related to military spending and national defence programmes (Mowery 1992, 136, Table 3; Mowery and Rosenberg 1993, 42, Table 2.4). This massive public commitment swept the US to world leadership in basic scientific research – a position which, as we have seen, it did not previously hold. Meanwhile, a 'by-product' of these huge military commissions was the development of new technologies for civilian use in strategic sectors such as aerospace, semiconductors, computers and software (Mowery 1998, 640). Only in recent decades has there been a reduction in federal research funding, with a sharp decline especially towards the end of the eighties (Figure 5.2). This, however, is in line with what happened in other developed OECD countries.

As an idea of this contraction, it is enough to say that in the seventies US federal spending on R&D still accounted for 53 per cent of the national total. In the eighties this slipped to 46 per cent, and then in the following two decades plunged to 34 per cent and 28 per cent (based on National Science Foundation

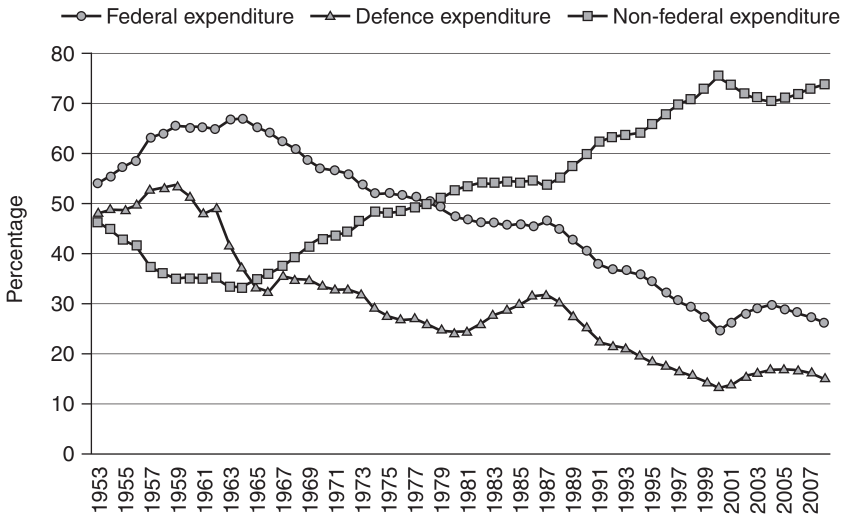

Figure 5.2 Share of federal public, non-federal and defence program expenditure in total US R&D funding (source: National Science Foundation, Division of Science Resources Statistics).

data). Much of this reduction was due to cuts in defence programmes. At the height of the Cold War, during the fifties, this sector alone funded more than 50 per cent of national research. This share progressively dwindled over the next few decades, to arrive at around 16 per cent in the twenty-first century.

The study carried out on the US clearly shows the analytical approach of the book edited by Nelson, heavily focused as it is on the contribution to R&D of the main actors in the system. This was not always intentional, as the example of the influence of the antitrust legislation shows. As we have seen, in some periods of American history this had the counterintuitive effect of stimulating the emergence of large corporations, which, through massive investment in research, managed to maintain a dominant position in the US innovation system for a long period of time. The comparison of national cases conducted by Richard Nelson and Nathan Rosenberg in the introduction to their book also prompts a reflection on the differences between the various national systems, which are stable over time and, above all, related to the role of government in the economy. The strength of innovation systems, in fact, reflects the conscious efforts made by the public sector to support the national economy. As seen above, in the case of the US a crucial role was played by policies dealing with defence.

According to the two scholars, however, the key ingredient to ensure NIS have a good performance is the innovative strength, competence and competitiveness of domestic firms. This does not mean that companies should necessarily be large and specialised in high-tech areas. Some of the cases studied, in fact, show that good innovative performance is possible even by national systems specialised in traditional industries and characterised by the presence of many small businesses. In all successful national cases, however, there is one common trait: companies were not protected against the market and were exposed to strong competitive pressures. But which conditions favoured the emergence and consolidation of a competitive economy, based on a dynamic entrepreneurial structure? Once again, the arrow points in the direction of the different forms of public regulation, and in particular the quality of the national education system and macroeconomic policies (fiscal, monetary and trade) aimed at stimulating exports. Interventions in favour of innovation also play an important role, but the results are rather variable depending on the measures taken. Support for scientific research has a significant impact on some sectors – the most science-based – especially if it is accompanied by specific measures designed to foster relations between universities and the business world. As regards direct financing of industrial research, the verdict is more controversial, however: national programmes are as highly differentiated as their outcomes.

Turning now to another book, edited by Lundvall (1992b), and published at the beginning of the nineties, it should first be noted that this does not contain a comparative study of national cases. Rather, it provides a theoretico-conceptual framework of innovation systems derived from research on economic development conducted by a team of economists from the Danish University of Aalborg. The starting point is represented by the statement that, in the new economic scenarios, the fundamental resources for competition are represented by *knowledge* and *learning processes*. A new stage in the development of capitalism has begun, one characterised by rapid economic change and driven by technology, and in which the success of companies, territories and nation states depends on their ability to learn – to create and/or acquire new knowledge. What can be defined, in other words, as a *learning economy* (Lundvall and Johnson 1994).

According to Lundvall, mainstream neo-classical economics, focused as it is on the static allocation of scarce resources, is not equipped with the wherewithal to explain these changes. In traditional theory, in fact, innovation is configured as an extraordinary exogenous event – one that removes the system from its state of equilibrium. In contrast, in modern capitalism, innovation is:

- *constitutive and ubiquitous* – it is spread throughout the economic fabric and involves continuous processes of learning;
- *gradual and cumulative* – it consists of 'new combinations' based on previously available knowledge, opportunities and components which are combined in a different way, introducing a variable level of radical discontinuity with the past;
- *processual* – it does not consist of a single event but a series of activities linked to, and influencing, each other, with a blurring of the classical distinctions between invention, innovation and diffusion;
- *interactive and collective* – learning is configured in relational terms (*interactive learning*) and knowledge is a common good that is shared within networks and organisations.

For all these reasons, Lundvall sustains the need for a new analytical model, an alternative to the neo-classical one with, at its centre, learning aimed at the acquisition and creation of knowledge useful for innovation. In this new approach, knowledge is more than the simple accumulation of information since it includes the ability to interpret and use it. *Learning,* therefore, is configured as a *process of skill-building* (Lundvall 1996, 3). There are four types of knowledge that are based on different kinds of skill: *know-what* and *know-why* relate to knowledge of facts (natural, social, etc.) and the principles that explain them, and rely on cognitive skills. *Know-how* refers to the practical knowledge and skills needed to perform specific tasks. And *know-who* refers to knowledge and social skills, to knowledge about people ('who knows what' and 'who knows how to do what') and the ability to build interpersonal relationships.

These kinds of knowledge are learned in different ways. The first two are more formalised and can be assimilated through study. The other two, however, present tacit aspects that are difficult to codify, and are acquired through practical experience and social relations. Their circulation, moreover, does not take place through ordinary market channels since the transmission of tacit knowledge and forms of learning mediated by interpersonal relationships are profoundly influenced by trust aspects. In other words, the *learning economy* requires a great deal of trust and social cohesion (ibid., 15–17). Precisely because of this socio-relational aspect, innovative processes cannot be understood without taking into account their specific cultural and institutional context: the national innovation system, in other words, which regulates the production, use and dissemination of new, economically useful knowledge. It is a *social* system, since these activities involve interaction between people, and *dynamic*, as it is driven by feedback that can either reinforce or hinder the growth and reproduction of its constituent elements.

Lundvall acknowledges a broad definition of NIS, one that focuses not only on the institutions and organisations that deal with scientific and technological research, but on all the components of the economic and institutional structure that influence learning processes. The latter are, in fact, embedded in routine activities that take place in the sphere of production, distribution and consumption and provide important stimuli for innovation. These 'ordinary' activities generate learning economies of three types: *learning by doing* produces improvements in the production process (Arrow 1962b); *learning by using* increases the efficiency of use of complex systems (Rosenberg 1982); *learning by interacting* introduces refinements and innovations that are derived from relationships with other subjects (e.g. between producers, suppliers and consumers) (Lundvall 1988, 1992a).

The Lundvall approach, too, combines economic and institutional analysis. The relationship between these two parts is a circular one. Production specialisations, in fact, influence national institutions and the latter, in turn, tend to attract and favour the most compatible businesses and industries. There is therefore a strong interdependence between economic structure and institutional context (Lundvall and Maskell 2000, 363). Institutions are understood as 'set of habits, routines, rules, norms and laws, which regulate the relations between people and shape human interaction' (Johnson 1992, 26). They are not necessarily the most efficient or most suitable solution and, in addition, they embody power relations. That said, institutions play a fundamental role in learning and innovation processes: they reduce risk, distribute incentives, mediate conflict and coordinate the use of knowledge. If, on the one hand, they provide the stability necessary for social reproduction, on the other hand they are also essential to facilitate change. In situations of uncertainty, such as those found in innovation processes, they provide a framework of certainty that actors find useful to stabilise – at least relatively speaking – their expectations. Institutions also organise the cognitive process through both the accumulation and transmission of knowledge that must be 'remembered'; and selecting what is to be forgotten and abandoned through the 'creative destruction' of knowledge. Both learning and 'creative forgetting' are essential for innovation processes, and these are governed through institutional channels (ibid., 29–30).

Institutions also shape four aspects that impact on the innovative orientations of economic actors: (1) the time horizons of the actors; (2) the role of trust; (3) the mix of rationales used; (4) the ways in which authority is exercised (Lundvall and Maskell 2000, 360–1; Lundvall *et al.* 2002, 220). For these reasons, the institutional, cultural and historical differences of various countries are reflected in the specificity of NIS through their influence on business structures, on firms' relationships, on the role of the public sector, on the structure of the financial sector, on the intensity of R&D, and on the organisations who deal with it (Lundvall 1992a, 13). Lundvall, for example, has applied this approach to the Danish case (DISKO, *Danish System of Innovation in a Comparative Perspective*), showing the importance of incremental innovation in an economy specialised in mature, low-tech industries. In recent years, moreover, he has sought to extend and adapt the NIS approach to developing countries, where greater attention must be paid to the overall system of the creation of socio-economic skills and not only those based on the science sector (Lundvall *et al.* 2002, 216). As can be seen, the analytical approach used by the Danish scholar is very close to themes and concepts of a sociological nature. But the same is true, more generally, for all the studies that fall within the NIS framework. The attention given to both the social networks of learning and to the institutional context builds interesting bridges towards the world of economic sociology. The first, more micro dimension pushes the dialogue in the direction of the new economic sociology; while the second, more macro dimension presses towards comparative political economy. As seen in Chapter 1, certain authors have already started – in a more systematic manner – to connect studies on the varieties of capitalism with studies regarding innovation. Another important trend, and one that we will look at in the next chapter, develops around the territorial aspects of innovation. First, however, other variants of the systemic approach must be introduced that do not – as their authors themselves recognise – offer an alternative to the study of national systems, but rather provide complementary perspectives.

5.4 Sectoral systems

So far we have focused on innovation systems defined on a geographical basis. Certain authors have proposed a different approach, based on production sectors. The assumption is that modalities of technological change and innovation depend on the specific characteristics of the various industries. There is a wide literature in economics on the industrial sectors – both theoretical and empirical – but the *sectoral innovation systems* (SIS) approach is one that stands apart from traditional perspectives. First, because, unlike industrial economics, it analyses the sectors in terms of their innovation processes and does not consider their boundaries as utterly static and fixed. Second, because it examines not only the companies but also other actors, analysing their interactions within institutionally shaped contexts (Malerba 2004a, 1; 2004c, 16).

Evolutionary economics provides the theoretical framework of this approach, furnishing some of the basic assumptions: (1) technological transformations are central to explaining economic change; (2) the actors involved in innovation processes are heterogeneous in terms of skills, experience and organisation, and act according to bounded rationality, within highly uncertain and continuously evolving scenarios; (3) company behaviour is shaped by context, and so their modalities of action and learning are constrained by technology, knowledge base and the institutional environment (Malerba 2002, 250). Starting from these premises, we can proceed to a first definition of SIS. A *sectoral system of innovation and production* 'is composed of a set of new and estabilished products for specific uses, and a set of agents carrying out activities and market and non-market interactions for the creation, production and sale of those products' (Malerba 2004c, 16).

SIS have three main components.

1 *Knowledge and technology*. New knowledge is the foundation of technological change and each sector has its own knowledge base and specific learning processes.
2 *Agents and networks*. The main players in sectoral systems may be individuals (e.g. consumers, entrepreneurs or scientists) and/or organisations (companies, universities, research centres, government agencies, etc.). Analytical focus, as well as on agents, is also placed on their interactions, namely on the formal and informal ties of cooperation that unite them and which serve to integrate the complementarity of their knowledge, skills and specialisations (Malerba 2005).
3 *Institutions*. These include norms, routines, habits, practices, rules, laws and standards that shape the knowledge and behaviour of the actors (ibid., 385). These rules have different degrees of formality and cogency; some arise from interaction between agents (such as contracts), others impose rules and constraints from outside (such as laws). Institutions govern the interaction between the actors and their impact on technological change and the innovation activities of companies. Relevant institutions are both national (e.g.

patent laws, antitrust laws, a country's tax system, etc.) and sectoral (the specific characteristics of its labour market, training systems, funding methods, etc.). But the impact of national institutions is also differentiated at a sectoral level.

The first of the three factors mentioned above (knowledge and technology) represents the central and distinctive element of this approach. The idea is that each SIS has a different *technological regime* as its foundation. This concept, introduced by Nelson and Winter (1982) and redeveloped by Malerba and Orsenigo (1993; 1997; 2000) refers to the 'technological environment' in which companies operate. This differs in relation to the conditions in which technological change takes place (opportunity, appropriability, and degree of cumulativeness of technological progress) and the characteristics of the knowledge base.

Conditions of opportunity represent the 'likelihood of innovating for any given amount of money investend in research' (Malerba 2004c, 21). The presence of *high/low* opportunity defines a technological environment where there is *wide/narrow* potential for innovation and so *strong/weak* incentives are created to invest resources. *Conditions of appropriability* regard the possibility of protecting the results of innovation in order to achieve the relative economic benefits. A high *level of appropriability* means that through various *means* (patents, secrecy, continuous innovation, control of resources and complementary services) the company succeeds in protecting itself from imitation, thus translating its innovative activities into a source of profit. *Conditions of cumulativity* refer to the degree to which knowledge accumulated in the past is important for the production of new knowledge in the future: in other words, the extent to which the introduction of new technological solutions depends on those already previously introduced. Cumulativity can be connected to both the cognitive dimension (technological level) and to the sedimented experience and expertise in a specific productive organisation (company level), industry (sectoral level) or geographical area (local level). Finally, *knowledge base* refers to the necessary *know-how* for innovative activity, and differs according to its (more or less specific, tacit, complex and independent) *nature* and (formal/informal) *means of transmission*.[6]

The combination of these elements defines the technological regimes of the various sectors, with which various models of innovation are associated. Malerba and Orsenigo (2000, 231ff.) refer in particular to the two models proposed by Joseph Schumpeter, already mentioned in Chapter 1. The first is that of *creative destruction* – so-called *Schumpeter Mark I* – which is typical of markets with low entry barriers. These are markets characterised by the presence of many small- and medium-sized companies where innovation is generated by innovative entrepreneurs. The second is the *creative accumulation* model – *Schumpeter Mark II* – which is found in markets with high entry barriers, where innovative processes are dominated by the R&D labs of large companies (Nelson and Winter 1982; Kamien and Schwartz 1982; Fagerberg 2003). The two models imply different modes of technological change: Schumpeter Mark I is characterised by high innovation opportunities, low appropriability and low cumulativity (at company level). Schumpeter Mark II, on the other hand, features high appropriability and high cumulativity. But how can these models be linked to sectoral analysis? The study by Malerba and Orsenigo on patented innovations in the seventies and eighties in six advanced economies (Germany, France, Britain, Italy, the US and Japan) shows a remarkable *similarity between the countries* in sectoral models of innovation, and a remarkable *diversity between sectors* within the countries themselves. The first model (Schumpeter Mark I) tends to prevail in some traditional and mechanical sectors (clothing and footwear, furniture, machinery, industrial automation, etc.), while the second (Schumpeter Mark II) dominates in sectors that employ chemical and electronic technologies. To sum up: technological regimes influence the ways in which innovative activities are organised and produced in various industrial sectors (Malerba and Orsenigo 2000, 241–3).

Models of innovation are not static, however. They change over time, following the life cycle of a sector and the evolution of its technological regime. In the initial phase, when knowledge is still fluid, technological trajectory uncertain and entry barriers low, small, new companies are the mainspring of innovation. A Schumpeter Mark I model prevails, therefore. When the sector moves into a period of greater maturity and the technological trajectory stabilises, financial endowments and economies of scale instead begin to become more relevant. With the rise of market entry barriers, then, large companies take over and there emerges a Schumpeter Mark II model of innovation (Malerba 2005). This does not mean that we should imagine a linear type of evolution which inevitably leads all sectors to pass from a Mark I to a Mark II model. Trajectories may, in fact, also be of an opposite kind, since in the presence of strong discontinuities in the technological regime or market conditions, a sector characterised by large dominant companies (incumbent firms) may see the arrival of new firms (new entries) that are exploiting innovative technologies or meeting new demands. This represents a shift from a Mark II to a Mark I model, or even a hybrid of the two.

Some examples might be useful here to clarify this point. The evolution of the *pharmaceutical industry* has brought with it several structural rearrangements as a result of changes taking place in its technological regime (McKelvey *et al*. 2004).

- In its first phase of development (1850–1945) the pharmaceutical sector was part of the chemical industry and was mainly dominated by large German and Swiss companies (followed by British and North American companies), which started mass production of drugs without carrying out a great deal of research (at least up until the 1930s).
- During the second phase (1946–80) – the golden age of the pharmaceutical industry – the system changed. Large firms invested more in R&D, acquiring large laboratories that, employing random screening research methods,[7] discovered new molecules or active principles for potential therapeutic and pharmacological use. Many new drugs were launched by leading companies

in the industry – thanks to a growing demand on an international scale – due to the setting up of new national healthcare systems and public support for pharmaceutical research. At this stage the notable prominence of large firms in the field of innovation was due to the extensive R&D resources required for developing new drugs. The regulatory regime, moreover, also guaranteed the high levels of appropriability of the research results. In this area, in fact, patents were a particularly effective tool for the protection of intellectual property, making it easy to protect new discoveries from imitation by competitors. All of these sectoral characteristics, therefore, rendered the innovative core of the sector fairly stable, composed of large enterprises around which other minor actors operated following a mainly imitative kind of competitive strategy. At this stage, however, European supremacy in the pharmaceutical industry was challenged. The huge resources spent in the US on scientific research in the biomedical field, the building of relationships between businesses and universities, and a very strict regulatory regime for drug approval, laid the foundation of American leadership in the life sciences – which came to full fruition in the following period (ibid., 82ff.).

- During the third phase of development (from 1980 onwards), the scientific revolution represented by the development of molecular biology and recombinant DNA techniques created in the area a new system of learning that can be defined as *guided search* – a method that stands in contrast to the previous random screening regime which owed its existence to the lack of adequate knowledge regarding the biological basis of disease. By applying new theoretical discoveries in biology, new methods of drug discovery were launched that enabled a more focused and rational design of new compounds and drugs. All these developments modified the process of innovation and the organisational structure of the sector: relations between companies and universities grew far closer and university spin-offs[8] came dynamically to the fore, commercially exploiting the knowledge gained through scientific research. The new learning regime provided ample space for the so-called new biotechnology companies (NBC) – small firms with a high intensity of knowledge, often founded by star-scientists, and employing particularly productive and innovative researchers (Zucker and Darby 1996; Zucker *et al*. 1998, 292) who were able to come up with great, commercially viable discoveries.

The point to emphasise here is that the changes that occurred in this sector's technological regime reshaped the balance between the big sector leaders, the *incumbent* companies, and the *new entries* – the newly created small businesses that were taking their place in the market for the first time. The new technological regime, in fact – especially at the beginning – allowed a great deal of room for the innovations that the NBC brought to the table. It is worth adding, however, that, for the development and commercialisation of new discoveries, the NBC almost always made use of – or in some cases were even absorbed by – the large pharmaceutical companies. As time went on a collaborative co-existence was established between these two entities, thus creating a new division of innovative labour within the industry (Sharp and Senker 1999; McKelvey *et al*. 2004, 96). In phases of technological discontinuity, innovation is, in fact, not infrequently introduced by start-ups, passing through the establishment of small firms that bring new business ideas to market – or develop them in the early years of their existence (Bhide 2000) – working as trailblazers for subsequent exploitation on a larger scale.[9] There tends to prevail in these phases, in other words, a kind of innovation that approximates to the Schumpeter Mark I model – but this is not a foregone outcome. In the chemical industry, for example, where discontinuity occurred as radical as that which took place in the pharmaceutical sector, large incumbent firms never lost their central position within the SIS (Cesaroni *et al.* 2004).

Processes of sectoral change are far from linear, therefore, and mainly proceed through three types of evolutionary process:

1 the *creation of variety*, which increases the options available in terms of technology, product, business, organisation, institution, strategy and so on;
2 the *selection* of one or more of these options, which decreases variety in the economic system and reduces the inefficient use of resources;
3 the *reproduction* of the established solution, which, replicated, generates continuity and inertia.

These evolutionary mechanisms, however, never produce stable and long-lasting equilibriums and do not always select the best possible solutions since the trajectory of change also depends on the constraints derived from the actions previously carried out. The success and diffusion of certain initial solutions, the increasing profits associated with them, and the interdependence between the actors, can create situations of irreversibility in relation to the technological choices made in the early stages of development of an industry. This *path-dependency* can determine a *lock-in* effect – an 'entrapment' of the system within technological and structural configurations that are not always the very best available (Malerba 2004c, 98). A classic example of this is the 'QWERTY' keyboard, still in use today in our computer.

This type of keyboard is named after the sequence of letters placed on the left of the top row of keys. Why this strange layout? It was invented in 1873 by Christopher Sholes, a Milwaukee newspaper editor, with the intention of solving a problem related to frequent type-bar jamming in early versions of typewriters. Sholes' idea was to replace the keyboard's alphabetical order by separating the pairs of letters most commonly used in the English language so as to prevent the keys pertaining to these letters from being placed nearby and causing the type-bars to stick. Later, when this mechanical problem was solved in more advanced versions of the typewriter, other arrangements of the alphabetic keys were also tried out, which could speed writing up and make it easier. One example is the Dvorak Simplified Keyboard, patented in 1936 by

August Dvorak and William Dealey, which placed the most-used letters in the centre of the keyboard, facilitating the alternation of the two hands. But this alternative layout was never a success: the 'QWERTY' version had become the dominant standard and switching to other schemes, even more efficient ones, would have meant substantial learning and adaptation costs (David 1985, 334–5).

Returning to the evolution of SIS, it should be added that it depends not only on changes that occur in individual components (knowledge, technologies, actors and networks, institutions, etc.) but also on their *co-evolution* – the latter being defined as the joint and interdependent transformation of 'technology, demand, institutions and firm organizations and strategies' that takes place during the evolution of an industry (Malerba 2004c, 31).[10]

Another important aspect of SIS regards the technology flow between companies and sectors – the sources of innovation, that is, and the diffusion and utilisation processes of new technologies. This analytical perspective sheds light on a complex web of 'technology transactions' between various industries which occur not only through the purchase and sale of goods that incorporate the technology, but also through the exchange of information and expertise between the companies and product diversification in related sectors (suppliers and product users).

In relation to this, Keith Pavitt (1984) studied the models present in different industrial sectors, using information on 2,000 innovations introduced into Britain between 1945–79. Two main elements emerge from the analysis. The first is that companies explore new technical solutions based on the knowledge and skills available to them, implying that technological change at firm level is a cumulative process. The second concerns sectoral variety in the types of innovation (process or product) and in the sources of the technological process. In other words, recurrent models of technological change emerge that allow Pavitt to develop a *sectoral taxonomy* 'according to whether or not the sectors of production, of use, and the principal activity of the innovating firm, are the same' (ibid., 346). This classification – still the most widely accepted in Innovation Studies – is based on several aspects:

- *sectoral sources* of technology, to assess whether this is generated within a sector or comes from outside through the purchase of materials and means of production;
- *institutional sources* and the *nature* of the technology that is produced (in particular the sources of knowledge and innovation, which may be intramural or come from universities, research centres, etc.);
- *characteristics of innovative companies* (with reference to size, their primary activities and the degree of product diversification).

Using innovative companies and their technological trajectories as the unit of analysis, Pavitt develops the following classification: (1) supplier-dominated firms; (2) production-intensive firms, in turn divided into (a) scale-intensive firms and (b) specialised suppliers; and (3) science-based firms.[11]

Supplier-dominated firms prevail in traditional manufacturing sectors (textiles, footwear, etc.), agriculture, construction and services. They are usually small, carry out little research, and their competitive advantages are based on professional skills, product design, brands and advertising. Their technological trajectories are based mainly on cost reduction. They do not contribute, except to a limited extent, to the development of the technologies that they use: innovation comes mainly from the suppliers of materials or equipment, or from consumers, services or public research.

Scale-intensive firms operate in the production of materials (glass, steel, concrete, etc.), consumer durables and vehicles. They take advantage of the large size of the markets of reference to obtain economies of scale by implementing a strong division of labour internally, with standardisation and simplification of tasks and increasing mechanisation to make it possible to reduce production costs. Technological trajectories are mostly geared towards process innovation and, in certain cases, to improving product quality. These firms are typically medium to large in size and operate in productive sectors that can generate the technological innovations they use internally. Innovation sources come from the experience and skill gained by the production departments or from internal R&D activity, or from relationships with suppliers of specialised machinery. This last point brings us to the third class.

Specialised supplier firms operate in the field of industrial machines and in the production of machinery and equipment. Their technological trajectory is different from the previous one, oriented as it is towards product innovation designed to improve performance rather than towards process innovation to reduce costs. They are mostly small in size and produce innovation that is used by other companies and in other sectors. Innovation sources come from learning from experience (learning by doing) and interaction with users (learning by interacting), especially with large companies that can provide operational expertise, complementary design resources, and opportunities for innovation experimentation and testing.

Finally, *science-based companies* operate mainly in the chemical-pharmaceutical and electrical/electronics fields. In both cases, innovation sources come from company R&D activity – which tends to exploit knowledge produced by the scientific community. They often, therefore, maintain collaborative relationships with universities and other research centres. The high level of sophistication of knowledge required in the sectors in which they operate, and economies of learning related to internally carried out research, generate high barriers that hinder the entry of new actors. Firms are generally (though not always) medium to large in size – especially in the chemicals and electronics sectors – and produce much of the process and product innovation used in their respective fields, which are then employed in other productive sectors.

Before closing this section on SIS, a mention should be given to the studies of *technological innovation systems* (TIS). This approach, like that of sectoral systems, insists on the specificity of the cognitive and relational processes underlying technological change. While, on the one hand, it can be seen as restricting analytical focus – since it refers to specific technologies rather than to an entire industrial sector – on the other hand it also expands it, since it deals with generic technologies with less well defined sectoral and geographical boundaries, which can be applied to a plurality of industrial sectors and go beyond the regional and national level (Carlsson *et al.* 2002, 236). The starting point is provided by the *technological system* concept, understood as 'a network of agents interacting in the economic/industrial area under a particular institutional infrastructure and involved in the generation, diffusion, and utilization of technology' (Carlsson and Stankiewicz 1991, 94; 1995, 49). Technological systems are defined in terms of cognitive and experiential flows rather than of ordinary goods and services, and among their components – in addition to actors, organisations and institutions – there also appear physical or technological 'artefacts' such as turbo-generators, transformers and transmission lines in electric power systems and diagnostic techniques and drugs in biomedical systems (to give only a few examples related to artifacts that have actually been studied) (Carlsson *et al.* 2002, 234).[12]

5.5 The triple helix

The *triple helix (TH)* model also emphasises the systemic-interactional component of innovation processes. However, it stands partially apart from the literature on national systems of innovation, which TH scholars consider more appropriate for the study of innovation of an incremental kind since it treats companies as the main actors and focuses on the path-dependent features of institutional systems. The TH model, conversely, focuses mainly on radical innovation, which creates major structural discontinuities (Etzkowitz and Leydesdorff 2000, 109; Etzkowitz 2002, 2).

What is proposed is a spiral model of innovation which focuses on the interactions between three distinct institutional spheres – *universities, industry and government (UIG)* – considered to be the cornerstones for innovation and growth (Etzkowitz 2008, 1). In the new context of the knowledge economy a dense network of communications is created between these three spheres, modifying institutional structure and innovative dynamics and giving an increasingly central role to the university (Etzkowitz and Leydesdorff 1997). The TH – the spiral interaction, in other words, between universities, industry and government – evokes the image of the screw-type hydraulic pump, better known as Archimedes' screw: a mechanical device for raising liquids which in ancient Mesopotamia gave rise to an innovative hydraulic system for agriculture.[13]

This new model derives from the convergence of two different institutional structures: the *statist model*, under which the government controls both the university and the economy; and the liberal-style *laissez-faire model*, in which the spheres are independent and interact very weakly, separated as they are by rigid boundaries (Figure 5.3).

This of course means two opposing ideal-types in terms of governance: in the first, the government has the central role in promoting economic growth and

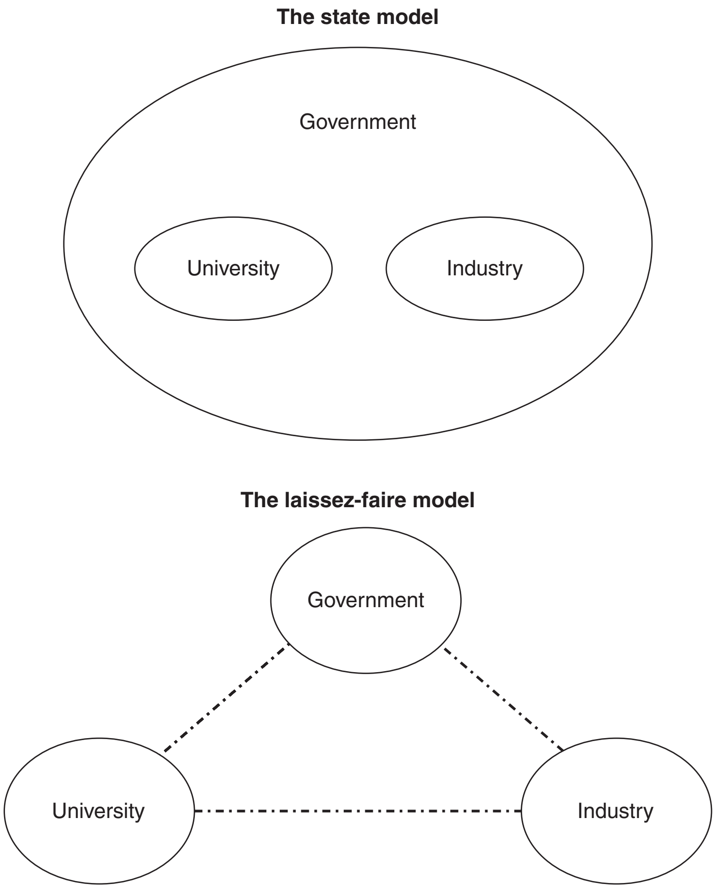

Figure 5.3 Models of relations between universities, industry and government (source: adapted from Etzkowitz (2002)).

social development; while in the second, this is the market's responsibility. In the new competitive scenarios, both of these models are unsuitable and are subject to growing pressures to change in the direction of institutional convergence. There are therefore two distinct pathways that lead towards the TH. The first – involving the statist model – is developed as a process of relative institutional *differentiation*, which gives greater autonomy to the university and industry, and then leads to a new point of equilibrium: here, there is interaction between the three institutional spheres, but on the basis of greater independence and equality. The second route – which regards the laissez-faire model – instead follows an opposite path, reducing the autonomy of the institutions and producing increasing integration between the institutional spheres. As a result of this convergence 'the common triple helix format supersedes variations in national innovation systems' (Etzkowitz 2008, 12).

In the TH model (Figure 5.4), unlike the previous two, a partial overlap of institutional spheres can be seen, which induces changes not only in their relationships but also within each of them: this does not, however, call their basic function into question. Each institution, in fact, tends to maintain its core identity, the loss of which would otherwise mean renouncing their autonomy.

The TH image is proposed in order to emphasise how innovation requires the contribution of all three institutional spheres. In addition, the change takes effect in all fields of society, albeit with slightly different modalities. While economic growth relies on technological innovation, social development requires institutional and organisational innovation. With regard to advanced economies, Etzkowitz refers to 'social inventions' – *hybrid organisations* that carry elements of TH inscribed in their very DNA, and which develop at the points of interconnection between the institutional spheres. These hybrid organisations are the result of a new configuration of relations between universities, industry and government, where the institutions increasingly assume each other's role. Universities carry out economic functions through the capitalisation of knowledge; companies shoulder responsibility for advanced training and research; and governments stimulate research, turning themselves into venture capitalists to finance innovation in order to sustain national competitiveness. This new configuration of relations triggers substantial changes in the institutional framework. At a first level, the transformations occur within each sphere – i.e. in each of the helixes – as a result of the hybridisation process of institutional logics. At a second level, there are changes related to the influence that each helix exerts upon the others. The typical example is represented by the Bayh–Dole Act passed by the US government in 1980.

This law meant that the ownership of patent rights arising from research funded by the public sector was granted to American universities, providing enormous stimulation for the commercialisation of scientific results and the development of entrepreneurial universities. And at a third level, there is 'the creation of a new overlay of trilateral networks and organizations from the interaction among the three helixes, formed for the purpose of coming up with new ideas and formats for high-tech development' (Etzkowitz and Leydesdorff 2000; Etzkowitz 2002, 2).

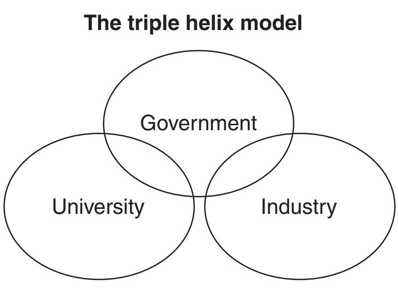

Figure 5.4 The triple helix (source: adapted from Etzkowitz (2002)).

The evolutionary spiral of TH is fed by circulation processes that occur at both micro and macro levels (Etzkowitz 2008, 21), with micro circulation taking place within each helix, and macro between the helixes, thus triggering inter-institutional fertilisation (through new ideas, collaborative projects and a better understanding between institutions). Both are fed by:

- the *circulation of individuals* among the occupational positions of the various institutions (or by simultaneous or alternating covering of roles);
- the *circulation of information* through innovative networks;
- *the circulation of results* achieved in various areas that – triggering dynamic imbalances – tend to strengthen innovative effort in complementary fields.

These various forms of 'horizontal' social mobility – transferring skills and experience from one institutional sphere to another – promote socio-organisational hybridisation and innovation processes. The 'functional contamination' associated with these horizontal interactions – with new actors dealing with tasks traditionally carried out by other institutions – results in the contribution of new ideas that improve both the performance of the system as a whole and that of individual institutions. For example, universities contribute to economic innovation through venture capital firms, incubators for the creation of start-ups and academic spin-offs.

But these phenomena also retroact on their two traditional missions (education and research), fostering the renewal of curricula and research programmes: 'Each institutional sphere is thus more likely to become a creative source of innovation and to support the emergence of creativity that arises in other spirals' (ibid., 9).

To sum up, the triple helix is a generative platform for institutions, creating new organisational formats for the promotion of innovation, as a synthesis of elements of the three helixes (ibid., 8). These developments take place primarily on a regional scale, whenever there is the intentional adoption of an innovative strategy based on the creation of new science-based companies – ones that make use of the knowledge generated by the scientific community. *TH regions* do not necessarily match the politico-administrative borders, and include three constitutive elements:

1 a source of knowledge (*knowledge space*);
2 a mechanism for achieving consensus (*consensus space*);
3 a project aimed at fostering innovation (*innovation space*).

As 'exemplary cases' of this particular development strategy, Etzkowitz indicates Silicon Valley (specialising in ICT) and the Boston area (specialising in biotechnology) in the United States; and the Linköping area in Sweden (specialising in the aerospace industry): all these areas feature a high concentration of innovative high-tech companies closely linked to universities and scientific research.

But how do these situations come about? The initial phase is often represented by the creation of a *knowledge space* – the territorial agglomeration of research activities focused on a specific theme – which can give rise to significant technological and commercial developments. In order for these knowledge resources to be put to good use, however, the relevant actors in the territory need to develop a shared strategy directed at their valorisation. A *consensus space* has to be created, in other words: a place where the major regional actors, hailing from different sectors and experiences, come together to develop a joint project, thus creating 'discussion networks' that go beyond the boundaries of institutional spheres. Examples of this are the New England Council in the Boston area during the twenties, or the Joint Venture Silicon Valley during the crisis of the early nineties. Finally, these projects must be actualised within an *innovation space*: a new hybrid organisation (business incubators, technology transfer offices, science parks, etc.) that promotes innovation on a regional scale, connecting TH resources, people and networks together in order to realise the goals articulated in the consensus space (Etzkowitz 2002, 7; 2008, 80). Not all TH institutions assume the same importance in promoting these 'regional projects'. One of them can take on the role of *regional innovation organiser*, operating as a leader in the planning and coordination of the other actors.

To take a concrete historical example one only has to look at the development of Route 128, a highly developed and innovative technology district in the Boston area (also discussed in Chapter 7). The genesis of an agglomeration of firms and universities with high innovative potential derives from a long incubation process made up of choices intentionally directed at the development of new knowledge and technologies with commercial value. A first step was the creation of the Massachusetts Institute of Technology in the mid-nineteenth century. William Barton Rogers, in fact, founded MIT with the precise idea of combining basic research and the development of new technologies, while gathering a pool of top-class researchers around the project (*knowledge space*). A second step was the establishment of the New England Council in the twenties and thirties, which brought together the area's academic, economic and political élite (*consensus space*). It was here that the then president of MIT, Karl Compton, relying on experience gained in the university in the creation of science-based companies, was able to launch a new project for the development of the region. The idea was to exploit comparative regional advantages related to the presence of a high endowment of academic resources, through a systematic strategy of start-up creation aimed at commercialising the results of scientific research. In 1946 this strategy also led to the creation of the first venture capital firm: the American Research and Development Corporation (*innovation space*). This was a hybrid organisation, which represented an early and informal version of the business incubators: in addition to funding firms, it also provided technical and entrepreneurial support, sometimes even allowing the location of new businesses directly inside the MIT campus.

Although the TH model places strong emphasis on the interaction and contribution of all three institutional spheres, Etzkowitz believes that universities represent the dynamic heart of the knowledge society: its 'generative principle' (Etzkowitz 2008, 1). In the scenarios of contemporary capitalism they are the equivalent of what coal mines and steel mills represented in the period of early industrialisation: formidable resources for social, economic and environmental transformation. According to Etzkowitz, there is under way in the universities of advanced countries – but with particular reference to the US – a major transformation, of a revolutionary kind. The 'primary mission' of medieval universities was originally the preservation and transmission of knowledge. A first revolution took place during the nineteenth century, inspired by the ideas of academic freedom and the unity of teaching and research propagated in Prussia in the early years of the century by the statesman and liberal philosopher Wilhelm von Humboldt. This new phase tended to emphasise the role of research as the universities' 'second mission', designed to complement – and integrate with – the first mission: the education and training of 'human capital'. A further revolution that affected the university began in the last decades of the twentieth century and introduced a third mission, which manifested itself as greater responsibility for the promotion of economic and social development.

This *third mission* involves a 'capitalisation of knowledge' and a greater openness to the outside world, linking teachers/researchers to the actual end-users of their thinking: creating, in other words, the *entrepreneurial university*. This rests on four pillars:

1 academic leadership capable of developing a strategic vision of its own role;
2 full control by the universities of their own resources (including tangible assets such as real estate and financial capitals, as well as intangible assets related to the intellectual property of research results etc.);
3 an organisational structure capable of activating technology transfer through patents, licences, incubators etc.;
4 the diffusion of an entrepreneurial *ethos* among administrators, teachers and students.

The process of capitalisation means that scientific knowledge is no longer only an epistemological enterprise: it also becomes an economically significant one. As we have seen, the creation of academic start-ups is not a recent development in the US, beginning as it did in the late nineteenth century in the Boston area, at Harvard and MIT, and then, later, after World War Two, moving out to the west coast, to Stanford University. That said, it is only in recent decades that the entrepreneurialisation of the academic world has really grown, with strong support and legitimacy provided by the Bayh–Dole Act – which allows universities to hold the intellectual property rights on the results of research funded by the federal government. In so doing, it has given a strong incentive to the commercial exploitation of academic research, offering a significant boost to the patenting of scientific discoveries.

According to Etzkowitz, the diffusion of the entrepreneurial model gives universities a leadership role in the emerging new mode of production of advanced countries 'based on continuing organizational and technological innovation' (Etzkowitz 2008, 1). Although TH scholars recognise some variability in this process (depending on previous national academic traditions and regional diversity), the strong hypothesis put forward is that of a convergence dictated by the functional requirements of the knowledge economy. In this perspective, the TH model is configured as a new system of innovation on a global scale, with the university becoming the predominant organisational format (ibid., 147). A progressive 'universalization of academic entrepreneurship' is, in other words, under way (ibid., 30–1).

Formulated in such a way, the thesis, however, appears a highly questionable one, tending to simplify processes that are in fact far more varied and complex, and most importantly, providing a functionalist explanation of the process of change, where the requirements of economic development determine the congruent institutional transformations. In reality, while it is true that universities are undergoing a process of institutional change that has reshaped internal governance and organisational models – in some cases pushing towards greater entrepreneurialisation and openness to the outside world – it is also true that the resulting model is a far from homogeneous one. Recent studies conducted on various European university systems show a wide difference in terms of the extension, pattern and speed of these changes – which can only be explained by taking into account regulatory and institutional frameworks and the specific relational dynamics of national systems (Regini 2011).

Box 5 Self-study prompts

1 Why are systemic study approaches to innovation so successful and what traits do they share?
2 What is a national innovation system and what are its main components?
3 Do differences exist within this particular strand of study?
4 What are the different types of skills and learning models illustrated by Lundvall?
5 What are sectoral innovation systems and what are their characteristics?
6 How can technological regimes be combined with the innovation models suggested by Schumpeter?
7 In Pavitt's taxonomy, what are the four main types of company?
8 What is the triple helix?
9 What are the constituent elements of triple helix regions?

Notes

1 The theme of industrial districts and local development will be addressed organically in Chapter 7. Suffice to say here that this concept – coined by Alfred Marshall and reintroduced to international debate by the Italian economist Giacomo Becattini – refers to systems of small- and medium-sized companies, *concentrated* in a specific area, *specialised* in a productive sector, and *integrated* into the production of certain

goods. Such systems generate a combination of cooperation and competition that rely on the social capital and networks of relationships that innervate the local communities. For an updated review of recent studies on industrial districts, including at an international level, see Becattini *et al*. (2009).

2 For some data regarding this growth, please refer to the Introduction.

3 In the original 1997 version, organisations were not mentioned in the definition of institutions. These were added by Edquist (2005, 188) in later versions of the same citation. I have decided to follow this use, given that it is more suitably congruent with the analytical distinction introduced by the authors.

4 More recently, however, Nelson has acknowledged that the 'evolutionary economists' under-theorised institutions and that the NIS 'is an institutional concept par excellence' (Nelson and Nelson 2002, 267). A definition of institutions was therefore proposed in terms of 'social technologies', which takes as its reference the routines, or more or less standardised procedures, that shape economic action and interaction. In other words, institutions are social technologies 'that have come to be regarded by the relevant social group as standard in the context' (Nelson and Sampat 2001, 40). As Nelson observed, this use of the concept – in terms of standard models of behaviour – is close to Veblen's, which defines institutions as widespread habits of action, or more precisely as 'settled habits of thought common to the generality of men' (1909, 626).

5 Lundvall, however, cannot be counted among those who support the need for greater theoretical abstraction as a necessary prerequisite for achieving a high level of 'scientific rigour'. The Danish scholar argued that the flexible and pragmatic nature of the concept of NIS – more so than its theoretical and formal rigour – was one of its major advantages. This has fostered its widespread application in policies as well as growing use in studies on economic development (Lundvall *et al.* 2002, 221; Johnson *et al*. 2003, 8).

6 For a more detailed look at the constitutive aspects of technological regimes, see Malerba and Orsenigo (2000, 236–40).

7 A research method that employs blanket testing of natural and chemically derived compounds.

8 In economics, the term *spin-off* refers to the birth of a new company that derives from organisational units or human resources which have become autonomous from the company/organisation of which they were originally a part. As regards universities, this means the creation of independent companies for the economic exploitation of discoveries and knowledge gained through scientific research.

9 With regard to software companies, for example, Torrisi (1996) observed a division of labour between firms that follows a dimensional logic. For the complex architecture that unites the various players in the software SIS in Europe, see Steinmueller (2004).

10 For examples of these co-evolution processes, see the detailed reports of six sectoral cases (pharmaceuticals and biotechnology, telecommunications, chemical, software, machine tools, services) in Malerba (2004b).

11 Pavitt later added another class to the taxonomy – information-intensive firms – deleting the category of supplier-dominated businesses. Information-intensive companies operate mainly in the banking, commerce and tourism sectors, and have advanced data processing as their main source of technological accumulation. The original taxonomy is, however, still the one generally referred to in IS. For a critical discussion of these changes, see Archibugi (2001).

12 The conceptual framework of technological systems has actually been applied to objects of study collocated at different levels of analysis: (1) to a technology, in the sense of a 'field of knowledge'; (2) to a product or artifact; (3) to a connected set of products or artifacts designed to satisfy a particular function. The first level is the study of technologies that can be applied to a plurality of products, such as the research conducted by Holmén (2002) on the microwave antennae that are used in

mobile phones, ovens, radar and automatic doors. At the second level, instead, specific 'technological products' are studied and these are what define the boundaries of the system in terms of the actors, networks and institutions involved. An example of this type is the study by Carlsson (1995) regarding numerical control machines and robots for industrial automation. And at the third level lies the study of a coordinated set of technological products and the relative 'skill blocks' that are necessary to meet the functional needs of complex systems, such as those in the healthcare field or the aviation industry (Eliasson 1998).

13 The invention of the hydraulic pump screw is attributed to the Greek scientist Archimedes, who lived in Syracuse in the third century BC, but its genesis is in fact a matter of some controversy. Some studies seem to indicate that Archimedes became aware of the mechanism – already known in the Middle East – during a period of study in Alexandria in Egypt. Its origins can therefore be back-dated to the seventh century BC. Stephanie Dalley (1993, 1994), for example, argues that the screw pump was already known during the reign of the Assyrian king, Sennacherib, and had been used to irrigate the gardens of the royal palace – the famous 'Hanging Gardens of Babylon', no less – which, however, were located in the city of Nineveh, also known as the 'old Babylon'. The controversy has been reconstructed and discussed in detail by Dalley and Oleson (supporters of the two opposing arguments), who came to the conclusion that, while the exact origin of the invention is still uncertain, Archimedes may at least be credited with its reinvention and diffusion throughout the Greco-Latin world – probably to solve the problem of irrigation in the Nile Delta (Dalley and Oleson 2003). For further development in this controversy, see also Simms and Dalley (2009).