

**Catch up in different sectoral systems:
some introductory remarks.**

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1. Introduction¹

This paper aims to discuss the major factors that affect the catch up of countries in different sectoral systems. The paper is organized as follows. After an introduction to the catch up of countries in general, Section 2 puts forward the claim that catch up of countries has been usually associated with the emergence and growth of some leading sectors. These sectors are characterized by sectoral systems that differ greatly in their characteristics and dynamics. The notion of sectoral system is discussed in general in Section 3, while in Section 4 some basic evidence on the factors affecting catch up of countries in different sectoral systems is discussed. Then in Section 5 differences in the catch up across countries but in the same sectoral system are discussed. The paper then concludes discussing the Catch up Project which is underway and, among other issues, aims to tackle catch up in sectoral systems.

2. Key sectors as driving the catch up of countries

In general terms catch up refers to the ability of a country to reduce the gap in productivity and income with respect the leading international countries (Fagerberg-Godinho,2005). The very rich literature on catch-up is full of countries that in the past decades have caught-up, others that have forged ahead and several that have fallen behind (Abramovitz,1986). The literature has identified a series of factors that have affected the sources of catch-up. The first element regards the presence of learning and capabilities in domestic firms (Bell and Pavitt, 1993, Kim, 1997; 1999, Lall, 2001, Kim and Nelson, 2000, Lee, 2005). From the early traditional literature that emphasized how it was possible to close the gap through transfer of technology and the imitation of easily available technology, the literature on competences has forcefully moved to show the central role of the process of capability accumulation by domestic firms and the need of various types of capabilities for catch up: absorptive capabilities, innovation capabilities and complementary assets in order to

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adopt, adapt and modify technologies developed elsewhere or eventually generate new ones. Actually, the most current research has shown that any process of development and growth implies some kind of innovation, and that a sequence of steps in the capability building process are necessary for development. The literature has also stressed the role of social capabilities (Abramovitz 1986) and the broad institutions of a country, including the research infrastructure (Mazzoleni and Nelson,2006) and financial institutions (Gerschenkron, 1962). In the catching up in income per capita or productivity public policy has often played a major role in different ways and forms in several countries such as Japan (Johnson,1982), Korea (Kim 1997), Taiwan (Wade, 1990) and Brazil (Mani, 2004). Also the upgrading of the level of human capital has proven a key element for catching up (Fagerberg and Godinho,2004 and Bernardes and Albuquerque, 2003). Finally, some research has focused on the fact that catch up has been associated with organizational innovations. For example, new organizational forms such as the industrial R&D laboratory and commercial bank have accompanied the growth of Germany in the XIX century; mass production the growth of the US in the first part of the XX century and the kanban system the growth of Japan in the 1970s (Aoki,1988). Recently, it has been proposed that the OEM has to be seen as an organizational innovation which has allowed countries to develop capabilities (Hobday, 1995). It must be noted that in all the literature, factors affecting catching-up have been discussed broadly for a country as a whole, although specific sectors have been mentioned.

The starting point of this paper is that countries catch up in income per capita is usually associated with the emergence and growth of some leading sectors. These leading sectors have spurred the economic growth of countries both directly and through their effects and interdependencies with the rest of the economy. This has been so during the past centuries: in the now advanced countries, cases of emergence and growth of sectors that have become large and highly competitive in the world markets are now abundant. In this paper, I do not want to make a review of all the studies regarding countries' catching up lead by some leading sectors. I want to just mention few cases.

Historically, one could start from the catching up of Germany with Britain in the XIX century, associated with the growth of the chemical industry (Murmann, 2003). More recently, one could look at the catch up of Japan during the 1970s led by sectors such as automobile and electronics (Goto and Odagiri, 1993), of Korea led by auto and electronics (Lee and Lim, 2001) and Taiwan led by electronics (Amsden and Chu, 2003). Those leading sectors have been changing over time, according to the specific historical time, the stage of the industry life cycle or the initial specialization of the country. Similarly to the studies focussing on the catching up in income per capita for the countries as a whole, these studies show that same factors are at the base of the emergence and growth of a sectors in a country: learning and capabilities by domestic firms, active government policy, a highly skilled labor force, entrepreneurship and highly dynamic small and medium size firms, some key large firms as drivers of growth.

In this paper the term catch up will be used for sectors, as it has been done in macroeconomic analysis and analyses of countries growth in income per capita or productivity. I will do because the term is commonly used, it is quite evocative, and it conveys the notion of a country progress in a sector. However, when we deal with sectors, the term catch up does not have the same meaning as in macroeconomics: in a sector, a country does not necessarily arrive to the same level and characteristics of the leading countries in terms of products, technology, specialization (and the related organization of innovation and production). Nor a country may catch up with all the advanced countries: often it does only with one or two. And in many circumstances processes of leapfrogging, creative trajectories of growth and innovation or focalization on different products and market niches are relevant. Therefore for sectors it would be more appropriate to talk about emergence, growth and competitiveness of a country, and eventually of trajectories of indigenous innovation. However for the moment I will continue to use this term for the reasons just mentioned.

From an attentive analysis of countries' catching up in sectors two additional points emerge. First, the factors at the base of catch up may drastically differ across sectors. This is due to the fact that sectors are characterized by different technologies, actors, networks and institutions.

Second, that even within the same sectoral system, countries may exhibit differences in the factors that drive the catch up process. This is due to differences in national innovation systems, to different specialization within sectors or within the global value chain, to the presence of specific actors or to "historical accidents" with path dependent processes.

This paper is going to discuss these two issues. In order to do that, the notion of sectoral system has to be discussed.

3. Sectoral systems: a general discussion

A sectoral perspective is relevant for the analysis of the determinants and the factors driving the catch-up process of countries because it identifies key driving dimensions of catching-up. In fact it allows analyzing a sector in its building blocks, structure and factors conducive to innovation and growth. A traditional way to look at sectors is to focus on the traditional structure-conduct-performance variables. But this is a very static way to look at the emergence and growth of sectors, and does not pay too much attention to learning, capabilities, actors other than firms and interactions.

A more useful perspective is the one that takes uses the notion of *sectoral systems* (Malerba, 2002 and 2004). This notion has the evolutionary theory and the innovation system approach as building blocks. *Evolutionary theory* places a key emphasis on dynamics, innovation processes, and

economic transformation. Learning and knowledge are key elements in the change of the economic system. “Boundedly rational” agents act, learn, and search in uncertain and changing environments. Agents know how to do things in different ways. Thus learning, knowledge, and behaviour entail agents’ heterogeneity in experience and organization. And different competences affect persistent differential performance. In addition, evolutionary theory places emphasis on cognitive aspects such as beliefs, objectives, and expectations, which are in turn affected by previous learning and experience and by the environment in which agents act. A central place in the evolutionary approach is occupied by the processes of variety creation (in technologies, products, firms and organizations), replication (that generates inertia and continuity in the system), and selection (that reduces variety in the economic system and discourages the inefficient or ineffective utilization of resources). Finally, aggregate phenomena are emergent properties of far-from equilibrium interactions and have a metastable nature (Nelson, 1995; Dosi, 1997; Metcalfe, 1998). For evolutionary theory the environment and conditions in which agents operate may drastically differ. Evolutionary theory stresses major sectoral differences in opportunities related to science and technologies. The same holds for the knowledge base underpinning innovative activities, as well as for the institutional context. Thus the learning, behavior, and capabilities of agents is constrained and “bounded” by the technology, knowledge base, and institutional context. Heterogeneous firms facing similar technologies, searching around similar knowledge bases, undertaking similar production activities, and “embedded” in the same institutional setting, share some common behavioral and organizational traits and develop a similar range of learning patterns. The notion of sectoral system of innovation and production is also linked to the *innovation system* literature (Edquist,1997) in that it focuses on learning and interaction among agents. It complements concepts such as *national systems of innovation*, which is delimited by national boundaries and focused on the role of non-firms organizations and institutions (Freeman,1987; Nelson 1993; and Lundvall 1993), *regional/local innovation systems* in which the boundary is the region (Cooke et al.,1997), *technological systems*, in which the focus is on technologies and not on sectors (Carlsson-

Stankiewicz,1995; Hughes,1984; Callon,1992), and distributed *innovation system* in which the focus is on specific innovations (Andersen-Metcalfe-Tether,2002).

Drawing from these perspectives, a sector can be broadly defined as a set of activities that are unified by some linked product groups for a given or emerging demand and that share some common knowledge. Firms in a sector have some commonalities and at the same time are heterogeneous in terms of learning processes and capabilities.

A *sectoral system* framework focuses on the nature, structure, organization and dynamics of innovation and production in sectors. Here we can identify the following elements: (a) firms (b) other actors (in addition to firms) (c) networks (d) demand (e) institutions (f) knowledge and (g) the basic processes of interaction, variety generation, selection and coevolution. Let's discuss briefly these elements and processes.

a. Firms

Firms are the key actors in a sectoral system and are characterized by specific learning processes, competences and organizations, as well as beliefs, expectations, and goals. (Nelson-Winter,1982; Malerba,1992, Teece-Pisano,1994, Dosi-Marengo-Fagiolo,1998, Metcalfe,1998).²

b. Other actors . In addition to firms, a sector is composed of other agents that are organizations or individuals. Organizations may be suppliers, users, universities, financial institutions, government agencies, trade-unions, or technical associations. Individuals may be consumers, entrepreneurs, scientists. Agents are characterised by specific learning processes, competencies, beliefs, objectives,

² The extent of firm heterogeneity is the result of the opposing forces of variety creation, replication, and selection (Nelson, 1995, Metcalfe,1998). Selection increases homogeneity, while entry and technological and organizational innovations are fundamental sources of heterogeneity. Firm heterogeneity is also affected by the characteristics of the knowledge base, by specific experience and learning processes, and by the working of dynamic complementarities.

organisational structures, and behaviors. Agents interact through processes of communication, exchange, cooperation, competition, and command.

c. Networks

Within any sectoral system, firms are connected in various ways through *market and non-market relationships*.³ The evolutionary approach and the innovation systems literature have also paid a lot of attention to the wide range of formal and informal cooperation and interaction among firms. However, according to this perspective, in uncertain and changing environments networks emerge not because agents are similar, but because they are different. Thus, networks integrate complementarities in knowledge, capabilities, and specialization (see Lundvall,1993; Edquist 1997; Nelson,1995; Teubal et al.1991). Relationships between firms and non-firm organizations (such as universities and public research centres) have been a source of innovation and change in several sectoral systems: pharmaceuticals and biotechnology, information technology, and telecommunications (Nelson-Rosenberg,1993). The types and structures of relationships and networks differ greatly from sectoral system to sectoral system, as a consequence of the features of the knowledge base, the relevant learning processes, the basic technologies, the characteristics of demand, the key links, and the dynamic complementarities.⁴

³ It is possible to identify different types of relations, linked to different analytical cuts. First, traditional analyses of industrial organizations have examined agents as involved in processes of exchange, competition, and command (such as vertical integration). Second, in more recent analyses, processes of formal cooperation or informal interaction among firms or among firms and non-firm organizations have been examined in depth (as one may see from the literature on tacit or explicit collusion, or hybrid governance forms, or formal R&D cooperation). This literature has analyzed firms with certain market power, suppliers, users facing opportunistic behavior or asset specificities in transaction, or firms with similar knowledge having appropriability and indivisibility problems in R&D.

⁴ The comparison of different sectoral systems, such as chemicals, computers, semiconductors, and software, illustrate this point. In *chemicals*, the structure of the sectoral system has been centered around large firms, which have been the major source of innovation over a long period of time. Large R&D expenditures, economies of scale and scope (Chandler,1990), cumulateness of technical advance, and commercialization capabilities have given these firms major innovative and commercial advantages (Arora-Gambardella-Rosenberg, 1999). With the diffusion of the synthetic dyestuff model, firms scaled up their R&D departments and the role of universities increased. The introduction of polymer chemistry (1920s) affected the structure of the industry because knowledge about the characteristics of different market segments became important, so that firms had to develop extensive linkages with downstream markets. The other major change related to the development of chemical engineering and the concept of unit of operation led to an increasing division of labor between chemical companies and technology suppliers, with the rise of the specialized engineering firms (SEFs), which developed vertical links with chemical companies. In this period, university research continued to be important for the development of innovations, and links between universities and industry increased. In

d. Demand

In a sectoral system, demand may be domestic or international. Demand is not seen as an aggregate set of similar buyers or of atomistic undifferentiated customers, but as composed of heterogeneous agents who interact in various ways with producers. In this way, demand then becomes composed by individual consumers, firms, and public agencies, which could be part of different countries and national innovation systems, characterized by different size, knowledge, learning processes, and competencies, and are affected by different social factors and institutions..

e. Institutions.

addition, advances in chemical disciplines and the separability of knowledge increased the transferability of chemical technologies. Thus, there has been a greater role of licensing also by large firms, which in turn increased knowledge diffusion

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

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

In *software*, specialization of both global players and local producers is present. In addition, the changing knowledge base has created an evolving division of labor among users, 'platform' developers, and specialized software vendors (Bresnahan-Greenstein 1996). The sectoral system of innovation in software, however, is incomplete without the addition of companies that utilize these platforms to deliver enterprise-critical applications. Many of these applications continue to be produced in-house by organizations using the tools provided as part of the platform or available from the development tools markets (Steinmueller, 2004).

Agents' cognition, actions and interactions are shaped by institutions, which include norms, routines, common habits, established practices, rules, laws, standards, and so on. Institutions may range from ones that bind or impose enforcements on agents to ones that are created by the interaction among agents (such as contracts); from more binding to less binding; from formal to informal (such as patent laws or specific regulations vs. traditions and conventions). A lot of institutions are national (such as the patent system), while others are specific to sectors (such as sectoral labor markets or sector specific financial institutions). In all sectoral systems, institutions play a major role in affecting the rate of technological change, the organization of innovative activity, and performance. They may emerge either as a result of deliberated planned decision by firms or other organizations, or as the unpredicted consequence of agents' interaction. Some institutions are sectoral (i.e. specific to a sector), while others are national, and others may be international. The relationship between national institutions and sectoral systems is quite important in most sectors. National institutions have different effects on sectors. For example, the patent system, property rights, or antitrust regulations have different effects as a consequence of the different features of the sectoral systems, as surveys and empirical analyses have shown (see for example Levin-Klevorick-Nelson-Winter,1987). However, the same institution may take different features in different countries, and thus may affect the same sectoral system differently. For example, the well-known diversity between the first-to-invent and the first-to-file rules in the patent systems in the United States and in Japan had major consequences on the behavior of firms in these two countries. Often, the characteristics of national institutions favor specific sectors that fit better the specificities of the national institutions. Thus, in certain cases, some sectoral systems become predominant in a country because the existing institutions of that country provide an environment more suitable for certain types of sectors and not for others. For example, in France sectors related to public demand have grown considerably (Chesnais in Nelson,1993). In other cases, national institutions may constrain the development or innovation in specific sectors, or mismatches between national and sectoral institutions and agents may take place. The examples of the different types of

interaction between national institutions and sectoral evolution in various advanced countries in Dosi and Malerba (1996) are cases in point. The relationship between national institutions and sectoral systems is not always one-way, as it is in the case of the effects of national institutions on sectoral variables. Sometimes, the direction is reversed, and goes from the sectoral to the national level. In fact, it may occur that the institutions of a sector, which are extremely important for a country in terms of employment, competitiveness, or strategic relevance, end up emerging as national, thus becoming relevant for other sectors. But in the process of becoming national, they may change some of their original distinctive features.⁵

f. The Knowledge base

Any sector may be characterised by a specific knowledge base, technologies and inputs. Knowledge plays a central role in innovation and affect the types of learning and capabilities of firms. In a dynamic way, the focus on knowledge and the technological domain places at the centre of the analysis the issue of sectoral boundaries, which usually are not fixed, but change over time. Knowledge is highly idiosyncratic at the firm level, does not diffuse automatically and freely among firms, and has to be absorbed by firms through their differential abilities accumulated over time. The evolutionary literature has proposed that sectors and technologies differ greatly in terms of the knowledge base and learning processes related to innovation. Knowledge differs across

⁵ Again, major differences emerge across sectors. Let's compare for example pharmaceuticals, software, machine tools, and telecommunication. In *pharmaceuticals*, national health systems and regulations have played a major role in affecting the direction of technical change, in some cases even blocking or retarding innovation. In addition, patents have played a major role in the appropriability of the returns from innovations. In *software*, standards and standard setting organizations are important, and IPR play a major role in strengthening appropriability. However, the emerging open source movement aims to create a new segment of the software industry which is characterized by new distribution methods and by cooperative production activities based on voluntary association. This has reduced the possibility of maintaining proprietary control over data structure, thus inducing entry and more competition (Steinmueller,2004). In *machine tools*, internal and regional labor markets and local institutions (e.g. local banks) have played a major role in influencing international advantages of specific areas. Trust based, close relationships on the regional level have over a long time ensured a sufficient financing of the innovation and of the expansion plans of family businesses in Germany and Italy (Wengel and Shapira,2004). Finally, in *telecommunications*, the role of regulation, liberalization/privatization, and standards have played a key role in the organization and performance of the sector. As discussed in Dalum and Villumsen (2001), liberalization and privatization have had major effects on the behavior and performance of incumbents and have transformed the structure of the industry. An example of the role of institutions is given by GSM in Europe.

sectors in terms of domains. One knowledge domain refers to the specific scientific and technological fields at the base of innovative activities in a sector (Dosi, 1988; Nelson and Rosenberg,1993), while another regards applications, users, and the demand for sectoral products. Recently, a major discontinuity has taken place in the processes of knowledge accumulation and distribution with the emergence of the knowledge-based economy which has redefined existing sectoral boundaries, has affected relationships among actors, has reshaped the innovation process, and has modified the links among sectors. (Nelson,1995; Dosi,1997; Metcalfe,1998; Lundvall,1993; Lundvall and Johnson,1994).⁶ The sources of technological opportunities markedly differ among sectors. As Freeman (1982) and Rosenberg (1982), among others, have shown, in some sectors opportunity conditions are related to major scientific breakthroughs in universities. In other sectors, opportunities to innovate may often come from advancements in R&D, equipment, and instrumentation. In still other sectors, external sources of knowledge in terms of suppliers or users may play a crucial role. Not all external knowledge may be easily used and transformed into new artefacts. If external knowledge is easily accessible, transformable into new artefacts and exposed to a lot of actors (such as customers or suppliers), then innovative entry may take place (Winter,1984). If advanced integration capabilities are necessary (Cohen and Levinthal,1989), the industry may be concentrated and formed by large, established firms. Knowledge affects also the types of learning processes and

⁶ What do we know about the main dimensions of knowledge? First, knowledge may have different degrees of accessibility (Malerba and Orsenigo,2000), i.e. opportunities of gaining knowledge external to firms, which in turn may be internal or external to the sector. In both cases, greater accessibility of knowledge may decrease industrial concentration. Greater accessibility internal to the sector implies lower appropriability: competitors may gain knowledge about new products and processes and, if competent, imitate those new products and processes. Accessibility of knowledge that is external to the sector may be related to the levels and sources of scientific and technological opportunities. Here, the external environment may affect firms through human capital with a certain level and type of knowledge or through scientific and technological knowledge developed in firms or non-firms organizations, such as universities or research laboratories (Malerba and Orsenigo, 2000). Knowledge may be more or less cumulative, i.e. the degree by which the generation of new knowledge builds upon current knowledge. One can identify three different sources of cumulateness. The first source is cognitive. The learning processes and past knowledge constrain current research, but also generate new questions and new knowledge. The second source is related to the firm and to its organizational capabilities. Organizational capabilities are firm-specific and generate knowledge which is highly path-dependent. They implicitly define what a firm learns and what it can hope to achieve in the future. A third source is the feedback from the market, such as in the "success-breeds-success" process. Innovative success yields profits that can be reinvested in R&D, thereby increasing the probability to innovate again. In the case of knowledge spillovers within an industry, however, it is also possible to observe cumulateness at the sectoral level. Cumulateness may also be present at the local level. In this case, high cumulateness within specific locations is more likely to be associated with low appropriability conditions and spatially localised knowledge spillovers.

the relevant capabilities that firms have in order to be competitive and innovate. In general, the features and sources of knowledge affect the rate and direction of technological change, the organization of innovative and production activities, and the factors at the base of firms' successful performance.⁷

The *boundaries* of sectoral systems are affected by the knowledge base and technologies, as well as by the type of *demand* and *links and complementarities* among artefacts and activities. These links and complementarities are, first of all, of the static type, as are input-output links. Then there are dynamic complementarities, which take into account interdependencies and feed-backs, both at the demand and at the production levels. Dynamic complementarities among artefacts and activities are major sources of transformation and growth of sectoral systems, and may set in motion virtuous cycles of innovation and change. This could be related to the concept of *filière* and the notion of development blocks (Dahmen,1989). Links and complementarities change over time and greatly affect a wide variety of variables of a sectoral system: firms' strategies, organization and performance, the rate and direction of technological change, the type of competition and the

⁷ Great differences among sectors in the dimensions discussed above exist. Let's compare, for example, pharmaceuticals and machine tools. In the *pharmaceutical industry*, the knowledge base and the learning processes have greatly affected innovation and the organization of innovative activities. In the early stages (1850-1945), the industry was close to chemicals, with little formal research until the 1930s and a major use of licenses. The following period (1945-early 1980s) was characterized by the introduction of random screening of natural and chemically derived compounds. This led to an explosion of R&D. Few blockbusters were discovered every period: each one had high growth. The advent of molecular biology since the 1980s led to a new learning regime based on molecular genetics and rDNA technology, with two search regimes: one regarding specialised technologies, the other generic technologies. Nowadays, no individual firm can gain control on more than a subset of the search space. Innovation increasingly depends on strong scientific capabilities and on the ability to interact with science and scientific institutions in order to explore the search space. (McKelvey,Orsenigo,Pammolli, 2004, Henderson, Orsenigo,Pisano, 1999). In *machine tools*, innovation has been mainly incremental and now is increasingly systemic. Knowledge about applications is very important, and therefore user-producer relationships as well as partnerships with customers are common. The knowledge base has been embodied in skilled personnel on the shop floor level (with applied technical qualification) and in design engineers (not necessarily with a university degree but with long-term employment in the company). Internal training (particularly apprenticeships) is quite relevant. In small firms, R&D is not done extensively and R&D cooperation is not common. Recently, the knowledge base has shifted from purely mechanical to mechanic, microelectronic and information intensive, with an increasing codification and an increasing use of formal R&D. Products have increasingly being modularized and standardized. A key role is also played by information flows about components coming from producers of different technologies, such as lasers, materials, measurement, and control devices. Nowadays, many large machine tool companies operate already on an international basis making use of specific knowledge sources at their different firm sites (Wengel and Shapira,2003; Mazzoleni, in Mowery and Nelson,1999).

networks among agents. Thus the boundaries of sectoral systems may change more or less rapidly over time, as a consequence of dynamic processes related to the transformation of knowledge, the evolution and convergence in demand, changes in competition and learning by firms.

g. The main processes and coevolution

The analysis of sectoral systems requires also a careful understanding of the processes of interaction, cooperation and competition. In a sectoral system framework, innovation is considered to be a process that involves systematic interactions among a wide variety of actors for the generation and exchange of knowledge relevant to innovation and its commercialization. Interactions include market and non-market relations that are broader than the market for technological licensing and knowledge, inter-firm alliances, and formal networks of firms.

Over time, a sectoral system undergoes processes of change and transformation through the *coevolution* of its various elements.⁸ Because the elements of a sectoral system are closely connected, it follows that their change over time results in coevolutionary processes. This process involves technology, demand, knowledge base, learning processes, firms, non-firm organisations and institutions. Nelson(1994) and Metcalfe (1998) have discussed these processes at the general level by focusing on the interaction between technology, industrial structure, institutions and demand.⁹ Often coevolution is related to path-dependent processes (Arthur,1988; David,1985).

⁸ During the evolution of sectoral systems change may occur in the technological and learning regimes and in the patterns of innovations. Over time, a change in regimes may transform a Schumpeter Mark I pattern of innovative activities to a Schumpeter Mark II. Or, in the presence of major knowledge, technological or market discontinuities, a Schumpeter Mark II pattern of innovative activities may be replaced by a Schumpeter Mark I. Moreover, the knowledge base of innovative activities may change in two different ways: an evolution towards a dominant design or a drastic change. In the first case a growth of concentration and the rise of large dominant firms may take place (Utterback,1994). In the second case, new types of competencies may be required for innovation, with major industrial turbulence, entry of new firms and turnover in industrial leadership (Jovanovich and McDonald,1984; Tushman and Anderson,1986; and Henderson and Clark,1990). Finally, changes in demand, users and applications represent another major modification in the context in which firms operate and may favour the entry of new firms rather than the success of established ones (Christensen and Rosenbloom,1996).

⁹ The claim here is that these processes are sector-specific. For example, just looking at three elements such as technology, demand and firms, in sectors characterized by a system product and consumers with a rather homogeneous demand, coevolution leads to the emergence of a dominant design and industrial concentration (Klepper,1996).

Here local learning, interactions among agents and networks may generate increasing returns and irreversibilities that may lock sectoral systems into inferior technologies. The cases of sectors with competing technologies such as nuclear energy (Cowan,1990), cars (and their power sources – Foreman and Peck,1996), metallurgy (ferrous casting – Foray and Grubler,1990) and multimedia (VCR - Cusumano,1992) are interesting examples of path-dependent processes.

h. Three last introductory points

Three last points on sectoral systems have to be made here in a way of introduction. First, what are the main differences between a sectoral innovation system and a *national innovation system* perspective? While national innovation systems take innovation systems as delimited more or less clearly by national boundaries, a sectoral system approach would claim the boundaries of the innovations process in sectors have local, national, and/or global dimensions. Often these three different dimensions coexist in a sector. In addition, national innovation systems result from the different composition of sectors, some of which are so important that they drive the growth of the national economy. For example, Japanese growth in the 1970s and 1980s was driven by specific sectors, which were different from the sectors behind the American "resurgence" during the 1990s. As it has been pointed out previously, the understanding of the key driving sectors of an economy with their specificities greatly helps in understanding national growth and national patterns of innovative activities

Second, one relevant remark regards the *aggregation* issue regarding products agents or functions. For example, sectoral systems may be examined broadly or narrowly (for example in terms of a small set of product groups). A broad definition allows us to capture all the interdependencies and linkages in the transformation of sectors, while a narrow definition identifies more clearly specific

However in sectors with either a heterogeneous demand, specialized products and a more fragmented market structure may emerge.

relationships. Of course, within broad sectoral systems, different innovation systems related to different product groups may coexist. The choice of the level of aggregation depends on the goal of the analysis.

Third, a sectoral system perspective should not be seen as rigid and closed framework, but as *broad, open and flexible framework*, able to encompass different elements and variables, according to the focus of the analysis. However the driving elements of the analysis still have to be knowledge, capabilities, variety of actors, interactions and institutions.

4. Catch up in different sectoral systems: some general findings

The discussion so far has identified some key variables in the analysis of sectoral systems that are relevant for an understanding of countries catch up in sectors. And indeed these variables have been at the center of studies on countries and sectors.

The most important variable for catch up in sectors is the learning and capabilities of domestic firms. Now a lot of relevant evidence is available. Kim (1997) identifies different stages of capability development, from duplicative imitation to creative imitation to innovation. Amsden and Chu (2003) examine the combination of production engineering and design by large scale enterprises in electronics in Taiwan. Lee (2005) discusses the passage from the creation of absorptive capabilities to the development of complementary assets (complementary to the ones of firms in advanced countries). Lee and Lim (2001) focus on different trajectories of catching up, from path following to stage skipping, to path creating. Mathews (2002) and Lee (2005) discuss different steps that firms have followed in the process, from OEM to ODM to OBM for Taiwan, and from OEM to OBM for Korea. Several authors have discussed the process of capabilities

accumulation from learning from FDI as an initial channel, to licensing, to indigenous R&D (for example, Amsden and Chu, 2003 for electronics). This last process, as Lee (1995) emphasizes, has to be supported in various ways: production and R&D consortia and joint-ventures, scouting and foreign alliances, support of government research institutes. In sum, from all these studies it becomes evident that firms learning and capabilities as well as the type of firms, have been affected by different environments, in particular the national and the sectoral. The link with national systems of innovation has been explored and discussed at length in several studies. The link between learning and capabilities and sectoral system has been less studied, but it is quite important to examine it because capabilities are indeed affected by the sectoral knowledge base, type of actors (other than firms), networks and institutions.

Also the role of the government has been relevant in the catch up of countries in a sector. One can compare the role and the types of policies of the government in semiconductors and computer hardware in Japan (Goto and Odagiri, 1993), Korea (Kim1997, Lee and Lim,2001) and Taiwan (Mathews, 2002, Amsden and Chu, 2003 Hobday,1995) with the role of the government in telecommunication in Brazil and India (Mani,2004, 2007). Or compare the role of government in software in various countries (Arora and Gambardella, 2005) with the role of the government in aircraft in Brazil (Dahlman and Frischtak 1993 and Viotti 2002). These policies have been different from sector to sector, in particular in the use of different instruments, from R&D support, to protection of domestic firms, to policies of benign neglect, to creation of advanced government research institutes. However also in this case national innovation systems have acted as a major differentiation factor of policies across countries.

In some sectors universities and public research laboratories have played a role in catch up, as the experience of several countries indicate. As Mazzoleni and Nelson (2006) have shown, universities and public research laboratories performed advanced research and trained advanced

human capital which were important in the development of several sectors. However as an example of the quite different role played by universities and public research organizations in different sectoral systems, one could compare agriculture with electronics for countries such as Japan, Korea and Taiwan. In agriculture, in all these countries experimental stations had a pragmatic orientation and a focus on user needs in agriculture. On the contrary in telecommunications in all these countries universities formed advanced human capital and created and supported large public research laboratories doing advanced research and collaborating with domestic firms - such as the Korean KIET/ ETRI and the Taiwanese III/ITRI/ERSO - in electronics research (Hayami and Ruttan, 1985, Mazzoleni and Nelson, 2006).

In sectors such as software or biotechnology and pharmaceuticals, new actors such as venture capital companies software have emerged over time. These financial organizations have played a different role according to the stage of the industry life-cycle (Mani and Bartzokas, 2002, Avnimelech, Kenney and Teubal, 2004).

The catch up process of countries in different sectoral systems has been affected also by the specific types of networks. In some sectoral systems, vertical networks with suppliers have provided new inputs and shared relevant information for production and innovation, and led to learning and capability development by domestic firms. Electronics suppliers have been a source of knowledge and innovation, because they are characterized by competencies different and complementary from the ones of domestic producers (Lundvall,1993). Also local networks have been quite important for the catch up process in some sectors (Mytelka,2000). For example, in the Taiwanese electronic industry industrial districts have played a key role in the development of the sector. These local networks have allowed intense formal and informal interaction, knowledge sharing and intense division of labor. In other sectoral systems, such as telecommunications, catch up has been characterized by production and R&D collaborative agreements among domestic firms or among

domestic firms and foreign firms, as in Korea and China. In this way, complementary knowledge and capabilities may be shared. Also specialization in different stages of the global value chain has been another way to catch up, provided that learning and upgrading could be possible. The various case studies on the global value chain, ranging from ICT, to auto, from medical instruments to textiles, clothing and footwear, from furniture to agro-food, show the variety of ways in which governance, specialization, learning and capability formation, and upgrading take place in different sectoral systems and countries (Gereffi 2005, Ernst, 2002, Lee, 2005, Morrison, Pietrobelli and Rabellotti, 2006)

Then there is demand. Demand enters catch up in sectoral systems in two different ways. One is related to cross country differences in the size of the domestic market. Here this role affects most of the sectors within a country. For example, in China the large and growing domestic demand has been relevant to catch up for most sectors. On the contrary exporting and international demand has played a major role in catch up in small or medium size countries: for example, Taiwan. However, for a group of large and medium size countries - China, Japan and Korea – both domestic and international demand have played positive and complementary roles. To size, however, one has to add another role of demand related to the specificities of different sectoral systems: here specialization in product groups, demand segments or niches, or stages of the global value chain indeed fostered the catch up process. For example, in software, some demand segments and niches served by catch up countries are not served by advanced countries, so that there is no competition between these two groups of countries. For example, Indian firms specialized in software services, Irish firms in specific product groups and Israeli firms in some key advanced technological products. (Commander, 2005, Arora and Gambardella, 2005).

A final note regards standards, regulations, norms. In many cases, they proved very important in the catch up of several sectors. Software represents a good example (Arora and Gambardella, 2005;

Athreye, 2005). It must be stressed however that very often the effects of institutions in a sectoral system are shaped by the specificities of the national systems of innovation.

5. Differences across countries in sectoral systems

Up to now the discussion has centered on differences across sectoral systems in the factors leading to countries' catching up. However, the existing comparative work on sectors shows that for the same sector one may find major differences across countries in the role of key factors. These differences are related to the size of the country, the specificities of national innovation systems, the different choices of specializations, products or demand niches, the presence of some key unique actor (such as a large firm) or the role of "historical accidents" which started a specific path dependent process of catch up. As an example, two sectors can be examined: telecommunications and software. These sectors greatly differ in the nature, structure and dynamics of their sectoral systems, as the general discussion in section 3 has shown.

For telecommunications, the following discussion regards a comparison among India, Cina, Korea and Brazil and draws from the work of Mani (2003, 2004 and 2007), Lee (2005), Lee and Lim (2001) and Fransman (2006). Looking at these countries, one could see similar actors at work: private domestic firms and government laboratories. Catch up has been successful if domestic firms were able to learn and accumulate advanced technological capabilities through internal R&D and through learning from cooperation and access to foreign sources of knowledge. Korean and Chinese firms have been particularly successful in doing that, and were also able to move from fixed to mobile telecom to broadband technology. Brazilian and Indian firms were less successful. Also in all these countries, the presence of a public laboratory early on was fundamental in shaping the development of the sector and interact with private firms in research. A major difference regards

the specific role of public policy . Indeed public policy was quite active but differed across countries. In some countries such as Korea and China public policy used R&D support, R&D consortia and public research organizations and was able to successfully support and coordinate firms' domestic efforts and to help firms to move into new generations of telecom technologies and products. On the contrary Brazil and India had a less direct and coordinated intervention and public policy was less successful in actively fostering the direction of change in the domestic industry.

For software, the following discussion regards Brazil, China, India, Ireland and Israel and draws from Commander (2005) and Arora and Gambardella (2006). Many similarities across these countries are present for a successful catch up: the key role of firm learning and capabilities, dynamic entrepreneurship and abundant supply of advanced labor skills. However key differences emerge too. First of all specialization has been different across countries: India focussed on software services, Israel on high tech software products and Ireland on products for the European market. Similarly, differences emerged with respect to outsourcing and participation to the global value chain in vertical software applications, usually coordinated by final software suppliers. Differences have also emerged with respect to the size of the domestic market, which has been large for China and Brazil and therefore a focus for the activities of domestic firms. Smaller countries such as Ireland and Israel have focussed on exports. In these countries the role of foreign subsidiaries of multinational corporations played a major, but differentiated role: doing R&D in Israel, tapping into the European market in Ireland and get access to low cost skilled workers in India. Finally the role of different national innovation systems has been particularly relevant when actors such as universities and the government are considered. Universities and public institutions have been particularly active in new firm formation in China and Ireland. The government has used different policies and tools, ranging from procurement, to R&D support, favourable companies tax rates and incentives to attract foreign direct investments.

6. Conclusions

The previous discussion calls for a research agenda that aims to compare systematically the factors affecting the catch up of countries in different sectoral systems. This is one among the leading themes of the “Catch-up Project”. This Project aims at studying in a comparative way across a variety of countries sectors such as pharmaceuticals, auto, software, telecommunications and agro-food, and at identifying not only the factors which are responsible for successful catch up or failure to catch up, but also the linkages, interdependencies and systemic effects that take place among these factors. Only by systematically doing that it will be possible to isolate the necessary conditions and the key complementarities for catch-up in a sectoral system.

The analysis of catch up in a sectoral system has however to maintain a dynamic perspective. In fact catch up by a country in a sector is a process that unfolds over time, and calls for the identification of specific stages and trajectories of development. Some work for specific actors of a sectoral system has already been done: for example, for learning and capability formation of domestic firms Amsden and Chu (2003), Matthews (2002) and Lee (2005) have identified various stages, related to the passage from imitation to creative imitation and to innovation, and from OEM to OBM and to ODM. Now the analysis has to move to other actors, networks and institutions, and to the dynamic process and trajectories linking various factors in sectoral systems.

Finally, for the same sector differences across countries in the factors, stages and trajectories of the catching up process have to be examined. In order to do that, a strong link with the analysis of national innovation systems and with the examination of the within-sector specialization of countries has to be developed.

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