INNOVATION, INDUSTRIAL DYNAMICS AND INDUSTRY EVOLUTION: PROGRESS AND THE RESEARCH AGENDAS

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The analysis of innovation, industrial dynamics and the evolution of industries has witnessed major progress in several areas. The paper discusses the progress made in the industrial dynamics tradition and in the more recent stream of studies centred on the evolution of sectoral systems. It identifies some key challenges: the analysis of knowledge, actors, demand, networks, institutions and coevolution.

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1. Introduction [1]

Innovation has been recognised as a key element affecting the growth and transformation of industries, and the rate of entry, survival and growth of firms. Looking back at the last 25 years of research on these issues, one has to recognise that progress has indeed been impressive at both the empirical and the theoretical levels.

One could start from the so-called "SPRU tradition" related to Christopher Freeman (1974) and Keith Pavitt (1984), which greatly contributed to the recognition of the major differences existing across different industries, technologies and countries in the relationship between innovation and the evolution of industries.

Then, since the early 1980s two types of contributions have gained the centre of scholarly work. One stream of literature is concerned with industries as composed by firms and is concerned with the entry, survival and growth of firms. We can call it *industrial dynamics*.

The other, and more recent, is concerned with the evolution of sectors as systems composed of firms and other actors, each with a specific knowledge base, and in which institutions play a major role. We can call it *sectoral system evolution*.

This paper reviews the progress and challenges in these two traditions. Section 2 briefly discusses the most consolidated tradition, that of industrial dynamics. Section 3 focuses on the second tradition, and examines the progresses and the challenges involved. The paper concludes by claiming that although different in their assumptions, structure and theories, in the future these two traditions will converge in some key dimensions: industrial dynamics by taking into account other elements such as knowledge and networks, and sectoral systems by paying more attention to quantitative data, longitudinal analyses and formal modelling.

It should be noted that these two traditions do not completely overlap, with a distinction between the neoclassical and econometric tradition on the one side and the evolutionary and innovation system view on the other. In the first tradition (industrial dynamics) one can in fact find evolutionary authors, while the second (sectoral system evolution) is confined to neoclassical ones. The distinction between the two traditions regards how a sector is examined and which elements are investigated.

The *industrial dynamics* tradition goes back to the "market structure and innovation" approach (Kamien and Schwartz, 1975), the dynamic

1. This paper draws on my Presidential Address at the Schumpeterian Society Conference in Milan in June 2004, which was published in the *Journal of Evolutionary Economics*.

models of Jovanovic (1982) and the early empirical work of Geroski (1994) and Audretsch (1995). It is based on a solid tradition of examining an industry composed of firms in competition one with the other, and longitudinal analyses of firm dynamics and rate of technical change (see Audretsch, 1995; Malerba and Orsenigo, 1996; Dosi *et al.*, 1995 for a general discussion).

The *sectoral system evolution* tradition on the other hand was inspired by evolutionary theory and the innovation systems approach (see Malerba, 2002, 2004 for a discussion). Let us discuss this second tradition in more depth. Evolutionary theory places learning and knowledge as key elements fostering change in the economic system. "Boundedly rational" agents act, learn and search in uncertain and changing environments. Relatedly, competencies correspond to specific ways of packaging knowledge about different things and have an intrinsic organisational content. Different agents know how to do things in different ways. Evolutionary theory has placed emphasis on cognitive aspects such as beliefs, objectives and expectations, in turn affected by previous learning and experience and by the environment in which agents act (Nelson, 1995; Metcalfe, 1998). Thus learning, knowledge and behaviour entail agents' heterogeneity in experience, competencies and organisation, and their persistent differential performance. A central place in the evolutionary approach is occupied by three economic processes driving economic change: variety creation in technologies, products, firms and organisations, replication and selection (Nelson, 1995; Metcalfe, 1998). Moreover the environment and the conditions in which agents operate may differ drastically. Major differences exist in opportunity conditions 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, behaviour and capabilities of agents are constrained and bounded by the technology, knowledge base and institutional context in which firms act. Heterogeneous firms facing similar technologies, searching around similar knowledge bases, undertaking similar production activities and embedded in the same institutional setting share some common behavioural and organisational traits and develop a similar range of learning patterns, behaviour and organisational forms (Nelson and Winter, 1982). The other link in the sectoral system view is with the innovation system literature (Edquist, 1997) which considers innovation as an interactive process among a wide variety of actors: firms do not innovate in isolation and innovation is a collective process. In the innovative process firms interact with other firms as well as with non-firm organisations (such as universities, research centres, government agencies, financial institutions and so on). Their action is shaped by institutions (Lundvall, 1993; Carlsson, 1995; Edquist, 1997). This approach places a great deal of emphasis on an interdisciplinary approach, emphasises a historical perspective and puts learning as a key determinant of innovation.

2. Innovation and industrial dynamics: progress and challenges

2.1. The empirical work

With the availability of advanced computer technology and new firm level data, empirical analyses of industrial dynamics have moved from cross sectional work during the 1960s and 1970s to longitudinal analyses of the dynamics of firms, market structure and technology since the early 1990s (for surveys see Malerba andOrsenigo,1996; Dosi *et al.*, 1997 and Dosi, 2001).

Here, progress in identifying, measuring and understanding stylised facts and statistical regularities and the factors explaining them has examined the intersectoral diversity in firm size distribution, fat tailedness of corporate growth rates across industries, heterogeneous firm-specific autocorrelation profiles with each industry, the persistence of profitability, labour productivity and TFP differences across firms and within industries at all level of disaggregation. It has been shown that market selection does not seem to work effectively, particularly in the short and medium-run, the time span of the available statistics.

Concerning more specifically innovation, heterogeneity in firms' innovativeness has been shown to be quite pervasive and persistent over time (in spite of competition and selection processes). In most industries there are few firms which are responsible for a large number of innovations, and there is a core of innovators and a fringe. Heterogeneity across firms in innovation means the presence of idiosyncratic capabilities (absorptive, technological, etc.) and implies that firms not only do different things but, and most importantly, when they do the same thing, they know how to do it in different ways. This heterogeneity is closely associated to persistence in innovative activities, which is a key phenomenon that affects the patterns of innovation in a sector (Malerba *et al.*, 1997, Cefis, 2003). Some of this heterogeneity is related to entry (Geroski, 1995, Bartelsman *et al.*, 2005). In particular, new entrants are the vehicles for the introduction of new technologies, as Geroski (1995), Audretsch (1995) and Baldwin (1995) among others have shown. Heterogeneity in innovativeness is then translated into differential profitability, as documented by Geroski *et al.* (1993), while the impact of innovation on corporate growth is still a matter for deep empirical scrutiny (Baldwin, 1995). Actually in some specific industries (such as the international pharmaceutical industry) econometric evidence shows that dynamics is driven by the introduction of few major innovations and that there is a coexistence of quite heterogeneous innovators (Bottazzi *et al.*, 2001).

Sectors differ greatly in terms of market structure and the organisation of innovative activities. Work at patent level has found stylised and robust differences across sectors. In some sectors innovative activities are concentrated in a few firms, stability of innovators is relevant and new innovators are rare. In contrast, in other sectors patterns of innovation are distributed across a wide population of firms, with a high turbulence in innovative activity, and new innovators coming from every quarter. These two different models of organisation of innovative activities can be labelled Schumpeter Mark II and Schumpeter Mark I. These patterns have been found in several industries and, for the same industry are robust across countries (Malerba and Orsenigo, 1995, 1997). These findings can be related to the old stylised fact concerning major inter-industry differences in concentration and to the literature that has identified robust inter-industry differences in the rate of technological change and in firms age and size distribution.

2.2. Models

Models of industrial dynamics range from models of firms' entry, growth and size distribution, to models in which innovation and concentration are bound by technology and demand factors, to models of industry life cycle. In this tradition, they have focussed on modelling empirical regularities such as the asymmetric distribution of firms' size and different growth rates conditional on age. In some models there is passive technological learning by rational actors (be they incumbents or entrants or both) with the competitive process weeding out the heterogeneity in firm population (see for example, Jovanovic, 1982). Here the new firms do not know their own potential profitability. Major technological discontinuities create a shakeout in industrial dynamics and the transition to the new technology is associated to with the exit of unsuccessful innovators, and the survival of firms with larger scale technology (Jovanovic and MacDonald, 1994). On the other hand, active learning by firms is present in other models of industrial dynamics such as Ericson and Pakes (1995). Here firms explore the economic environment, invest and, if successful, grow. In this way industrial dynamics is driven by the growth of successful firms.

Evolutionary models explain similar stylised facts. However, they have bounded rational actors and firms that learn (Nelson and Winter, 1982). In addition, these models are able to take into account processes of experimentation and imperfect trial and error. Here selection processes take place on a heterogeneous population of firms (Nelson and Winter, 1982; Dosi *et al.*, 1995). These models have a de-strategising conjecture, because differences in structures and processes of change are understood as independent from firms' micro strategies (Winter *et al.*, 2000).

Demand and technological factors making bounds on industrial structures effective via no arbitrage conditions, characterise another set of models (Sutton, 1998). This results in corresponding Nash equilibrium on industry specific entry processes. Contrary to the previous models, here no attention is paid to the learning processes of firms, and much less attention is paid to industrial dynamics per se.

Finally, industry life cycle models examine jointly product and process innovations; rate and type of entrants; selection; firm size and growth; market concentration; market niches and shakeouts (Klepper, 1996, 2002; Klepper and Simons, 2000). In this group of models one can find a strong link between stylised facts, econometric analyses and formal theory, as well as an explanation of different types of industry life cycles. These models start from the evidence of life cycles in innovation, firm entry and growth, and changes in market structure (Abernathy and Utterback, 1978; Utterback, 1994) and of differences across industries in these dynamic sequences (Klepper, 1997). In industry life cycle models, the presence of submarkets may play a role in affecting the growth and size distribution of firms within an industry, as Klepper and Thompson (2002) show in their model, and for the laser industry.

3. Innovation and the evolution of sectoral systems: progress and challenges

In the sectoral systems tradition industries have been interpreted as systems in which actors are related and interact in various ways and whose actions are strongly influenced by their learning processes, competences and institutions. In this frame, the notion of sectoral systems of innovation (Malerba, 2002, 2004) is a useful tool for examining innovation in a sector. In this framework, innovation and industry evolution could be seen as the outcome of learning processes by firms and by individuals, based on a specific knowledge base which characterises the industry. Competitive and cooperative relationships among actors do matter tremendously: they are of market and non-market type, formal and informal, and take place in specific institutional settings, some of which are national while others are specific to the sector. Change and transformation does not refer only to products and processes, but also to actors, links, institutions and knowledge itself. Compared to the industrial dynamics approach, this view points to a richer and more articulated set of dimensions. In sum, during its evolution, an industry changes its structure, where the term structure means not only market structure, but also the network of relationships (competitive and cooperative, market and non market, formal and informal) among actors that affect innovation and performance in an industry.

What has been the progress and what are the challenges in this tradition in the last years? In the following I will discuss progress and challenges regarding *knowledge, actors (including demand), networks and institutions* (for a more in depth discussion, see Malerba 2002, 2004).

3.1. Knowledge

Sectors and technologies differ greatly in terms of knowledge base and learning processes. In some sectors science is the force driving knowledge growth, while in others learning by doing and cumulativeness of advancements are the major forces. We also know that knowledge differs across sectors in terms of sources (firms, universities, and so on), domains (i.e. the specific scientific and technological fields at the base of innovative activities in a sector) and applications. Knowledge also has different degrees of accessibility (i.e. opportunities of gaining knowledge that are external to firms and that may be internal or external to the sector) and of cumulativeness (i.e. the degree to which the generation of new knowledge builds upon current knowledge). And knowledge may flow or spill more or less intentionally across individuals and organisations, as the huge literature on knowledge spillovers (see for example Jaffe *et al.*, 2000) and the work on knowledge and mobility of inventors (Kogut, 2000, Balconi *et al.*, 2004, Breschi and Lissoni, 2004) show.

The challenge is to move from the broad identification of the main characteristics of knowledge across sectors to a detailed understanding of the specific type and structure of knowledge, its various effects on innovation, and the two-way relationship between knowledge evolution and industry evolution.

In this respect, finer grained dimensions of knowledge (such as the ones mentioned for example in Winter, 1987) and links and complementarities have to be taken into account (Malerba, 1992). They may refer to scientific, technological or application knowledge and are often a major source of increasing returns. A related major area of inquiry refers to knowledge transmission, flows and spillovers within industries and across industries, the coordination and integration of knowledge, and the relevance of modularity of knowledge (as in the work by Loasby, 1999, 2001; Foray, 2004; Brusoni *et al.*, 2001).

In addition, a deeper understanding of the effects of the type of knowledge on the organisation of innovative activities may be achieved in various ways. One is to link one specific dimension of knowledge with the organisation of knowledge production. For example, one could link codified knowledge, the specialisation in knowledge production and the division of innovative labour, as Arora *et al.* (2001) do. Another is to link the learning and knowledge environment to the patterns of innovative activities in a sector. The identification of some key properties of knowledge such as accessibility, opportunity and cumulativeness can be related to the notion of technological and learning regimes (dating back to Nelson and Winter, 1982), providing a description of the knowledge environment in which firms operate. Malerba and Orsenigo (1996, 1997) proposed that a technological regime is composed of opportunity and appropriability conditions; degrees of cumulativeness of technological knowledge and characteristics of the relevant knowledge base. Then one could test empirically some general propositions on the relationship between technological regimes and patterns of innovation in industries, related to a fundamental distinction between the Schumpeter Mark I and the Schumpeter Mark II models. The first is characterised by "creative destruction" with technological ease of entry and a major role played by entrepreneurs and new firms in innovative activities, the second by "creative accumulation" with the prevalence of a stable core of a few large firms and the presence of relevant barriers to entry for new innovators. Although rather archetypical, these analyses show that knowledge and learning regimes indeed affect the way innovative activities take place in industries (Marsili and Verspagen, 2002). Finally, one could go into sectoral analyses in much greater depth and relate the structure of knowledge in a sector to the type of actors and their relationships. As an example, let me mention here the work that Orsenigo *et al.* (1997) have done in pharmaceuticals and biotechnology. They found that there is an isomorphism between the cognitive structure underlying the dynamics of knowledge and the structure of the network. The impact of science has been the proliferation of more specialised and new hypotheses that have generated new sub-disciplines, requiring new sets of search techniques, testing procedures and skills. Over time entrants tend to be more specialised in terms of the scientific hypotheses they are trying to test and the search techniques they are employing. The intrinsic characteristics of the search techniques and the patterns of learning in pharmaceutical research and development (R&D) explain simultaneously why the network expands over time, why it remains relatively stable in its core-periphery profile and why entrants make agreements with incumbents or older non-biotech firms (NBF), rather than with firms of the same generation.

Finally, the boundaries of knowledge in a sector and their effects on innovation and industry evolution have to be properly examined. A focus on boundaries means highlighting all the interdependencies and complementarities that span outside the industry in related sectors or scientific fields. Think for example of multimedia, in which the convergence of different types of technologies and demand has originated a new sector with continuously expanding knowledge boundaries. A focus on boundaries also means that there are some bounds to knowledge growth which are related to the specificity of the technologies and the sector. This concept is present in the evolutionary literature. It is implicit in the notion of technological regimes and, from a different perspective, also of Sutton's bounds (Sutton, 1998, 2001). If we take this view of knowledge, the specificities of the technological regime and knowledge base of an industry put a powerful restriction on the patterns of firms' learning, competencies and behaviour and on the organisation of innovative and production activities. More generally, a given knowledge base, technological environment or demand defines the nature of the problems firms have to solve in their innovative and production activities and the types of incentives and constraints to particular behaviour and organisations. Within these constraints, however, great and persistent heterogeneity in firms' innovative and productive behaviour and organisation is possible.

3.2. Actors and institutions

There is now convincing evidence that technological change is the result of the contributions of quite different actors that have different relevance in different industries. It would be misleading to concentrate only on firms. Thus one may claim that a sector is composed of heterogeneous agents that could be organisations or individuals (e.g. consumers, entrepreneurs, scientists). Organisations may be firms (e.g. users, producers and input suppliers) or non-firms (e.g. universities, financial institutions, government agencies, trade-unions, or technical associations), and include sub-units of larger organisations (e.g. R&D or production departments) and groups of organisations (e.g. industry associations). These agents are characterised by specific learning processes, competencies, beliefs, objectives, organisational structures, and behaviour. They interact through processes of communication, exchange, cooperation, competition, and command.

As mentioned in the introduction, the SPRU tradition stresses the wide variety of actors involved in innovation in a sector and points out that major differences exist across industries (Freeman, 1974; Pavitt, 1984). For example, in several industries the contribution of universities is quite relevant in the generation and transmission of technological progress (Levin *et al.*, 1987). This is because universities generate new knowledge that is a major input to innovation, train the human capital that forms the backbone of the R&D laboratories of firms, sometimes patent in certain technologies, and often are a source of new firms in specific sectors (such as in biotechnology or electronics, see for example Zucker *et al.*, 1998; Mowery *et al.*, 2001). Another example is provided by venture capital, which plays a role in some industries, although additional empirical evidence and hard econometric analysis are needed before conclusive statements can be made (Kortum and Lerner, 2000).

Agents' cognition, actions and interactions are shaped by institutions, which include norms, routines, 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) (Edquist, 1997). Some institutions are national (such as the patent system), while others are specific to sectors (such as sectoral labour markets or sector specific financial institutions).

The role of different institutions— some of them national, others sectoral— has been recognised to be relevant for innovation and diffusion in industries (see for example Gruber and Verboven, 2001 for mobile communications). This is especially true for standards and regulations. Here a rich literature shows that standards enable innovation in industries by creating an infrastructure that allows sequences of innovations and the achievement of a critical mass in markets for new technologies.

3.3. Demand

Demand is a major factor affecting industrial dynamics. In the literature, user initiated innovation (Von Hippel, 1986), user-producer interaction (Lundvall, 1988) and value networks (Christensen and Rosenbloom, 1995) have been shown to be important in influencing the magnitude and orientation of inventive effort.

Demand has been analysed with respect to the emergence of disruptive technologies as Christensen (1997) has documented in the case of hard disk drives, earthmoving equipment, retail stores and motor controls. And one must not forget the huge literature on diffusion: several major empirical advancements and theoretical models regarding diffusion are nothing more than contributions regarding the demands of innovation. The same holds for the literature on competing technologies which pays a lot of attention to externalities and increasing returns.

Ground has also been covered at the empirical, appreciative and modelling levels in demand being examined with respect to the evolution of industries. At the empirical level, the role of demand during specific stages of the evolution of an industry has been shown to be relevant. In the early stages of the semiconductor and computer industries, public procurement has been important for innovation (Malerba, 1985). In computers experimental customers have been major actors in the emergent phase of the industry (Bresnahan and Malerba, 1999; Bresnahan and Greenstein, 2001). In information technology (IT) user involvement has been a key dimension for the development and modification of standards. In pharmaceuticals, demand channelled through agencies, physicians and the health system played a significant role in the diffusion of new drugs. Finally, in instrumentation (Von Hippel, 1988) and machine tools lead users have played a major role in innovation, and in shaping both the supplier and the user industries.

However, we need to look analytically at the ways that demand affects innovation in specific industries. Standard economic analysis claims that demand provides incentives to innovation during industry evolution. This is indeed a correct statement. The size, growth, structure and composition of demand, product differentiation and market segmentation affects innovation in various ways and in different stages of the evolution of an industry. One could also add that in terms of incentives demand is not homogeneous: it is highly heterogeneous in segments, types of firms (private vs public) or individual customers.

But there are other ways that are equally important, as Loasby (1999, 2001), Metcalfe (1998), Witt (2003), Saviotti (2001), Teubal (1979) and others have shown. In this respect, consumer behaviour plays a major role in affecting innovation. It may include the presence of information asymmetries and imperfect information with respect to new markets and submarkets as well as routines, inertia, and habits on the part of consumers. Also the knowledge and mental frameworks of consumers and users greatly affect innovation and performance. There is a "knowing that" and "knowing how" on the part of consumers. There is learning and knowledge growth in consumption, much of which is local. Consumers are characterised by routines in similar ways to firms, and deliberative decisions interact with habit when consumers confront new opportunities or new products. However, producers and consumers should not be treated as completely symmetrical because of the different stress they place on standardisation and variety (Langlois, 2001; Devetag, 1999; Aversi *et al.*, 1999). Also consumer competences play a major role in influencing innovation. One could mention the absorptive capabilities of users, or the role of lead users and experimental users. Finally, also the distribution of competencies among users greatly affects the dynamics of industries.

On these issues some strong empirical evidence exists for some specific industries. In some industries users participate intensively in the innovation process. Users' involvement is more than simple participation in the innovation process. Involvement implies a psychological dimension and a behavioural dimension. It is quite relevant for example in participatory design, IT and standards setting. Here the relationship between knowledge and the mental frameworks of producers and users plays a major role in innovation.

In other industries, coinvention is relevant: innovation by sellers and complementary investments and innovation by buyers (in terms of new products, services, applications and investments in human capital). As Bresnahan and Greenstein (2001), and Antonelli (2003) have shown for IT, coinvention involves the technology of the user as well as that of the supplier. Users' coinventions are particularly important in explaining technological change in IT applications. Coinvention pulls technological change in a variety of directions and ways. This means that in IT there is not "one" standard type of adoption. Rather, coinventions in IT and its applications represent developments in tightly coupled interconnected technologies (Bresnahan and Greenstein, 2001).

In instrumentation, lead users also play a major role (Von Hippel, 1988). Lead users face needs that will be general in the market place but face them months or years before the bulk of that marketplace encounters them. They are also positioned to benefit significantly from obtaining a solution to their needs (Urban and Von Hippel, 1988). One has to recognise however that the contribution of lead users comes from knowledge related to their experience. Therefore they have a major role in periods of stability of uses and applications, but they may be less relevant when radical change or instability affects demand. Finally, in some sectors, such as software (open source (OS) software), communities of practices are a source of incremental innovations and change. They act as facilitators of innovation, because members who innovate are able to share their ideas with other members, assist them and even obtain resources to develop their innovations. As Harhoff *et al.* (2003) show, for innovators it might be beneficial to reveal information inside a community because they may receive improvements by others; be helped to achieve a standard; face low rivalry conditions and expect reciprocity. Franke and Shah (2003) add to these reasons an additional one: the fun and enjoyment that emerges from engagement in the task and the community. Historically, a similar process can be found in other sectors: for example in machinery (see the case of the development of the Cornish steam engine during the British industrial revolution discussed by Nuvolari, 2004).

3.3.1. The different role of demand calls for the development of taxonomies for industries

As far as models are concerned, one would like to model the links between demand dynamics, firm dynamics and technology dynamics. In fact, on the one hand, the emergence and development of new technologies create new markets, submarkets and niches. On the other the dynamics of demand in terms of consumer learning may stimulate technological change and the entry of new firms. This is indeed a challenging task. In this perspective, interesting models by Adner and Levinthal (2001) and Adner (2003) examine how the demand life cycle in terms of performance thresholds, types of preferences, changing utility and differences across market segments interacts with technological change to guide the evolution of technology and competition during the life cycle of an industry. In another methodology, similar issues are tackled by "history friendly" models (Malerba *et al.*, 2003). Here various types of customers are present: "standard" ones attracted by established products and guided by product characteristics such as price and performance; experimental customers who crave new technologies in existing products; and consumers in new demand segments that look for completely new products. This history-friendly model is inspired by the case of the computer industry, in which experimental users and new demand have played a major role in affecting innovation, competition among technologies and the dynamics of market structure. Here the successful introduction of a radically new technology in an industry, in which a dominant design and a small collection of dominant firms and customers who are not willing to experiment, may be dependent upon a group of experimental customers, who are willing to experiment and buy the new products with the new technology.

The discussion on modelling brings the coupled dynamics of demand and technology to the forefront of the analysis of industry evolution. Some of these processes have started to be tackled at the conceptual and appreciative levels, by examining learning and specialisation in consumption and the increasing variety of goods and services offered in the market (Witt, 2001, 2003; Saviotti, 1996, 2001). These processes are indeed evolutionary in the sense that they imply learning, routinised behaviour and selection (Metcalfe, 2001).

3.4. Networks

In a sectoral systems perspective, 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 commercialisation. 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, and often their outcome is not adequately captured by existing means of measuring economic output.

The innovation systems literature has put the role of links and relationships among various actors at the centre of the analysis (see Lundvall, 1993; Edquist, 1997; Teubal *et al.*, 1991). In similar vein, evolutionary theory has stressed that in uncertain and changing environments networks emerge because agents are different, thus integrating complementarities in knowledge, capabilities and specialisation (see Nelson, 1995). Along these lines, progress has been made in the analysis of the characteristics and structure of networks in several industries: biotechnology (Powell *et al.*, 1996; Arora and Gambardella, 1998; McKelvey *et al.*, 2004; Orsenigo *et al.*, 2001; Nesta and Mangematin, 2002); ICT (Saxenian, 1994; Langlois and Robertson, 1995); auto (Dyer, 1996); aircraft (Bonaccorsi and Giuri, 2001); flight simulation (Rosenkofp and Tushman, 1998); steel (Rowley *et al.*, 2000); semiconductors (Stuart, 1998).

It has been recognised that the emergence of certain types of networks is a function of specific knowledge, industrial settings, demand and institutions and that their evolution is the result of the interplay between firms' internal capabilities and technological, social and institutional factors (Kogut, 2000). Therefore the types and structures of relationships and networks differ from industry to industry. If we go along this line, taxonomies of network structures for groups of industries (such as the one by Kogut, 2000) can be developed. Kogut relates types of networks to factors such as technology, resource bottlenecks, competing and regulatory rules and strength of property rights, and does it for broad industries such as microprocessors, information technology, software operating systems, pharmaceuticals and biotechnology, automobiles and financial markets.

A major issue is to understand how and why the specific features and characteristics of networks affect innovation, profitability and growth in an industry. Also in this respect, we are still at the beginning of the research agenda. From exploratory empirical analyses it seems that strong ties favour exploitation and weak ties favour exploration (as has been found in longitudinal analyses for the chemical, semiconductor and steel industries). But additional robust evidence and deep appreciative theorising on this and other connected issues are needed.

At the formal theoretical level, few models explore the relationship between the dynamics of networks and the dynamics of industries. Among them, Cowan *et al.* (2004) show that in industries where tacit knowledge is relevant and technological opportunities are high, regular structures generate higher knowledge growth, while in industries where knowledge is codified and technological opportunities are lower, communication without any structure performs better. Although very promising, this line of research is in its infancy, and needs to be developed further. For example, under which conditions early on in the life cycle of a sector do certain types of collaborations (for example to explore knowledge) emerge? And under which conditions in industry maturity do other types of collaborations (for example to exploit knowledge) gain in importance? And when and why at certain stages of industry evolution are large informal networks rather than formal ones a major source of knowledge generation (see for example Pyka, 2002)? Finally, what is the relationship between different types of industry life cycles and different types of network dynamics?

3.5. A note on modelling industry evolution

Attention is paid to the specificities of the evolution of various industries by history-friendly models, which fall within the evolutionary tradition (Malerba *et al.*, 1999; Malerba and Orsenigo, 2002). These models look at the evidence and the specific dynamics of the evolution of industries and the appreciative explanations and historical events that shaped them. History friendly models are in the tradition of behavioral and evolutionary models and attempt to formalise verbal appreciative theories about the major factors explaining the particular pattern of the evolution of an industry or technology proposed by empirical scholars of that industry. Thus these models tend to incorporate more industry specific detail than is customary in models built by economists. Since the logic of many verbal explanations for particular patterns of industry and technology evolution, or coevolution, involves non linear dynamics, history friendly models take the form of simulation models.

Modelling the evolution of industries necessarily implies a more rigorous dialogue with the empirical evidence and with non-formal explanations of industry histories, i.e. with appreciative theorising. The researcher is forced to spell out in a satisfactorily detailed way the hypotheses used as the bases for an "appreciative" explanation of the evolution of a certain sector. This allows the robustness of those assumptions to be tested, clarifying the key hypotheses and causal mechanisms and identifying variables and relationships that were not adequately considered in non-formal models.

The broad goal of history-friendly models is to match the overall patterns described in qualitative features, particularly the trend of the key descriptors of industry structure and performance. Further, the goal is to achieve this in a manner that features some particular causal mechanisms— namely, those that have been proposed in the appreciative theories that have been put forward in connection with the empirical studies of the industry historical episodes.

Various history-friendly models have been developed for several industries, such as chemicals, DRAM and environmental technologies. Three basic history-friendly models have been developed by Malerba, Nelson, Orsenigo and Winter. Two models of this type refer to the computer industry. One refers to the dynamics of technology, firms' competences, market structure and demand. During the long-term evolution of an industry major technological and demand discontinuities may occur, thereby greatly affecting market structure and the survival of established firms. In general, technological discontinuities have been absorbed successfully by industry leaders much more than demand discontinuities. When a technological discontinuity takes place within an existing demand, incumbents are sheltered from the major change in the technology through the lock-in of existing customers. On the other hand, a major change in demand is often associated with changes in related technologies, so that firms have to pass through several shifts in terms of knowledge, with major consequences for the entry and growth of new entrants. These results emphasise the need to examine the possible tradeoffs and complementarities between knowledge about technologies and knowledge about demand (Malerba *et al.*, 1999). A second model examines the organisation of innovative and production activities in computers when knowledge complementarities among components and systems are present as the result of the dynamic interplay of knowledge, competencies and market structure, and more broadly of the coevolution of the upstream and downstream industries (Malerba-Nelson-Orsenigo-Winter 2006). A third model by Malerba and Orsenigo (2002) refers to the evolution of the pharmaceutical industry. It is characterised by a highly segmented market and by low cumulativeness in the introduction of successful innovative products. The structure of the industry that emerges is has a low degree of concentration in the global market, while firms hold dominant positions in the single submarkets.

Once developed for several sectoral systems, history-friendly models will allow comparative analyses of the patterns of industrial dynamics and structural evolution, identify commonalities across sectors and enrich our understanding of the factors behind structural evolution. This is so because these models focus on several elements of sectoral systems: non-firm organisations, suppliers, users and public policy. They therefore could prove quite useful in the dynamic analysis of the interaction among several of these elements.

4. A key challenge common to both traditions: coupled dynamics and coevolution

Coevolution is at the heart of the dynamic analysis of innovation and the evolution of industries, and addresses the issue of transformation and structural change. In a broad sense coevolution entails variables that change together and the specific feedbacks loops that link them. Coevolutionary processes involve knowledge, technology, actors, demand and institutions, and are often path-dependent. Moreover, local learning, interactions among agents, and networks may generate increasing returns and irreversibilities that may lock sectoral systems into inferior technologies, as Richard Nelson, Stan Metcalfe, Paul David and Richard Langlois among others have shown.

Now for some examples, going back to the topics that have been examined above: one issue concerns the processes of change in knowledge and change in the innovative division of labour, a typical coevolutionaty process. Another progress in understanding the relationship between changes in demand, technological change and industry evolution, and the need for new detailed empirical analyses, deeper appreciative understanding and formal modelling of feedbacks, and processes of specialisation in consumption, of niche proliferation and of demand convergence. For networks progress is needed in terms of the coevolutionary processes of networks, technology and industry structure. As a starting point we know that networks show stability and change over the evolution of an industry (as demonstrated by longitudinal data for some industries), that stable networks are often formed early in the industry life cycle, and that major industry specific events shape the structure of networks. In this respect the work of Lundgren (1995) on digital image processing and Bonaccorsi and Giuri (2001) for aircraft are good examples of the coupled dynamics of networks and technology.

Coevolutionary processes are indeed sector specific (Nelson, 1995). For example, just looking at three elements such as technology, demand and firms, one could claim that in sectors characterised by a system product and consumers with fairly homogeneous demand, coevolution leads to the emergence of a dominant design and industrial concentration (Klepper, 1996). However in sectors with either heterogeneous demand, or competing technologies with lock-ins, specialised products and a more fragmented market structure may emerge. In general one could say that changes in the specific knowledge base of an industry or in the features of demand may affect the characteristics of actors, the organisation of R&D, the features of networks, the structure of the market and the specific role of the institutions. All these changes may in turn lead to further modifications in the technology, the knowledge base, demand, and so on. The cases of specific industries provide interesting examples. In chemicals Arora and Gambardella (1998) discussed the long run coevolution of technology, organisation of innovative activities and market structure, and Murman (2003) examined the joint interrelated evolution of technology, firms population, market structure, national organisations (such as universities and firms), and changing international leadership. In computers coevolutionary processes involving technology, demand, market structure, institutions and firms' organisation and strategies have differed greatly in mainframes, minicomputers, personal computers and computer networks, involving different actors, mechanisms, entry processes and producer-customers relationships (Bresnahan and Malerba, 1999). In pharmaceuticals and biotechnology the interaction between knowledge, technology, institutions and country-specific factors have shaped the evolution of the industry: changes in the knowledge base and in the relevant learning processes of firms have induced deep transformations in the behaviour, structure and interaction of agents, which in turn have changed knowledge and learning, leading to new products and so on (as McKelvey, 1997; McKelvey *et al.*, 2004). Another case refers to telecommunications equipment and services. The convergence within information and communication technology (ICT) and between ICT and broadcasting-audio-visual and the emergence of the internet brought about a more fluid market structure with a lot of actors with different specialisations and capabilities, and new types of users. This in turn greatly expanded the boundaries of the sector by creating new segments and new opportunities, with national differences in the organisation of innovation. Moreover, the emergence of the internet has generated more pressure in favour of open standards and has led to the rise of new actors (such as ISP and content providers) (Dalum and Villumsen, 2003). In software, since the early 1980s, the spread of networked computing, embedded software, the internet, the development of open system architecture and open source, and the growth of web-based network computing has led to the decline of large computer producers as developers of integrated hardware and software systems and to the emergence of a lot of specialised software companies, and to changes in software distribution (from licensing agreements in the early days, to the rise of independent software vendors, to price discounts for package software, and, with the diffusion of the CD-ROM and the internet, to shareware and freeware) (D'Adderio, 2004).

Research here has to reach a much finer analysis at both the empirical and the theoretical levels, and to move from the statement that everything is changing with everything else, to answering questions such as the following. What is coevolving with what? How intense is this process? And, most importantly, what are the specific feedback loops that link the variables that change together? In this spirit, Murmann (2003) and D'Adderio (2004) provide interesting examples of analyses of coevolution in industries.

The same type of reasoning applies to vertically related industries. In their work on the aircraft industry, Bonaccorsi and Giuri (2001) try to answer some of the questions posed above. At a more theoretical level one can find a first discussion of vertical interdependent processes in the contribution by Young (1928), in which the size of the market depends on prices, which in turn depend upon the cost of production, which depends on the extent of the division of labour. In other words, ultimately the division of labour is limited not by the extent of the market but by the division of labour itself. However, modelling coeovolutionary processes in vertically related industries is not an easy task and first attempts in this direction have only recently been made. Arora and Bokhari (2000) examine vertical integration and specialisation as driven by the interplay of the Babbage effect, the division of labour effect and coordination advantages. Jacobides and Winter (2005) explain the vertical scope of firms in terms of the coevolution of firms' capabilities and transaction costs, and focus their analysis on four factors— knowledge accumulation, capability differences, selection processes and endogenous transaction costs. Finally, in Malerba *et al.* (2006) vertical integration and specialisation is driven by firms' capabilities, the rate of technological change and the size and structure of markets, and it is the result of coevolutionary processes in the upstream and downstream industries.

5. Conclusions: converging research agendas in terms of topics

In this paper I have suggested that the analysis of innovation, industrial dynamics and industry evolution has witnessed major progress. I have grouped the contributions in two different but related traditions: one (older) which may be called industrial dynamics, the other (more recent) which can be labelled sectoral systems evolution. In both these traditions, contributions at the empirical, appreciative, econometric and formal modelling levels have greatly advanced our understanding of innovation, industrial dynamics and the different evolution of industries. In particular, the main part of the paper is centred on the point that a full understanding of the relationship between innovation and the evolution of sectoral systems has also to cope with a finer grained analysis of knowledge, actors, demand, networks and institutions. And coevolution is a major challenge for both approaches.

I am convinced that in the future both traditions will start to converge. The industrial dynamics tradition will open up to include some elements of the sectoral systems tradition: I am thinking mainly of different types of knowledge at the base of innovative activities and of specific actors and institutions. At the same time, the sectoral systems approach will attempt to be more quantitative in its analyses by trying to use new longitudinal database on several actors, networks and demand more extensively.

This is so because both traditions have followed a methodology that identifies empirical regularities, stylised facts or puzzles that need to be explained, develops appreciative theorising, conducts quantitative analyses and then builds formal models, which in turn feed back to empirical analyses in terms of tests, insights and questions.

Where those approaches may still diverge, however, is interdisciplinary. While the industrial dynamics tradition is focussed mainly on economic dimensions, the sectoral systems tradition claims that in the realm of innovation and the evolution of industries, research needs to be interdisciplinary. It means that the full understanding of topics such as innovation and the evolution of industries require the integration of economics, history, sociology, technology, management and organisation. And interdisciplinarity means eclecticism and openness to new contributions from different fields of research.

References

ABERNATHY W.J. and J.M. UTTERBACK, 1978: "Patterns of innovation in technology", *Technology Review*, 80: 0-47.

ADNER R., 2003: "When are technologies disruptive: A demand-based view of the emergence of competition", *Strategic Management Journal*, 23: 667-688.

ADNER R. and D. LEVINTHAL, 2001: "Demand heterogeneity and technology evolution: Implications for product and process innovation", *Management Science*, 47: 611-628.

ANTONELLI C., 2003: "The digital divide: Understanding the economics of new information and communication technology in the global economy", *Information Economics and Policy*, 15: 173-199.

ARORA A. and F. BOKHARI, 2000: *Vertical integration and dynamics and industry evolution*, Carnegie Mellon University, Mimeo, May.

ARORA A., A. FOSFURI and A. GAMBARDELLA, 2001: *Markets for Technology: Economics of Innovation and Corporate Strategy,* MIT Press, Cambridge, MA.

ARORA A. and A. GAMBARDELLA, 1998: "Evolution of industry structure in the chemical industry", in Arora A., Landau R. Rosenberg N. (eds), *Chemicals and Long-Term Economic Growth*, Wiley, New York.

AUDRETSCH D.B., 1995: *Innovation and Industry Evolution*, MIT Press, Boston.

AVERSI R., G. DOSI, G. FAGIOLO, M. MEACCI and C. OLIVETTI, 1999: "Demand dynamics with socially evolving preferences", *Industrial and Corporate Change*, 8: 353-408.

BALCONI M., S. BRESCHI and F. LISSONI, 2004: "Networks of inventors and the role of academia: An exploration of Italian patent data", *Research Policy*, 33: 127-145.

BALDWIN J., 1995: *The Dynamics of Industrial Competition*, Cambridge University Press, Cambridge.

BONACCORSI A. and P. GIURI, 2001: "Network structure and industrial dynamics. The long term evolution of the aircraft-engine industry", *Structural Change and Economic Dynamics*, 12: 201-223.

BOTTAZZI G., E. CEFIS and G. DOSI, 2002: "Corporate growth and industrial structures: Some evidence from the Italian manufacturing industry", *Industrial and Corporate Change*, 11: 705-723.

BRESCHI S. and F. LISSONI, 2004: "Knowledge networks from patent data: methodological issues and research targets", in H. Moed, W. Glänzel and U. Schmoch (eds), Handbook of Quantitative Science and Technology Research: The Use of Publication and Patent Statistics in Studies of S&T Systems, Springer, Berlin, 613-643.

BRESCHI S., F. MALERBA and L. ORSENIGO, 2000: "Technological regimes and Schumpeterian patterns of innovation", *Economic Journal*, 110: 388-410.

BRESNAHAN T. and S. GREENSTEIN, 2001: "The economic contribution of information technology: towards comparative and user studies", *Journal of Evolutionary Economics*, 11: 95-118.

BRESNAHAN T. and F. MALERBA, 1999: "Industrial dynamics and the evolution of firms and nations competitive capabilities in the world computer industry", in Mowery D. and Nelson R. (eds), *The Sources of Industrial Leadership,* Cambridge University Press, Cambridge.

BRUSONI S., A. PRENCIPE and K. PAVITT, 2001: "Knowledge specialization, organizational coupling and the boundaries of the firm: Why firms know more than they make?" *Administrative Science Quarterly*, 46: 597-621.

CHRISTENSEN C.M. and R. ROSENBLOOM, 1995: "Explaining the attacker's advantage: Technological paradigms, organisational dynamics and the value network", *Research Policy*, 24: 233-257.

CHRISTENSEN C.M., 1997: *The Innovators Dilemma: When New Technologies Cause Great Firms to Fail,* Harvard Business School Press, Boston, MA.

COWAN R., P.A. DAVID and D. FORAY, 2000: "The explicit economics of knowledge: Codification and tacitness", *Industrial and Corporate Change*, 9: 211-253.

COWAN R., N. JONARD and M. OZMAN, 2004: "Knowledge dynamics in a network industry", *Technological Forecasting and Social Change*, 71: 469-484.

D'ADDERIO L., 2004: *Inside the Virtual Product: How Organizations Create Knowledge Through Software,* Edward Elgar, Cheltenham.

DALUM B. and G. VILLUMSEN, 2003: "Fixed data communications: Challenges for Europe", in Edquist C. (ed.), *The Internet and Mobile Telecommunications System of Innovation*, Edward Elgar, Cheltenham & Northhampton.

DEVETAG G., 1999: "From utilities to mental models: A critical survey on decision rules and cognition in consumer choice", *Industrial and Corporate Change*, 8: 289-351.

DOSI G., 2001: *Innovation, Organization and Economic Dynamics: Selected Essays,* Edward Elgar Publishing, Cheltenham.

DOSI G., O. MARSILI, L. ORSENIGO and R. SALVATORE, 1995: "Learning, market selection and the evolution of industrial structures", *Small Business Economics*, 7: 411-436.

DYER J.H., 1996: "Specialized supplier networks as a source of competitive advantage: Evidence from the auto industry", *Strategic Management Journal*, 17: 271-291.

EDQUIST C., 1997: *Systems of Innovation; Technologies, Institutions and Organizations. Science, Technology and the International Political Economy Series,* Pinter, London.

ERICSON R. and A. PAKES, 1995: *Markov Perfect Industry Dynamics: a Framework for Empirical Work.* Review of Economic Studies, 62(210): 53-83.

FORAY D., 2004: *The Economics of Knowledge*, MIT Press, Boston, MA).

FRANKE N. and S.K. Shah, 2003: "How communities support innovative activities: An exploration of assistance and sharing among end-users", *Research Policy*, 32: 157-178.

FREEMAN C., 1974: *The Economics of Industrial Innovation*, Penguin, Harmondsworth, UK.

GEROSKI P., 1994: *Market Structure, Corporate Performance and Innovative Activity*, Oxford University Press, Oxford.

GRUBER, H., and F. VERBOVEN, 2001: "The evolution of markets under entry and standards regulation— the case of global mobile telecommunications", *International Journal of Industrial Organization*, 19(7): 1189-1213.

HARHOFF D., J. HENKEL and E. VON HIPPEL, 2003: "Profiting from voluntary information spillovers: How users benefit by freely revealing their innovations", *Research Policy*, 32: 1753-1769.

JACOBIDES M.G. and S.G. WINTER, 2005: "The co-evolution of capabilities and transaction costs: Explaining the institutional structure of production", *Strategic Management Journal*, 26: 395-413.

JAFFE A.B., M. TRAJTENBERG and M. FOGARTY, 2000: "Knowledge spillovers and patent citations: Evidence from a survey of inventors", *American Economic Review*, 90: 215-218.

JOVANOVIC B., 1982: "Selection and the evolution of industry", *Econometrica*, 50: 649-670.

KAMIEN M.I. and N.L. SCHWARTZ, 1975: "Market structure and innovation: a survey", *Journal of Economic Literature*, 13: 1-37.

KLEPPER S., 1996: "Entry, exit, growth and innovation over the product life cycle", *American Economic Review*, 86: 562-583.

KLEPPER S., 1997: "Industry life cycles", *Industrial and Corporate Change* 6: 145-181.

KLEPPER S., 2002: "Firm survival and the evolution of oligopoly", *RAND Journal of Economics*, 33: 37-61.

KLEPPER S. and K.L. SIMONS, 2000: "The making of an oligopoly: Firm survival and technological change in the evolution of the U.S. tire industry", *Journal of Political Economy*, 108: 728-760.

KLEPPER S. and P. THOMPSON, 2002: *Submarkets and the Evolution of Market Structure*, Carnegie Mellon University, Pittsburg, PA.

KOGUT B., 2000: "The network as knowledge: Generative rules and the emergence of structure", *Strategic Management Journal*, 21: 405-425.

KORTUM S., and J. LERNER, 2000: "Assessing the contribution of venture capital to innovation", *RAND Journal of Economics*, 31(4): 674-692.

LANGLOIS R.N., 2001: "Knowledge, consumption, and endogenous growth", *Journal of Evolutionary Economics*, 11: 77-93.

LANGLOIS R.N., P.L. ROBERTSON, 1995: "Innovation, networks, and vertical integration", *Research Policy*, 24: 543-562.

LEVIN R.C., A.K. KLEVORICK, R.R. NELSON and S.G. WINTER, 1987: "Appropriating the returns from industrial research and development", *Brookings Paper on Economic Activity,* 3: 783-820.

LOASBY B., 1999: *Knowledge, Institutions and Evolution in Economics*, Routledge, London.

LOASBY B., 2001: "Cognition, Imagination and institutions in demand creation", *Journal of Evolutionary Economics*, 11: 7-21.

LUNDGREN A., 1995: *Technological Innovation and Network Evolution*, Routledge, London and New York.

LUNDVALL B.-Å., 1988: "Innovation as an interactive process: From user-producer interaction to the National System of Innovation", in Dosi G., Freeman C., Nelson R., Silverberg G. and Soete L. (eds.), *Technical Change and Economic Theory*, Pinter, London, 349-369.

LUNDVALL B.-Å., 1993: "User-producer relationships, National Systems of Innovation and internationalisation", in Foray D. and Freeman C. (eds.), *Technology and the Wealth of Nations*, Pinter Publishers, London.

MALERBA F., 1985: *The Semiconductor Business: the Economics of Rapid Growth and Decline*, Frances Pinter, London.

MALERBA F., 1992: "Learning by firms and incremental technical change", *Economic Journal*, 102: 845-859.

MALERBA F., 2002: "Sectoral systems of innovation and production", *Research Policy*, 31(2): 247-264.

MALERBA F., 2004: *Sectoral Systems of Innovation,* Cambridge University Press, Cambridge, MA.

MALERBA F. and S. BRUSONI, 2006: *Perspectives on the economics of innovation*, Cambridge University Press, Cambridge, forthcoming.

MALERBA F. and L. ORSENIGO, 1995: "Schumpeterian patterns of innovation", *Cambridge Journal of Economics*, 19: 47-65.

MALERBA F. and L. ORSENIGO, 1996: "The dynamics and evolution of industries", *Industrial and Corporate Change*, 5: 51-87.

MALERBA F. and L. ORSENIGO, 1997: "Technological regimes and sectoral patterns of innovative activities", *Industrial and Corporate Change*, 6: 83-117.

MALERBA F. and L. ORSENIGO, 2002: "Innovation and market structure in the dynamics of the pharmaceutical industry and biotechnology: Towards a history friendly model", *Industrial and Corporate Change*, 11: 667-703.

MALERBA F., R. NELSON, L. ORSENIGO and S. WINTER, 1999: "History friendly models of industrial evolution: The computer industry", *Industrial and Corporate Change*, 1: 3-41.

MALERBA F., R. NELSON, L. ORSENIGO and S. WINTER, 2003: *Demand, Innovation and the Dynamics of Market Structure: The Role of Experimental Users and Diverse Preferences.* CESPRI WP No. 135, January.

MALERBA F., R. NELSON, L. ORSENIGO and S. WINTER, 2006: *The Dynamics of the Vertical Scope of Firms in Related Industries, The Coevolution of Competences, Technical change and the Size and Structure of Markets.* CESPR, Bocconi University, Milan.

MARSILI O., B. VERSPAGEN, 2002: "Technology and the dynamics of industrial structures: an empirical mapping of Dutch manufacturing", *Industrial and Corporate Change*, 11: 791-815.

McKelvey M., 1997: "Coevolution in commercial genetic engineering", *Industrial and Corporate Change*, 6: 503-532.

McKelvey M., L. Orsenigo and F. Pammolli, 2004: Pharmaceuticals analysed through the lens of a Sectoral Innovation System, in Malerba F. (ed.), *Sectoral Systems of Innovation*, Cambridge University Press, Cambridge.

Metcalfe S., 2001: "Consumption, preferences, and the evolutionary agenda", *Journal of Evolutionary Economics*, 11: 37-58.

Metcalfe S., 1998: *Evolutionary Economics and Creative Destruction,* Routledge, London.

Mowery D., C. Sampat and N. Bhaven, 2001: "Patenting and Licensing University Inventions: Lessons from the History of the Research Corporation", *Industrial & Corporate Change*, 10(2): 317-355.

Murman J.P., 2003: *Knowledge and Competitive Advantage, the Coevolution of Firms, Technology, and National Institutions*, Cambridge University Press, Cambridge.

Nelson R., 1995: "Recent evolutionary theorizing about economic change", *Journal of Economic Literature*, 33(1): 48-90.

Nelson R. and S. Winter, 1982: *An Evolutionary Theory of Economic Change*, Harvard University Press, Cambridge MA.

Nelson R., 1994: "The co-evolution of technology, industrial structure and supporting institutions", *Industrial and Corporate Change*, 3: 47-63.

Nesta L. and V. Mangematin, 2002: "Industry life cycle, knowledge generation and technological networks", in Gault F. and de La Mothe J. (eds), *Alliances, Networks, and Partnerships in the Innovation Process*, Kluwer Academic, Boston, MA.

Nuvolari A., 2004: "Collective invention during the British industrial revolution: the case of the Cornish pumping engine", *Cambridge Journal of Economics,* 28: 347-363.

Orsenigo L., F. Pammolli and M. Riccaboni, 2001: "Technological change and network dynamics: Lessons from the pharmaceutical industry", *Research Policy*, 30: 485-508.

Orsenigo L., F. Pammolli, M. Riccaboni, A. Bonaccorsi and G. Turchetti, 1997: "The evolution of knowledge and the dynamics of an industry network", *Journal of Management and Governance*, 1: 147-175.

Pavitt K., 1984: "Sectoral patterns of innovation: Towards a taxonomy and a theory", *Research Policy,* 13: 343-374.

Powell W.W., K.W. Kogut and L. Smith-Doerr, 1996: "Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology", *Administrative Science Quarterly*, 41: 116-145.

PYKA A., 2000: "Informal networking and industrial life cycles", *Technovation*, 20: 25-35.

ROSENKOPF L. and M. TUSHMAN, 1998: "The coevolution of community networks and technology: Lessons from the flight simulation industry", *Industrial and Corporate Change*, 7: 311-346.

ROWLEY T., D. BEHRENS and D. KRACKHARDT, 2000: "Redundant governance structures: An analysis of structural and relational embeddedness in the steel and semiconductor industries", *Strategic Management Journal*, 21: 369-386.

SAVIOTTI P., 1996: *Technicological Evolution, Variety and the Economy*, Edward Elgar, Cheltenham.

SAVIOTTI P., 2001: "Variety, growth and demand", *Journal of Evolutionary Economics*, 11: 119-142.

SAXENIAN A.L., 1994: *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, Harvard University Press, Cambridge, MA.

SCHUMPETER J., 1934: *The Theory of Economic Development*, Harvard University Press, Cambridge MA.

SCHUMPETER J., 1939: *Business Cycles*, MacGraw Hill, New York.

SCHUMPETER J., 1950: *Capitalism, Socialism and Democracy*, Harper Brothers, New York.

STUART T.E., 1998: "Network positions and the propensity to collaborate: An investigation of strategic alliance formation in a high-technology industry", *Administrative Science Quarterly*, 43: 668-698.

SUTTON J., 1991: *Sunk Costs and Market Structure,* MIT Press, Cambridge MA.

SUTTON J., 1998: *Technology and Market Structure: Theory and History*, MIT Press, Cambridge, MA.

TEUBAL M., 1979: "On user needs and need determination: Aspects of the theory of technological innovation", in Baker M. (ed.), *Industrial Innovation: Technology, Policy and Diffusion,* Macmillan, London.

TEUBAL M., T. YINNON and E. ZUSCOVITCH, 1991: "Networks and market creation", *Research Policy*, 20: 381.

URBAN G. and E. VON HIPPEL, 1988: "Lead user analyses for the development of new industrial products", *Management Science* 34: 569-582.

UTTERBACK J.M., 1994: *Mastering the Dynamics of Innovation,* Harvard Business School Press, Boston, MA.

VON HIPPEL E., 1986: "Lead users: A source of novel product concepts", *Management Science* 32: 791-805.

VON HIPPEL E., 1988: *The Sources of Innovation*, Oxford University Press, New York.

WINTER S.G., 1987: "Knowledge and competence as strategic assets", in Teece D.J. (ed.), *The Competitive Challenge*, Ballinger, Cambridge, MA.

WINTER S.G., Y.M. KANIOVSKI and G. DOSI, 2000: "Modeling industrial dynamics with innovative entrants", *Structural Change and Economic Dynamics*, 11: 255-293.

WITT U., 2003: *Evolving Economy: Essays on the Evolutionary Approach to Economics*, Edward Elgar, Cheltenham.

WITT U., 2001: "Learning to consume - A theory of wants and the growth of demand", *Journal of Evolutionary Economics*, 11: 23-36.

YOUNG A.A., 1928: "Increasing Returns and Economic Progress", *The Economic Journal*, 38, 527-542.

ZUCKER L., M. DARBY and M. BREWER, 1998: "Intellectual Human Capital and the Birth of U.S. Biotechnology Enterprises", *American Economic Review*, 88(1): 290-306.