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Journal of Economic Issues, XXXIX (1), 91-121, Year 2005.

Abstract

The article discusses recent advances and future challenges in innovation studies. First, it separately considers four main strands of research, studying innovation at the organisational, systemic, sectoral and macroeconomic levels. Then, considering the field as a whole, the article points to the existence of important neglected topics and methodological challenges for future research. In fact, several fundamental issues are still unexplored, such as the co-evolution between technological and institutional change; the role of demand; and the impacts of innovation on individual and collective welfare. There are also important methodological challenges, such as the need for more systematic interactions between the different levels of analysis; the importance of an interdisciplinary approach to the study of technological and institutional changes; and the search for a combination of contingent explanations based on case studies with general analytical results based on econometric and formal models.

Advances and challenges in innovation studies

The study of innovation is a relatively young and fast growing branch of social sciences. Mainly inspired by the work of Joseph Schumpeter and by other research traditions outside the economics mainstream, it has developed as an interdisciplinary field studying the relationships between economic, technological, organisational and institutional changes. In his *Theory of Economic Development*, Schumpeter (1934) had pointed out that the main function of entrepreneurs in private firms is to combine existing resources to put forward "new uses and new combinations", or "innovations". These he conceived in a broad sense, so as to encompass new processes and new products, as well as new sources of supply of raw materials, new markets, and organisational changes.

A surge of interest in the Schumpeterian theory came at the beginning of 1980s with the seminal contributions in the evolutionary (Dosi 1982, Nelson and Winter 1982) and neo-Schumpeterian (Freeman et al. 1982) approaches to the study of economic growth, which focussed on the central role of innovation for the process of economic development. After such pioneering works, innovation studies have rapidly developed in the last fifteen-twenty years, bringing new insights into the study of economic change, and increasingly attracting researchers and policy makers.

As it is the case for other young and emerging scientific fields, the rapid development of the discipline has resulted in a great richness and heterogeneity of concepts, theoretical approaches and empirical results. At present, there exists yet no attempt to construct a coherent theoretical framework linking the different findings from this now huge literature. In

this respect, there is a need for more systematic efforts to discuss the state of the art of innovation studies, and to point out the directions for future research.[1]

This article is intended as a contribution to this purpose. It presents the state of the art of the field of innovation studies, and it discusses the challenges and perspectives for future research. The purpose is not to provide the reader with a complete and detailed overview, but rather to focus on recent advances, and to point to the challenges ahead.

Our discussion will mainly reflect the evolutionary (or post-Schumpeterian) economic traditions. Other approaches to the study of technology and innovation, such as science and technology studies, business and management literature, and sociological approaches, though potentially relevant, are not considered to the same extent.

The paper has the following structure. First, it separately considers different streams of the literature on innovation by dividing them into different 'levels of analysis'. The first section will describe the theory of innovation at the microeconomic level. The complexity of the innovative process at the microeconomic level calls for a 'systemic' approach to the study of innovation, which will be presented in the second section. Such complexity, moreover, makes the patterns and effects of innovative activity rather heterogeneous across different sectors of the economy. Therefore, the third section will discuss the main challenges in studying 'why innovation differs at the meso level'. The fourth section will shift to the macroeconomic level, and it will consider the impacts of innovation on the performance of national economies in the long run, in terms of aggregate growth, catching up, and employment trends. Then, the fifth section will point out the main challenges common to the whole field. It will focus on some theoretical and methodological issues that need to be considered by innovation scholars in future research. Finally, the last section will sum up the main conclusions.

Innovation at the organizational level

Innovative activities have taken different forms in different historical periods and in different countries (Freeman and Louça 2001, Bruland and Mowery 2004, Lazonick, 2004). The British industrial revolution in the nineteenth century was based on the on-the-job apprenticeship system, through which craft workers passed on their skills to the next generation. A few decades later, the US innovative revolution was characterized by the rise of the professional manager, due to the separation between ownership and control, and to the growth of graduate management education. This transition started at the beginning of the twentieth century, and by the end of World War II US industrial corporations had powerful managerial organizations for developing new technologies. During 1970s and 1980s, Japanese companies challenged US industrial corporations in the very industrial sectors in which American corporations had previously gained great competitive advantages. According to Lazonick (2004), three kinds of institutions constituted the foundation of the Japanese success: cross-shareholding, the banking system, and lifelong employment. The importance of lifelong employment in securing Japan's competitive advantage was that, unlike in the US, there was no separation between salaried and hourly workers, which integrated shop-floor workers into the process of organizational learning.

The innovative process and the innovative firm

The British, American and Japanese models of innovative firms are important examples that show how heterogeneous the innovative process tends to be in different historical periods and in different national contexts. *Variety* over time and space is certainly a fundamental starting point for scholars of innovation. However, the existence of different models of innovation has not discouraged the investigation of the main common factors driving innovation in different historical and geographical situations. In fact, a large number of studies on the innovative

process at the organisational level have been carried out since the seminal contributions in the evolutionary economic approach by Dosi (1982) and Nelson and Winter (1977, 1982).

A theory of the innovative firm needs to be based on a few fundamental facts pointed out by evolutionary scholars.[2] First, the technological knowledge of the firm is often tacit and embodied in the minds and in the routines of the individuals within each organization, e.g. it is not always codified and easily codifiable.[3] Secondly, knowledge is not static, but dynamic, cumulative, evolving over time. It changes as a result of individuals' creativity, but more commonly new knowledge and innovations are products of intra- and interorganisational interactions. In other words, innovation is a collective endeavour. Third, economic agents operate in an ever-changing and highly uncertain environment, and they have limited information and limited capability to process and interpret such information. In other words, far from being perfect rational maximizers, individuals and firms tends to perform their working and business activities based on a 'bounded' kind of rationality (Simon 1959, 1965), which is a limited capability to use information and to make their economic and technological choices. Such characterization of knowledge and technology implies that the heterogeneity in technological capabilities and competencies is important for understanding the process by which new technologies are introduced. Heterogeneity (between firms, technologies, national and historical contexts), therefore, is not an obstacle to the study of innovation, but a fundamental precondition for it.

A few decades ago, before evolutionary theories of the innovative firm started to be developed, the common approach to the study of innovation was the so-called 'linear model'. According to it, the linear sequence originates with an invention that most often comes out of universities or industrial R&D departments. Thereafter, the innovative idea is developed into a working artefact. Finally the artefact is matched with users' requirements and placed commercially on the market. Several researchers have later criticized the linear model of

innovation (more recently: Gittelman and Kogut 2001, Ruttan 2001, Pavitt, 2004). They have argued that innovation is a "non-linear cycle of divergent and convergent activities that may repeat over time and at different organizational levels if resources are obtained to renew the cycle" (Van de Ven et al. 1999: 16). The unpredictable nature of innovation is due to the conditions of strong uncertainty in which it occurs, given the unfeasibility of accurately predicting the cost and value of a new product, or the users' demand. Moreover, the innovative process involves the exploration and exploitation of opportunities (March 1991), that can be based either on an advance in technical practice, on a change in market demand, or on a combination of the two (Mowery and Rosenberg 1979).

Recently, the characteristics of the innovative process described above are made more complex by some important trends: (i) the increasing specialization in knowledge production; (ii) the increasing complexity in the physical artefacts, and in the knowledge base underpinning them; (iii) the continuous matching of technological opportunities with market needs and organisational practices (Pavitt 2004). On the whole, two central features of the innovative process have been stressed in the more recent literature: first, that the innovative process involves the co-ordination and integration of specialized knowledge, and, second, that it requires learning in conditions of uncertainty.

Given the difficulties and complexities associated with the innovative process, great demands are placed on the innovative firm. In order to manage this inherent uncertainty, the innovative firm must continuously engage in activities of strategizing, financing, and organizing. Furthermore, by definition innovation requires learning about how to transform technologies and how to access markets in order to achieve higher quality and lower production costs. Learning is a social activity that renders the innovative process uncertain, cumulative, and collective (Lazonick 2004).

Organizational forms and networks of innovators

The firm can also be innovative with respect to its organizational structure. In this regard, competitive advantage can be achieved by changing the skill base of the firm with respect to both function and hierarchical integration. Many studies have shown that cross-function collaboration positively contributes to innovation (Tsai and Ghoshal 1998). This suggests the existence of important interactions between the organizational structure and the firm's innovative capability. Other studies emphasize the need for a correspondence between organizational structure and contextual factors in order to maximize the innovative output (Galbraith 1974, Lawrence and Lorsch 1967). Mintzberg (1980) points to five dominant organizational configurations: simple structure, machine bureaucracy, professional bureaucracy, divisionalized form, and adhocracy. Bureaucracies tend to dominate in stable environments, whereas adhocracies tend to dominate in fast changing environments. The organizational forms tend to vary in their innovative ability: the very rigid structure of the machine bureaucracy makes it unlikely to innovate, whereas the adhocracy's more flexible structure makes it more innovative (Lam 2004). Recently, adhocracies have more frequently emerged, due to the increased velocity of change of the environment, and to the greater need for firms to be innovative.

Another feature of changing organisational structures that has emerged over the last two decades is a rise in the number of organizations engaged in collaborative activities, especially within the R&D area (Hagedoorn 2002). Many empirical studies have shown that this form of collaborative activity has a positive impact on firms' innovative capability, especially when they have diverse ties and a central location within the network (Ahuja 2000, Baum, Calabrese and Silverman 2000, George, Zahra and Wood 2002, Godoe 2000, Sarkar, Echambadi and Harrison 2001, Stuart 2000, Vinding 2002; Walker, Kogut and Shan 1997). The effect of interorganisational networks on innovation has proved to be more important for

young, less established and small firms (Baum, Calabrese and Silverman 2000, Shan, Walker and Kogut 1994, Stuart 2000). It has been shown that innovative firms become more prone to cooperate, and thus tend to take a more central place within the alliance network. At the same time, firms that are centrally placed within an alliance network tend to be more innovative. This suggests a positive feedback loop, where innovative firms constantly become more centrally placed within the alliance network, and thus more innovative (Powell and Grodal 2004).

On the whole, theories of innovation at the organisational level have recently experienced significant advances. Scholars of innovation now agree that the innovative behaviour of firms must be characterized by some basic common characteristics: co-ordination and integration of specialized knowledge, learning in conditions of uncertainty, innovative strategies, good match between organisational structure and environmental factors, and interorganisational collaborative activities.

Moreover, evolutionary scholars tend to agree that studying innovation from a strictly economic point of view will hardly be successful in explaining the determinants of technological change at the organisational level. A broader interdisciplinary perspective is necessary. Rather than considering only economic factors, an account of firms' innovative behaviour needs to explain the formation and change of firms' routines, objectives and behaviours in the specific social, cultural and historical context in which they operate. In this respect, cognitive psychology along with business and organisation studies must all find a more important role in future studies of the innovative firm.

Linking actors and structure: innovation at the systemic level

During the last decade, there has been a proliferation of studies on the systemic features of innovation, much of which has centred around the concept of 'innovation systems' (IS).[4] The IS concept was developed towards the end of 1980s. At that time, the Japanese economy was growing at an extraordinarily rapid rate, the newly industrialised economies (NIEs) of East Asia were emerging as key players in the global economy, at the same time as the previously leading economies of United States and Europe were experiencing severe stagnation. These trends received great attention both in academic and policy-making circles, and constituted the backdrop for the IS approach, which was developed as an attempt to understand, measure and compare the dynamics involved in the changing configuration of the world economy of the 1980s (Freeman 1987, Nelson 1993). Two different IS traditions became crystallized, both of which were mainly concerned with conducting an analysis at the level of the nation state. The two approaches, which we may label as the 'historical-empirical' and the 'interactive learning-based' approach respectively, differ in many respects, most predominantly in what is included into the definition of the innovation system, and what purpose the concept of innovation system is used for.

The historical-empirical approach

In the historical-empirical approach, the idea of a national innovation system (NIS) was developed as a guiding concept for empirical research on how institutional and production structures affect economic performances in firms and industries in different national contexts (Freeman 1987, Nelson 1993). In addition, the NIS concept may serve as a focussing device for the development of industrial and innovation policy instruments. A special emphasis is put on the historical evolution of national institutions, as these are understood to result from historical socio-economic behaviours and practices. Consequently,

national institutions represent a medium through which the current options that firms and policy makers are confronted with are affected by previous economic agents' choices and actions.

Hence, the historical-empirical approach emphasizes *path-dependency* as a key concept to investigate national differences in innovative capabilities and economic performances. This emerges, for instance, from the comparative study by Mowery and Nelson (1999), who presented a historical description of the development of seven industries in Japan, United States and Europe during the twentieth century. The dominance of the United States and Japan industrial leadership in specific sectors is explained by the strength of the national institutional framework in supporting the evolution of new industries. Among the institutions at the national level, universities enjoy a special position as principal providers of new knowledge and technology to society, through their contribution of both basic research and educated labour. This dual function of universities may have determined technology and innovation policy to be increasingly oriented towards stimulating cooperation between universities and industry. An example of this is the US Bayh-Dole act of 1980, which was introduced to encourage this kind of interaction by making it easier for universities to patent new knowledge (Mowery 2004).[5]

The relative strength of the historical-empirical approach derives from its focus on the institutional set up as a key determinant of innovative activity in the economy. From an empirical point of view, this aspect adds operationalization, as it provides ways of measuring and comparing various aspects of different economies through selected indicators of national innovative activities. Although the approach is based on the insights of recent evolutionary 'appreciative' studies, no real effort is put into making it a more analytically rigorous theory. Hence, the main function of the innovation system in the historical-empirical approach is to

serve as a benchmarking tool for empirical analysis of innovation processes in existing national socio-economic systems.

The interactive learning-based approach

The second tradition, the 'Aalborg school'- 'interactive learning-based' NIS approach, conceives innovation systems somewhat differently, as the main purpose is to give the NIS a more precise conceptual and theoretical foundation. The Aalborg school aimed at accomplishing this objective by combining theories of national production systems of the French structuralists with the Anglo-Saxon tradition of innovation studies (Lundvall 1992). Thus, the scholars advocating the interactive learning-based IS approach addressed the idea of national innovation systems at a more abstract level, by focussing primarily on the role of knowledge, learning and institutions in innovation processes (Lundvall and Johnson 1994, Edquist 1997). The Aalborg school started out from two basic assumptions: (i) knowledge is the most fundamental resource in the modern economy, making learning the most important process; (ii) learning is interactive – i.e. a social process (Lundvall 1992). This orientation emphasizes the concept of *knowledge-based (or learning) economy*. In the knowledge-based economy, competitiveness is closely associated with innovativeness, which influences the organisation of firms, industries and regions. Hence, in order to obtain relevant knowledge, firms tend to engage in cooperative interactive learning relationships with a wide range of other actors, such as suppliers and users of new technologies, public research institutes and other organisations. Interactive learning has been originally investigated by Lundvall in his empirical study of user-producer relationships in the Danish economy (Lundvall 1985). Michael Porter (1990) also pointed out the importance of interactions between business firms and their environment, and he identified industrial clustering as the most important way for achieving competitive advantage on a national scale.

Within the field of economic geography, the 'regional innovation systems' approach (RIS) (Cooke 1992) resembles much the ideas of the Aalborg school. In addition, drawing on a well established tradition of agglomeration studies,[6] the key explanatory factor here is learning that occurs in the local industrial environment of firms – localised learning. RIS scholars argue that due to the local embeddedness of economically relevant knowledge, geographical clustering of economic activity promotes localised learning, which in the long run tends to drive the endogenous growth of regions (Morgan 1997, Maskell and Malmberg 1999). The importance of the local environment becomes more evident in the current 'post-fordist' learning economies,[7] dominated by economic globalisation and 'placeless' ICT-technologies, in which the economic behaviour of firms and industries continues to be strongly embedded in the local environment (Amin and Thrift 1994, Gertler et al. 2000).

Challenges for future research on systems of innovation

On the whole, it appears that the interactive learning-based approach is farther from fulfilling it's proponents ambitions than the historical-empirical IS approach, which is already operative as a benchmarking tool for economic and policy analysis. The main challenge ahead for the latter approach is to refine the IS into an even more advanced benchmarking tool. This could be achieved through the development of increasingly sophisticated data and indicators. These are necessary in order to produce more detailed accounts of innovative activity within specific NIS, and to carry out more advanced international and cross-sectoral comparisons.

As regards the interactive learning-based approach, Edquist (2004) argues that since the *raison d'être* of the IS conceptual framework depends on its stronger theoretical orientation, future research that endeavours to expand innovation systems ideas must revisit the 'general system theory' at a more profound level. In this respect, IS studies have so far concentrated the attention on the role of (i) system components, and (ii) relations among

them. However, according to general system analysis, there are other important issues that need to be considered. Among these: (iii) the system must constitute a coherent whole, i.e. there must be some activities that the system or the system components perform that make them part of the system. Additionally, the system must also serve a function, so that (iv) there must be a reason why the system exists, a function that it needs to perform. Due to the failure of previous approaches to address the two last points in a systematic manner, Edquist (2004) argues that further research in the field must concentrate on the system level by making broad analysis of activities and functions of innovation systems. The latter seems to be the trend that is prevailing at the moment. A fifth lesson from general systems theory is that (v) there has to be some way of identifying what is and what is not part of the system. This means that there have to be clear criteria to identify what constitute the boundaries of the system. Such criteria could be based on the specificities of different industrial sectors, like in the recent stream of literature on sectoral systems of innovation (Malerba 2002, 2004). Traditionally and more often, however, the boundaries of IS have been geographically determined, that is identified with the boundaries of a nation or a region.

Globalisation and innovation systems

In the identification of spatial boundaries of systems of innovation, therefore, another important challenge ahead is to take into account the all-increasing phenomenon of socio-economic globalisation. This requires the study of how processes of globalisation interact with and shape the local (national and regional) systems, and how globalisation affects learning processes locally. Asheim and Gertler (2004) identify five main processes that come with globalisation that challenge localised learning and endogenous growth of regions, and that need to be dealt with by the IS theories. First, the transition in production from carrying out all steps of the value chain within the region towards global outsourcing for cost reasons

may disturb the internal environment of the regions, as local skills and knowledge are rendered superfluous. ‘Learning regions’ need to adapt to these changes, and to diversify their activities towards other areas of economic activity. Secondly, recent research has shown that regional innovation systems are not sufficiently competitive on their own in the global context and must link up with national or supranational systems to remain so. To capture and understand this process, the IS approach must aim at a multi-level analysis of the situation which may require new perspectives and frameworks. Thirdly, increased globalisation and knowledge codification have led to a greater availability of knowledge, which has acted to weaken the competitiveness of some regions. If this is true, there is an increased pressure on high-cost regions to innovate in the attempt to remain competitive. Four, localised learning may be challenged by the increased tendency in some industries to organise work through temporary organisations and projects. This may lead to a fragmentation of the knowledge base, which would arguably threaten localised learning and endogenous growth. Finally, there might also be a problem for regional economic environment, in that when some firms are being acquired by multinational enterprises (MNEs), their knowledge base is being incorporated into the MNE, which in some cases might hollow out the regional knowledge base. However, this tendency may be countered if MNEs are more careful about embedding their knowledge enhancing activities in the socio-economic structure of the region. There is some evidence that this is becoming more common, although the propensity to internationalise R&D activity by MNEs is generally characterised by some inertia (Narula and Zanfei 2004).

How innovation differs across sectors

The phase of persistent and accelerated technical change and economic development that took off with the first industrial revolution has often been associated with highly visible technologies in particular core sectors of the economy (Freeman and Louça 2001). Following this view, which takes its inspiration from Joseph Schumpeter's book *Business Cycles* (1939), neo-Schumpeterian researchers stress the importance of innovation and diffusion in a few leading and fast growing sectors in pushing the growth of the whole economy. In this framework, technological change is mainly 'radical', and it is the main source of economic growth (Freeman et al. 1982, Freeman and Perez 1983).

A slightly different perspective is taken by other economic historians, which point to the wideness and variety of technological transformations even outside of core and leading sectors. For example, evidence shows that the development of capital goods for the textiles and transportation industries accelerated in the second half of the eighteenth century, but this should not obscure the fact that innovation was also taking place in a wider spectrum of other sectors (Bruland and Mowery 2004). At the same time as the critical innovations of steam engines, cotton spinning machines and metalworking tools were being implemented, small-scale ingenuity was mobilizing in and around sectors producing unglamorous consumption goods.

In retrospect, patenting behaviour and contemporary impressions indicate noticeable improvements in the quality of equipment used by agriculture, brewing, luxury and everyday goods. Innovation seems to have accelerated on an economy-wide basis with the first technological revolution, and it was not confined just to a few key sectors forging ahead and driving the whole economy. This 'gradualist' historical perspective (as opposed to the more 'saltationist' and 'disruptive' view adopted by neo-Schumpeterian scholars) emphasises the

persistent stream of minor and continuous changes that occur in a variety of activities as time goes by (Bruland and Mowery 2004).

The recognition of the wide spread of technical creativity across different economic activities can enrich our understanding of innovation. This section focuses on those *sectoral* patterns of innovation that are traditionally underplayed when scholars look out for the most conspicuous sources of structural change and economic growth. Indeed, and paraphrasing Alfred Marshall, innovation is an intrinsic part of the "ordinary business of life" for wide and increasing arrays of industries and territories.

Innovation in 'low-tech' industries

In the last few decades of the twentieth century, the emergence of radically new technologies like the microchip, software, bioengineering and nanotechnology led to a new emphasis of innovation research on the importance of ICTs, pharmaceuticals and other *high-tech* industries.[8] This has led to a relative lack of attention to changing patterns in traditional sectors and to a "high-tech bias" in innovation studies (Lundvall and Borrás 2004).

More than a contradiction in terms, innovation in *low-tech* industries is an indication that terminology and definitions are problematic issues that should be taken into more account in future research. Not only is it difficult to define exactly what an industry is, it is also difficult to formulate unambiguous and clear statements on the relative technological dynamism of productive sectors within each national economy. In reality, innovation happens everywhere, so that there is no such thing as purely low-tech industries. There is evidence of a wide-ranging reorganization in corporate technological portfolios that is affecting large manufacturing firms in all sectors: cutting-edge knowledge about ICT, new materials and drugs & bioengineering are increasingly becoming important for companies that are not specialized in serving those products in the market (Mendonça 2003). "New wine is pouring

from old products", in the sense that the production of established companies of traditional sectors is becoming more dependent on the new technologies produced in high-tech industries. Therefore, diffusion of new technologies and innovative activities are not passive processes. This might become truer than ever as the so-called 'knowledge society' develops. Changes occurring within traditional sectors are likely to be of great importance for middle-income economies that try to catch up with more technologically advanced countries.

For instance, today it is not prudent to state that low-tech sectors such as shoemaking and winemaking cannot be considered 'knowledge intensive'. In a country like Portugal, for example, the traditional low-tech footwear industry went through a substantial technological upgrading in the 1990s connected to a creative use of micro-electronics, and managed to expand in spite of raising relative labour costs (Godinho 2000). Biotechnology is an old body of knowledge that underwent a sequence of radical developments since its prehistoric origins in fermentation and baking operations. Today the new techniques of bioengineering are expected to contribute to the mature industry of wine through fermentation techniques that contribute to enhancing the quality of wine as well as bacteria biotechnology, which is contributing to renew the classic cork component that has been a traditional crop of the country since immemorial times.

Notwithstanding, it might still be important for purposes of analysis to distinguish between different sectors. Let us consider the textiles and food-processing industries as examples of low-tech sectors. These are industries, often called 'sunset' industries, which are usually considered to have reached the maturity stage a long time ago. There is, nonetheless, a useful distinction to be introduced between product and industry lifecycles.

These industries are old but products have come and gone. They do not manufacture exactly what they used to make and in the way they made it in the late eighteenth century. They are very interesting industries to study from the point of view of the innovation process

precisely because they are old and have accumulated technologies from different technological paradigms (von Tunzelmann and Acha 2004). During most of its historical development in the industrial era, textiles and food processing were dominated by machinery and chemicals, but today are multi-technology, an aspect that resembles what has happened in high-tech sectors. With the deepening in cognitive complexity (Wang and von Tunzelmann 2000), the changing nature of demand and market competition leads to innovations in internal organisation and relational capabilities in order to cope with an increasingly turbulent and fast changing environment. It is possible to conceive that the sophistication of markets and the importance of differentiation provoked a shift from static economies of scale, obtained by producing mass quantities of production, to dynamic economies of scale and scope, characterised by learning how to produce improved and new products in real time. The shift towards the 'knowledge-based economy' in a context of increasing globalisation accentuated the pressure for changing the methods of production.

Innovation in services

A way in which manufacturing companies have responded to the increasing complexity of demand has been to add after-sales services to their goods, i.e. to augment the service component of their end product. This means that manufacturing companies are following marketing strategies that complement their tangible products with an intangible component having the key characteristics of the archetypal service: intangibility (broadening the focus on material production of tangible artefacts), interactivity (client interaction in design, delivery, co-production, consumption and aftersales assistance), and information intensity (Miles 2004). Conversely, a feature that has marked evolution of services in the latest part of the twentieth century has been a drive for standardisation, so typical of manufacturing but so hard to implement in service production, and currently valued by many costumers worldwide.

Now, this opens the Pandora's box as regards to industry classifications, since one of the most accepted distinctions is the one between manufacturing and service branches. Many manufacturing firms are outsourcing functions traditionally carried out internally, so that the output of service firms is accounted for in the service sector. So, when confronted with the growth of the service sector, some researchers would argue that this dynamism is a consequence of the fact that manufacturing is increasingly outsourcing services. These two recent trends create uncertainty in the statistics, and might raise the question as to whether or not convergence is actually occurring (Miles 2004). This problem could be lessened with more detailed statistics for services. However, the production of data for the service sector remains scarce, and when statistics exist they are based on categories previously developed for physical products industries.

The problem of measurement in services becomes even more challenging when the task is to capture and to understand the patterns of innovation. Not only are there difficulties in properly defining what services are, these difficulties become harder when the objective is to detect novelties and quality changes in services. The borderlines between technological and organisational innovation, and between product and process innovation become especially blurred in this case. The typical innovative service firm tends to spend less in R&D than an innovative manufacturing firm. This, however, is insufficient to conclude that the changes occurring in services are less dynamic, because spending on training and marketing is not included in conventional statistics. There might be some current changes in services due to the development of some technologies that can be used widely, namely ICTs. For instance, finance and distribution are two industries usually pointed out as pioneers and creative users of ICTs.

In summary, the very existence of innovation complicates its study immensely as it muddles the establishment of industry classifications and taxonomies of innovation that prove reliable and robust to the passing of time.

Studying sectoral differences

Thus, it is hard to define and distinguish unambiguously between low-tech industries, high-tech industries, manufacturing and services. There are always areas of overlapping and rapid changes in the boundaries of sectors over time. In the absence of a universal and permanent classification, the study of innovation often has to rely on the analysis of concrete experiences, a blend of description and analysis that has been defined by Nelson and Winter (1982) as the "appreciative mode of theorising".

The relevant question then is how to distinguish and compare innovative patterns of diverse economic activities and industries. Answering this question requires a theoretical framework able to illuminate key stylised facts and to allow for comparative analysis. There are, however, serious constraints in understanding how and why innovation is pervasive but diverse among different sectors. Difficulties arise in performing reliable comparisons of such differences as well as integrating research data, case studies and conditional generalisations emerging from the applied work.

The same problem applies for the recent class of 'history-friendly models' (Malerba et al. 1999). While it is certainly interesting to build up a formal evolutionary model to reconstruct the historical evolution of a particular sector, the analytical and empirical results obtained in a specific case can hardly be generalized to other sectors and countries. Indeed, this shows that the study of innovation at the meso level still lacks a clear conceptual and theoretical framework to produce useful generalisations starting from the observed stylised facts.

The ‘sectoral systems of innovation’ approach (Breschi and Malerba 1997, Malerba 2002, 2004) is a recent attempt to give a more solid foundation to industrial comparative analysis. This approach highlights three key dimensions of the co-evolutionary process driving innovation at the sectoral level. The first is a set of sector-specific characteristics defining its ‘technological regime’, such as the knowledge base, the appropriability and cumulativeness conditions, and the technological opportunities in each sector. The second dimension concerns the actors and their networking relationships, that define how cooperation is realized by different organisations such as firms and universities, users and suppliers, individual entrepreneurs and finance, R&D institutes and government agencies, etc. The third dimension refers to the institutional framework and the impact of specific common habits of thought, norms, standards and laws. Although the sectoral systems of innovation perspective argues that these factors make the structure and boundaries of sectors endogenous, questions still remain as to what should exactly be meant by ‘sector’. In particular, if we are not talking about industries (say at the four digit ISIC or NACE level), how can we identify and distinguish between sets of activities that are linked by a shared technological regime, a common institutional mould and a set of related users’ needs?

The sectoral perspective also complements and challenges the ‘national systems’ perspective both downwards and upwards. On one hand, it is clear that sectoral systems transcend national borders, so that these can be seen as international technological and institutional systems. On the other hand, one could expect that different sectoral systems would somehow connect within national or regional boundaries. While these patterns have not been fully explained yet, the insights of the sectoral systems approach are sufficiently compelling so as to advocate the need for linking different policy levels that affect innovative activity and outcomes in different branches of the economy.

The impacts of innovation at the macroeconomic level

The paper has so far focused on the micro, systemic and meso levels of analysis. What are the impacts of innovation in terms of macroeconomic growth? How do innovation studies explain the persistent differences in rates and levels of economic growth and employment between different countries? This section considers these questions by presenting some of the main recent advances and future challenges in the huge literature on macroeconomic growth, catching up, and employment.

Taking into account the criticism to the neoclassical theory of growth (Solow 1956), the 'new growth theory' (Romer 1986, 1990, Grossman and Helpman 1991, Aghion and Howitt 1992) made an attempt to improve the old perspective by building up more realistic models of innovation-driven endogenous growth. In all of these models, technical change is seen as the outcome of deliberate efforts by profit-maximizing firms, and macroeconomic growth is thus mainly the result of the resources devoted to R&D activities and of the degree of appropriability of the innovative rents.

However, from the point of view of most scholars of innovation, new growth models do not represent in a realistic way the evolution of an economic world characterized by complex evolving knowledge, bounded rational agents and radical uncertainty (Verspagen and Louca 2004). What is necessary for a deeper understanding of the impacts of innovation on macroeconomic growth is a neo-Schumpeterian (or evolutionary) approach (Dosi 1982, Freeman et al. 1982, Nelson and Winter 1982).

The Neo-Schumpeterian approach

In this alternative theoretical approach to the study of macroeconomic phenomena, the focus of the research is on the discontinuities and disequilibriating effects brought by clustering of

radical innovations, which may be so strong and so pervasive to spread through the whole economy and sustain economic growth for a long period of time (Verspagen and Louca 2004). This neo-Schumpeterian approach to economic growth was inspired by Schumpeter's book *Business cycles* (1939), in which the author put forward a theory about the existence and cause of long waves of economic growth. His original point was to focus on the importance of basic or radical innovations in creating such long waves, because, he argued, they have potentially a deep impact on the whole economy.

The Schumpeterian insights on the central role of radical innovations in the macroeconomic growth process did not affect significantly the development of economic thought in the following four decades. Since the mid-1970s, however, there started to be greater criticism of the way in which mainstream economics approached the relationships between technical change and economic growth, and a renewed interest in the central role of innovation as a way to promote economic growth and welfare. This neo-Schumpeterian literature started with the publication of the book *Unemployment and Technical Innovation* (Freeman, Clark and Soete 1982), and was then followed by the works of Freeman (1983, 1984, 1987), Perez (1983, 1985), and more recently Freeman and Louca (2001). It provides a number of interesting concepts and ideas to describe macroeconomic growth as an ever-changing disequilibrium process. This view, therefore, is strictly interrelated and complementary to the evolutionary-systemic perspective that has been outlined in the previous sections for the micro and meso levels of analysis, although a consistent and complete theoretical and analytical framework linking the different levels of aggregation is still missing.[9]

As Carlota Perez (1983) points out, in Schumpeter's theory the social conditions and institutional framework are excluded from the causation mechanism that drives the rise and fall of long waves, and this is the reason why she states that "Schumpeter does lay the

foundations for a theory of the cyclical nature of the capitalist economy but not of long waves" (Perez 1983: 359). Starting from these considerations, neo-Schumpeterian authors see the capitalist system as formed by two related sub-systems: the 'techno-economic' and the 'socio-institutional'. It is the joint evolution of these sub-systems to determine the 'mode of development', and consequently the rise and fall of long waves.

According to this view, it is not important *when* a set of basic innovations is introduced, but rather that these radical innovations are strictly interrelated and pervasive, that is they may be applied in many fast growing sectors in the economy. Such a family of interrelated basic innovations may be called 'technological system' (Freeman et alia 1982), or 'technological paradigm' (Dosi 1982), or 'technological style' (Perez 1983). When a new technological style arises, there is a big impulse in the techno-economic sub-system to adopt the new best practice technology with high profit prospects. However, the techno-economic system tends to be more ready to accept and adopt changes, while the socio-institutional one may take some time before making the changes required by the new technological style. This mismatch between the two subsystems may retard the large-scale introduction of the new paradigm, just because some social, organizational and institutional changes are necessary before it can diffuse to the whole economy. As the socio-institutional system evolves, the 'harmonic complementarity' between the two systems is restored, and a new 'mode of development' sets in. This determines a long wave pattern very similar to the business cycle described by Schumpeter (1939): rapid diffusion of the new paradigm, incremental innovation over its 'natural trajectory' (Nelson and Winter 1977), upswing and prosperity, creative destruction, increased competition and market saturation, decline of profits, recession and depression.

Evolutionary scholars (Silverberg and Lehnert 1994, Silverberg and Verspagen 1994a, 1994b, 1995, 1996) have recently started to build up 'formal' models with the aim of

reproducing some of the insights of the 'appreciative' neo-Schumpeterian theory. In the attempt to formalize neo-Schumpeterian long wave patterns, there are two main challenges for future research. First, it is necessary to further investigate the microeconomic process that can explain the co-evolution between technological and socio-institutional changes at the macroeconomic level. In fact, while institutional and organizational changes are often regarded as fundamental elements of an evolutionary approach, a consistent theory linking individuals' habits of thought and organizational routines to aggregate institutions is still missing. Second, it would be important to study the conditions that may explain the co-existence of incremental changes and 'gradualist' dynamics (typical of Nelson and Winter-like evolutionary models) with radical innovations and 'saltationist' patterns (characterizing neo-Schumpeterian theory).

Why do growth rates differ?

A complementary stream of the literature considers in further detail why the macroeconomic impacts of innovation are often uneven between different countries (Fagerberg and Godinho 2004). Economic historians have long ago observed that many follower countries have been able to grow faster than the more advanced countries (what is usually referred to as 'catching-up') by imitating and using the technologies developed in more advanced countries. In historical perspective, the international diffusion of knowledge and technologies has been an important source of rapid economic growth for many follower countries. However, such catching-up process is not at all a necessary and natural result of industrialization, and since the Industrial Revolution many countries have not been able to grow faster than the leaders (i.e., they have been 'falling behind'). The lessons from the last two centuries of economic history may have a tremendous importance for understanding the patterns that we observe today.

Originating from some historically oriented studies on the experience of catching up and overtaking of some advanced countries in the last two centuries (Veblen 1915, Gerschenkron 1962, Habakkuk 1962, Landes 1969, Abramovitz 1986, 1994, Freeman 1987, Odagiri 1997), the modern strand of 'technology-gap' theory has developed since 1980s. The (mainly applied) works in this tradition explain differences in economic growth rates and trade performance by using indicators of national technological activities, such as R&D and patent statistics.[10] The strong correlations generally found between technological factors, national competitiveness and macroeconomic performances (Fagerberg 1987, 1988, Dosi, Pavitt and Soete 1990) were then interpreted as an indication that international trade and economic growth follow disequilibrium and discontinuous paths, whose main determinants are the creation and diffusion of technologically advanced processes and products (Cantwell 2004).

As developed by Cornwall (1977), Abramovitz (1986, 1994), Fagerberg (1987, 1988, 1994) and Verspagen (1991), the main idea of the technology-gap approach is that innovation and international diffusion of new technologies are the main sources of differential growth between countries. Follower countries have a 'technology-gap' or 'technological distance' from the leader country, and they can therefore exploit their backward position to imitate and use advanced technologies developed by the leader, instead of creating them.

However, the process of imitation and diffusion of new technologies is costly, it requires the existence of social and institutional capabilities that not all of the follower countries have. This explains why catching up and convergence are not automatic and common outcomes, but rather uncertain and uncommon ones. In particular, Abramovitz (1994) has pointed out that countries differ with regard to their 'technological congruence' and their 'social capability'. Such techno-economic and socio-institutional factors differ between countries in each technological paradigm, and these structural differences explain

why some countries manage to successfully catch up with the technological leader, while some others fall behind in the long run.

The main result in this mainly applied and empirically oriented literature is therefore that 'convergence' towards the same level of GDP per capita is not at all an automatic and necessary consequence of the process of technological development (Cappelen et al. 2003). Countries' capabilities to create and imitate new technologies differ in terms of structural and institutional characteristics, and these national factors are often hard to change over time, so that falling behind and stagnation in the long run is a common possibility that must be seriously taken into account.

Recently, other evolutionary scholars have started to address the old question as to 'why growth rates differ' between countries in the long run (Verspagen 1993, Chiaromonte and Dosi 1993, Dosi and Fabiani 1994, Dosi et al. 1994). The purpose of these recent works is to build up evolutionary microfounded models able to reproduce some of the macro stylized facts on catching up and falling behind, convergence and divergence, so to bridge the gap with the appreciative technology-gap studies. Trying to give evolutionary microfoundations and more analytical rigour to such applied technology-gap studies, the challenge ahead for evolutionary scholars is recognised by Dosi (1997: 1544), according to which "there is a long way to go in order to incorporate path-dependent learning, micro heterogeneity, out-of-equilibrium inteactions, etc. into a robust aggregate story of trade, growth, international convergence, divergence, forging ahead and falling behind".

Innovation and employment

What are the implications of these evolutionary theories of innovation and growth for the understanding of the employment performance of different countries? Unemployment is currently an important concern for policy makers in many middle-income and more advanced

countries. In the last two decades, in fact, the traditional idea that macroeconomic growth necessarily implies positive employment performance has been challenged by recent trends. Many countries, especially in Europe, have associated high rates of economic growth with high and persisting levels of unemployment.

In innovation studies, this phenomenon of 'jobless growth' has been analysed in terms of the complex relationships between technology, growth and employment (Pianta 2004). According to this view, the obvious starting point is that technological change has an immediate negative effect on the demand for labour, because firms need to employ less workers to produce the same amount of output. However, there exist important indirect forces, which tend to compensate this initial displacement of labour resources. Thus, 'technological unemployment' occurs if the displacement of labour caused by the introduction of an innovation (new technologies in the production process, or new products brought to the market) is not fully compensated in the long run by market forces, the so called 'compensation mechanisms' (Vivarelli 1995, Pianta and Vivarelli 1999).

Following the insights given by classical authors such as Ricardo, Marx and Schumpeter, such compensation mechanisms may operate in several different ways. The main channels of indirect job creations are the construction of new machines, the decrease in prices of the final products, new investments, a possible decrease in wages, the additional incomes brought by the innovative rents, and the creation of new products and markets. The overall effect of such compensation mechanisms (through changes in aggregate demand) determines the final outcome in terms of employment. In general terms, the employment impact of innovation is better the higher the pace of introduction of new products, the investments in new markets, and the decrease of prices which lead to higher consumption and demand (Pianta, 2004). The relationship between technological development and jobs creation, however, is not necessarily positive, as commonly assumed by neoclassical labour

economists. ‘Technological unemployment’ appears to be a rather frequent outcome, as it has been the case for many European countries in the last two decades.

In order to study the functioning of compensation mechanisms, two important qualifications are often made by evolutionary scholars. First, innovation is a complex and differentiated process, and its employment impacts can only be analysed by clearly distinguishing between product and process innovations, and between technological and organisational changes. Product and process innovations, in particular, tend to have diverging effects on the patterns of labour creation, and traditional measures of innovative activity, such as R&D and patents indicators, are not able to take these effects into account. Recently, the increasing availability of data based on innovation surveys (such as the Community Innovation Surveys in Europe) appears as a promising step in the direction of drawing a more precise picture of the employment impacts of innovative activities carried out by private firms.

Second, it is often stressed in the literature that the analysis of the relationships between innovation and employment cannot be done on *a priori* ground, but has to consider the role jointly played by a set of structural and institutional factors in a long term perspective. These nation-specific factors include the institutions of the labour market, the organization and strategies of firms, their innovative capabilities, the national systems of innovation, the international regime, various State interventions at the industrial and macroeconomic level, and the dynamics of aggregate demand. These factors persistently differ between countries, and they strongly affect the interaction between the dynamics of aggregate production and productivity, thus determining the effectiveness of such compensation mechanisms and the consequent trends of employment. In other words, compensation mechanisms are just the final outcome of a complex process of interaction between the dynamics of demand and the dynamics of technical change over time. Only a

good match between the patterns of aggregate demand, the creation of new products and processes, and various national institutions may ensure a sustained period of economic growth and positive performance of aggregate employment.

On the whole, although technological unemployment is currently an important concern for policy makers in many industrialized countries, the unemployment issue has so far been investigated only by a relatively small number of innovation scholars. This is especially true when the literature on innovation and employment is compared with the other research traditions discussed so far, where the economic impacts of innovation have almost exclusively been analysed in terms of productivity and GDP per capita growth. The rapid development of evolutionary theories of economic growth, in fact, has not been accompanied by equally rapid advances of evolutionary theories of employment. The key concepts of the evolutionary economic approach (heterogeneity and systemic interactions, selection and competition, radical and incremental innovations, technological paradigms and trajectories, long waves and catching-up) have seldom been used to investigate employment trends. The main challenge ahead is then to search for a more systematic application of evolutionary theories and concepts to the domain of labour economics, and for a stronger cross-fertilization between evolutionary studies of long run growth, catching up and technological unemployment.

Challenges and perspectives

The previous sections have outlined recent advances and future challenges in four branches of innovation studies. The paper has so far discussed separately the developments and perspectives of the research at different levels of analysis. The present section takes a broader

perspective by pointing to the main theoretical and methodological challenges common to the whole field.

Topics for future research

(*i) 'Co-evolutionary' change*: scholars of innovation increasingly argue that technological change cannot be properly understood without studying the supporting institutions and their evolution over time. This is an important point stressed by evolutionary studies at all levels of analysis previously considered, the innovative firm, innovation systems, sectoral patterns and macroeconomic growth. In this view, economic change must then be conceived as a 'co-evolutionary' process in which technological and institutional transformations go hand in hand.

However, the 'co-evolution' between technological and institutional changes (Dosi and Winter 2000) is often mentioned but not systematically analysed yet. Why? As Nelson puts it:

> Undoubtedly part of the problem reflects the still primitive state of our ability to work with cultural evolutionary theories. In this particular case I am sure it also stems from an overly broad and vague concept of the variable in question -institutions- which is defined so as to cover an extraordinarily diverse set of things. Before we make more headway in understanding how 'institutions' evolve we may have to unpack and drastically disaggregate the concept. But our difficulty also may signal the limits of the power of economics or social science theory more generally to comprehend a set of processes as complex as those behind economic growth as we have known it (Nelson 1995: 83-84).

This is the prevailing point of view among evolutionary scholars of technological innovation. However, another important strand of evolutionary research, mostly inspired by Veblen and other old American institutionalists, gives a more prominent role to the study of

institutional change.[11] The links between the two approaches, evolutionary studies of technological *and* of institutional change, have not systematically been explored yet. A closer connection between the two could in the future improve our understanding of the complex mechanisms behind the co-evolution between technological and institutional changes.

In this respect, innovation studies must be based on the fact that institutional inertia and institutional changes are both coexisting aspects of the interactions of economic agents. Not only do institutions constitute the *given structure* that supports and bounds economic actors' innovative behaviour, they are in turn a product of agents' creativity and interactions. In the same way as organisational 'routines' are the basic unit of analysis to study technological changes, Hodgson (1998) suggests that individuals' 'habits of thought' may constitute the adequate unit of analysis in order to investigate institutional transformations. The challenge ahead is therefore to explore why institutional rigidities tend to prevail over change in some historical and geographical situations, while rapid institutional transformations overcome inertia in others. In this respect, it is clear that the development of a co-evolutionary theory of technological and institutional change will only be possible through a closer interaction with other research fields outside the economic domain, particularly business and organization studies, economic sociology, political science and economic history.

(ii) Demand: following the original insights given by Schumpeter in his *Theory of Economic Development* (1934) on the importance of entrepreneurs in creating 'new combinations', innovation studies have mainly adopted a supply-side point of view, and the focus has so far been almost exclusively on the innovative behaviour of private firms and public organisations. Nevertheless, the importance of demand at all levels of analysis is increasingly recognized (Redmond 2003, Malerba 2004, Pianta 2004). From the microeconomic point of

view, demand may constitute an important incentive or constraint in shaping the innovative activity carried out by private firms, but at the same time it defines the range of new technological solutions and products which can be successfully brought to the market. The microeconomic literature, moreover, shows rapid advances in the theory of the innovative firm, but less systematic attempts to build up a theory of the 'innovative consumer', which in the future will necessarily have to complement the supply-side studies of innovation (Redmond 2003).

The same is true in other branches of innovation studies. In the systems of innovation framework, the interactions between producers and users of new technologies are fundamental, so that the systemic approach will necessarily have to consider in greater details the role of users and consumers. Demand is also important to study the impacts of innovation at the sectoral and aggregate levels, in terms of sectoral patterns (Malerba 2004), macroeconomic growth (Verspagen and Louca 2004), catching-up (Fagerberg and Godinho 2004), and employment (Pianta 2004). The investigation of demand and consumers' behaviour, on the whole, appears as a very challenging issue for future research on innovation.

(iii) Welfare and development issues: innovation studies have so far neglected important ethical aspects of individual and collective welfare. In fact, while it is widely accepted that a good innovative performance is the primary factor to reach higher economic growth and material welfare, less often is it considered that technological, organizational and institutional changes may sometimes have perverse and negative impacts. In particular, scholars of innovation have so far focused on some of the main economic impacts of innovation, such as competitiveness, GDP per capita and productivity growth, catching-up and convergence, and

employment trends. Similarly to what is commonly assumed in mainstream economics, these are the only factors that are implicitly assumed to (positively) affect economic welfare.

Other important impacts, on the other hand, have so far been neglected. It would be desirable in the future to initiate a discussion of the other economic and non-economic impacts of innovation that may have tremendous importance for individual and collective welfare. In this respect, important questions arise: what are the effects of innovation on the *quality* of employment, in terms of changes in skills, competencies, and wage structure? What are the effects, more generally, on the distribution of income? What are the implications in terms of environmental and social sustainability?

Moreover, scholars of innovation have mainly adopted the point of view of advanced and fast catching up countries (United States, Europe, Japan and other advanced Asian economies), and much less that of low income economies. What are the opportunities for less developed countries to exploit the possibilities offered by the new technologies developed in the advanced countries? More generally, what are the insights that development studies could gain from adopting an evolutionary perspective on innovation and economic growth?

Methodological challenges

(i) 'Non-reductionism': it emerges from the review presented in the previous sections that the research on innovation at different levels of aggregation has been carried out by *distinct* groups of scholars. Studies on innovative firms, systems of innovation, sectoral patterns and macroeconomic impacts have been carried out, with a few exceptions, by distinct groups of scholars, and the links between theoretical and empirical results obtained at different levels of analysis have been seldom explored. Nonetheless, most of the innovation studies considered in this paper have in common a broad evolutionary understanding of the process of economic change, and they tend to apply similar concepts and methods at different levels

of analysis. So, although the connections between the study of the organizational, systemic, sectoral and macroeconomic levels have not been systematically explored yet, there is a strong potential for such a future integration. According to Metcalfe (2001), a consistent framework linking together theories, methods and empirical results at different levels of analysis may in the future lead towards a theory of 'general economic evolution'.

In this respect, what is needed is a 'non-reductionist' theory of innovation and economic growth, in which the different levels of analysis may coexist and interact (Hodgson 1993, 1998). A non-reductionist theory is one in which economic change is explained by the co-evolutionary process of transformation at different levels of analysis, such as individuals, firms, systems, sectors, and countries. No unit of analysis must be predominant over the others, and this has a twofold implication. On the one hand, it is important to investigate the microfounded evolutionary process that generates given sectoral and macroeconomic patterns; this seems to be the current trend in recent evolutionary models, as previously outlined in the third and fourth sections. On the other, it is fundamental to specify how individuals' habits of thought and organizational routines, in turn, are shaped and affected by the sectoral and aggregate economic and socio-institutional structures. So far, the micro → macro causation mechanism has certainly been investigated much more than the macro → micro one. The whole field of innovation studies would greatly benefit from using multiple levels of analysis, and from systematically exploring their interactions and connections.

(ii) Interdisciplinarity: the co-evolutionary analysis of technological and institutional changes cannot be done in terms of purely economic incentives, opportunities and constraints. In an appraisal of recent developments in evolutionary economics, Nelson and Winter (2002: 42) conclude: "the citations to our 1982 book suggest that the evolutionary approach has had broad appeal to a wide range of scholars from a variety of different disciplines [...].

Evolutionary economics therefore has open frontiers, lives with other disciplines in what is recognizably the same intellectual world and has much to offer and to gain from trade".

Compared to mainstream economic analyses of innovation, interdisciplinarity is certainly an important methodological novelty of evolutionary studies. Here again, however, the methodological novelty is increasingly mentioned by innovation scholars, but not systematically applied yet in their works. Therefore, the interactions and collaborations between economists of innovation with researchers in other disciplines in social sciences should in the future be even stronger than has been the case so far. There are two main reasons for this.

First, at the microeconomic level, in order to understand how incremental changes (learning) and radical inventions may coexist in individual minds and organizational routines, a theory of innovation needs to be more strongly interdisciplinary than it is at present. Cognitive psychology should shed some light on the mechanisms of human cognition, learning, and the formation of routines and individuals' thought processes (Stein 1997); while organization and business studies could improve our understanding of the collective and interactional aspects of innovation within and between organizations. Second, at the macroeconomic level, advances in our understanding of the co-evolution between technological and institutional changes will only be possible by looking outside the economic domain, particularly at economic sociology, political science and economic history.

Insights coming from other disciplines should enable evolutionary scholars to investigate the individual and aggregate conditions (psychological, social, political and cultural, rather than just economic) in which radical innovations and rapid institutional changes tend to prevail over gradual incremental change and institutional inertia; and the geographical and historical situations in which, on the other hand, individual and collective behaviour tend to favour inertia, rigidities and the status quo.

(iii) Contingent explanations vs. general results: criticising the abstract and highly formalized character of analytical models built up by new growth theorists, evolutionary scholars of innovation have made use of a wider range of methods. Innovation studies have been carried out by using both qualitative methods of research, such as case studies, and quantitative techniques, such as econometric and analytical models. On the one hand, case studies provide a detailed understanding of the evolution of a particular firm/sector/country, but the results coming from a specific case can hardly be generalized to others (Nelson 1995, Verspagen and Louca 2004). On the other hand, econometric and analytical models seek more general results valid for a large sample of statistical units (firms/sectors/regions), but the process behind each units' performance remains unexplained. The co-existence of contingent explanations and general analytical results is another important methodological novelty that innovation studies have the potential to bring. A stronger connection between the two complementary methods could lead to important advances in our understanding of economic evolution, but it has not been fully realized yet. How could this be achieved in the future?

The generalization of the recent class of 'history-friendly models' (Malerba et al. 1999) could constitute a promising step in this direction. History-friendly models start with an accurate description and empirical study of the evolution of a particular sector (e.g. the computer industry), and then try to reproduce it through the use of an analytical model solved by computer simulations. The same methodology could in the future be extended to other sectors of the economy, and possibly be used to reproduce the evolution of aggregate trends in national economic growth in the long run for the main industrialized countries.

The advantage of this new class of models is the attempt to bridge the gap between qualitative case studies and analytical-econometric works. However, the risk is that it is

difficult to compare models and outcomes obtained from different sectoral (or national) studies, so that history-friendly modellers should make a clear distinction between systematic and contingent factors which may explain particular historical trends (Silverberg and Verspagen 2003). In this respect, computer simulations are a flexible tool through which it is possible to do both things, to reproduce a given historical path, and to explore the effects of variations in the model's parameters on the observed trend. A systematic comparative analysis of sectors (countries) could be carried out by using history-friendly models for different sectors (countries), so that general analytical results could be compared to historically-specific descriptions.

Concluding remarks

This article discusses some of the main advances and challenges for future research in innovation studies. A convenient way to organize the discussion has been to consider the main contributions in the literature by dividing them according to their level of analysis. The first section has considered the theory of innovation at the organizational level, and it has pointed to the need that an evolutionary microeconomic theory of innovation develop in strict connection and closer interaction with other disciplines outside the economic domain, such as cognitive psychology, business and organizational studies.

The complexity of the innovative process at the organizational level calls for a systemic approach to the study of innovation, which has been presented in the second section. Scholars in the NIS tradition need to face three main challenges: (i) the development of more advanced data and indicators, in order to carry out more systematic cross-country empirical analyses; (ii) the search for a more precise analytical framework linking the economic actors

to the socio-institutional structure; (iii) the identification of system boundaries in an era in which economic globalisation makes national borders less relevant.

The complexity of the innovative process, moreover, makes the patterns and effects of innovative activity rather heterogeneous in different sectors of the economy. Thus, the third section has discussed the major contemporary debates over 'how innovation differs' at the meso level. The sectoral perspective points to important problems of definitions, boundaries and measurement, such as the distinction between high-tech and low-tech industries, and between manufacturing and services. However, such difficulties should not obscure the fact that important advances have been recently obtained, particularly through the study of 'sectoral systems' and 'history-friendly models'.

The next section considered the impacts of innovation at the macroeconomic level. In this field, the recent trend is to try to reproduce the main stylized facts of macroeconomic growth and catching-up as 'emergent properties' of microfounded evolutionary models. The purpose of such modelling exercises is to bridge the gap between the modern strand of evolutionary theorizing and other complementary perspectives, such as the 'appreciative' neo-Schumpeterian theory of long waves, and the historically-oriented applied studies of technology-gap, catching-up and falling behind. The links between evolutionary theories and the literature on technological unemployment, on the other hand, have not been explored yet, and mark an important field for future research.

Finally, the fifth section has adopted a broader perspective by pointing to the main neglected topics and methodological challenges common to the whole field. At all levels of analysis important issues are still unexplored, such as the co-evolution of technological and institutional change, the role of demand, and the implications of innovation in terms of individual and collective welfare. There are also important methodological challenges ahead, such as the need for more interactions between the different levels of analysis; the importance

of interdisciplinary analysis of technological and institutional changes; and the search for a combination of contingent explanations based on case studies with general analytical results based on econometric and formal models. On the whole, in pointing to all of those theoretical and methodological challenges for future research, our intention has not been to obscure the great advances obtained in the recent past, but rather to focus on the ones to come in the future.

Endnotes

[1] Recognising the importance of this problem, the European Commission is currently funding the TEARI Project ("Towards an European Area of Research and Innovation"), whose purpose is to bring together some of the leading scholars in this field to discuss the main advances obtained so far and the challenges for future research. The main contribution of the TEARI Project is the publication of a *Handbook of Innovation* edited by Jan Fagerberg, David Mowery and Richard Nelson (forthcoming in 2004), that will bring together the main analytical results, concepts and empirical insights existing at present in innovation studies. The present article draws extensively on the chapters of the forthcoming *Handbook of Innovation*, whose drafts have been presented at the TEARI workshop in Lisbon, November 2002, and at the TEARI workshop in Roermond, June 2003. We would like to thank all the participants to these workshops, and particularly Jan Fagerberg, Ove Granstand, Bengt Åke Lundvall and Richard Nelson, for helpful comments and suggestions on a previous draft of the paper. We are also grateful for the comments received from two anonymous referees of this *Journal*. The usual disclaimers apply.

[2] In this *Journal*, Pitelis (1998) has discussed the relationships between evolutionary theories of the firm and transaction costs economics; and Hunt (1997) has interpreted resource-advantage theories from an evolutionary perspective.

[3] Tacit knowledge may be defined as things that you know and thus can act upon, but that you cannot express verbally. An example of tacit knowledge is for example the ability to ride a bike (Polanyi 1958).

[4] The concept of innovation systems has been used by different scholars to analyse innovation processes at different levels of aggregation. The most notable contributions have been in the literature on national innovation systems (NIS) (Freeman 1987, Lundvall 1992, Nelson 1993, Edquist 1997), regional innovation systems (RIS) (Cooke 1992, Braczyk et al. 1998), sectoral innovation systems (SIS) (Breschi and Malerba 1997, Malerba 2002, 2004), as well as the technological systems approach (Carlsson and Stankiewicz, 1995).

[5] According to Mowery, there is so far no unambiguous evidence of increased economic growth resulting from the Bayh-Dole act, perhaps with the only exception of the bio-medical sector. Mowery explains this with reference to the linear understanding of innovation processes embedded in the act, and he therefore concludes that there is currently no rationale for other countries to emulate the Bayh-Dole act as a policy instrument.

[6] Alfred Marshall, in his 1890 *Principles of Economics*, observed and discussed the agglomeration of small firms in what he referred to as "industrial districts".

[7] Amin (1994) distinguishes between three different 'post-fordist' approaches: (i) the regulation approach, which focuses on the the dynamics of capitalism as a whole; (ii) the neo-Schumpeterian approach, studying industrial and technological paradigms; (iii) the flexible specialisation approach, which focuses on learning economies. We refer here to the latter approach, which argues that in the current economy there has been a transition from unskilled fordist mass production to the skilled customised production of flexible specialisation (Piore and Sabel 1984).

[8] The recent technological and institutional developments in the telecommunications sector, in particular, have been extensively discussed in this *Journal* (Miller 1996, Mansell 1997, Bauer 1997).

[9] Ohara (1994) and Tylecote (1994) discuss long wave theory from an institutionalist perspective.

[10] Mazzoleni and Nelson (1998) discuss the advantages and problems related to the use of patents as an indicator of technological activities and capabilities.

[11] For a critical review of the way in which American institutionalism deals with technological change, see in this *Journal* Brinkman (1997) and Wisman and Smith (1999).

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