An introductory overview of innovation studies

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1. Introduction

The purpose of this paper is to provide a broad overview of the field of innovation studies. We focus on the the economics and sociology of innovation, which we can define as the study of the dynamic processes of generation, development, adoption ad diffusion of innovations in the economic and social system, as well as the characteristics of such processes and their effects on society and the economy. In order to present the many, complex and sometimes overlapping strands of research on innovation, we have chosen a disciplinary criterion. We have therefore identified several different theoretical perspectives on innovation and within each one we have tried to unravel the main issues that are being investigated. However, any attempt to categorise and streamline such a complex topic does, to some exent, introduce arbitrary distinctions in the analysis. In the last section, we explicitly focus on trying to re-estabilish some connections between different perspectives, and we try to uncover some general trends in innovation studies. Innovation studies are a wide and fragmented topic[1] and they are "work in progress": this survey, therefore, cannot pretend to be exhaustive nor completely consistent.

1.1 Definitions

The famous definition of innovation provided by Schumpeter in his "Theory of Economic Development" (1934) still constitutes a fundamental reference for contemporary innovation studies. Schumpeter focused on innovations as "new combinations" of production factors - namely, the

[1] According to Sahal (1981): "Traditionally, the subject of technological innovation...has existed in the shadow of other disciplines...on the one hand [this] has led to a field of enquiry that is uniquely rich in the diversity of viewpoints. On the other hand, it is singularly lacking in terms of a set of comprehensive, well integrated themes."

production of new goods, the introduction of new processes, the opening of new markets, the access to new sources of raw materials and intermediates, the re-organization of an industry. Contemporary definitions are often based on Schumpeter's approach. For example, Malerba (2000) defines "invention" as a new idea, a new scientific discovery or a technological novelty which has not yet been implemented technically and commercially, whereas "innovation" is defined as the instantiation of the invention in a new product or production process and its commercial exploitation – bearing in mind that many innovations consist of new combinations of existing knowledge, or can involve new organizational forms, the fulfillment of new demand on the part of existing products, the opening of new markets. A widely used dicotomy distinguishes between "product innovation" and "process innovation". The former defines the design, introduction and diffusion of a new product, the latter the development, introduction and diffusion of a new production process. This dicotomy is conceptually useful although in practice the two concepts are often related: for instance, a product innovation for one firm can become a process innovation for another, if the latter buys the product of the former in order to use it in its production processes (Stoneman, 1995); or it can be difficult to distinguish between them, for instance when the firm produces services rather than tangible artifacts. Another common dicotomy distingushes radical from incremental innovation. Incremental innovations are improvements of existing products, processes or services, within the context of a dominant design, product architecture or existing demand. Radical innovations, on the other hand, involve a radical break from existing products and processes and often open up new industries and new markets. Radical and incremental innovations can be seen as extreme archetypes, but in practice it may be difficult to distinguish them. Often a distinction can only be made ex-post, since the impact that an innovation has on the economic system generally cannot be known ex-ante, and since all innovations, even radical ones, build to some extent on the existing knowledge base. There are also measurament issues[2].

Recent contributions, especially from the field of organization studies, emphasise the cognitive nature of innovation, which is seen as the introduction of new knowledge in the economy, or as the new combination of existing knowledge (Edquist and Johnson, 1997). When innovation is conceived as new knowledge, the definition becomes broader: the creation of new knowledge is not limited to the design and production phases of a new process or product, but it involves all stages of the chain: for instance, new knowledge can be created also when users adopt a technology or when a technology is imitated by a rival firm. What is knowledge and how such knowledge can be "new"

[2] See, for example, Grandstrand (1994) for an attempt to define a cardinal measure of radical and incremental innovation.

(with respect to what) are all issues that need to be clarified in order for the concept to be operational and analytically useful. Some studies linking innovation and knowledge are surveyed in section 2.5.

Because of its generality, "innovation" is a concept that can be interpreted in numerous ways; consequently, the proxies used in the attempt to find empirical measuraments for innovation are so many and so varied that what is labelled and measured as "innovation" are often very different phenomena, as we discuss in section 2.2. A deeper exploration of the concepts of "invention", "innovation", "technological change" and the like would help overcome many problems and promote the use of a common lexicon among innovation researchers.

2. Innovation and economics

2.1 Neoclassical economics

In neoclassical economics[3], the technology used by the firm is incorporated in the production function, where each combination of input quantities (usually capital and labor) is associated to a corresponding quantity of output. Innovation consists of changes in the production processes of the firm. Neoclassical theory, therefore, is only concerned with process innovations, technical and/or organizational. Firms innovate, in this narrow sense, as a reaction to changes in factor prices: if the cost of a given input changes, the firm resorts to technical or organizational changes in order to economise on the most expensive input, and thus restore the equilibrium (it moves along the isoquant towards a new optimal combination of production factors)[4]. Firms also innovate when new techniques that allow for the production of a larger quantity of output with the same input quantities become exogenously available, and the firm then moves on to a new isoquant. Innovation is thus identified either as factor substitution or as the arrival of new exogenous techniques that make the production process more efficient.

This view is consistent with the fact that neoclassical economists are far more interested in studying the mechanisms of resource allocation in the economy than the dynamic phenomena of discontinuity and change associated to technological innovation; therefore, they see innovation as a reaction to change that brings the system back to equilibrium. A sharp distinction is made between the economic and technical aspects of technological change (Sahal, 1981).

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[3] An extensive account of the neoclassical approach to technological change can be found in Stoneman (1983).

[4] According to this view, innovation is induced by changes in the prices of factors that are used in production, as well as by changes in prices of their immediate substitutes. Moreover, according to Hicks (1932), innovation is also induced by changes in the relative prices of these factors (Coombs, Saviotti and Walsh, 1987).

Neoclassical theory has often been criticised for its treatment of innovation. Some authors point out that the assertion that a firm can implement any optimal combination of input quantities, without taking into account technical constraints to production, is unrealistic (Rosenberg, 1994)[5]; others underline that neoclassical theorists completely neglect the characteristics of production processes and that they forget that innovation is not just about changes in production processes but it often involves the creation of new products (Russo, 1996).

We can highlight two main areas of research where neoclassical theory and innovation studies intersect. On the one hand, traditional microeconomics sees innovation as the application of new scientific and technological knowledge to existing production processes. The characteristics of these kinds of knowledge, therefore, have a direct bearing on firms' incentives to innovate. It has been shown that scientific and technological knowledge often has the character of a public good: it is non-rival and non-exclusive, and consequently it cannot be appropriated by agents who have invested resources in order to produce it. Knowledge-creating activities, such as R&D, are therefore prone to market failure, for various reasons: knowledge cannot be appropriated; these activities often involve high fixed costs; their results are uncertain (Geroski, 1995). This is certainly the case for scientific knowledge, in fact private investment for basic research is often lacking and public support becomes necessary (Stephan, 1996). However, also those forms of scientific-technological knowledge that are intermediate between basic research and implementation in a product can suffer from market failure, and for this reason the patent system has been put in place. Patenting grants the inventor exclusive rights on his own discoveries and gives him a return on the investment made in order to achieve them (Scherer, 1999). An extensive empirical literature has been developed around these themes, especially with regard to patents, knowledge spillovers and the social and private returns to innovation.

On the other hand, in macroeconomics, innovation has been modelled as one of the determinants of economic growth[6]. Interest for the possible macroeconomic effects of technical change began in the 1950s, following an article by Robert Solow (1957) in which the author showed how, within a relatively simple neoclassical model, a stable pattern of growth could be obtained when the rate of demographic growth and the rate of capital productivity growth were positive. A positive rate of

[5] Rosenberg adds that, even if we considered the isoquant as the representation of all the technological options that are made possibile by the current state of scientific knowledge, as was suggested by Salter (1960), acquiring information about all these options would be extremely expensive for the firm, so, realistically, there is always a limited number of alternative technologies that the firm can choose from.

[6] Economic growth theories consititute a vast body of work; recent surveys can be found in Solow (1994) and Grossman and Helpmann (1994).

capital productivity growth was then ascribed to technical change, taken as an exogenous variable. This meant that in Solow's model economic growth itself was exogenous (Freeman and Soete, 1997). From the mid-1980s economists began to work on models in which the determinants of growth were treated as endogenous, the so-called "New Growth Theories". Romer (1986) and Lucas (1988) were the first to publish successful models of economic growth driven by endogenous forces: in Romer's work, the driving force was technological change, modelled as the result of private investment decisions; for Lucas, somewhat differently, the engine of growth was the accumulation of human capital. In a later article, Romer (1990) developed a model where growth was driven by knowledge spillovers in the economy: ideas are non-rival (the marginal cost of knowledge is zero) and partially exclusive, which means that there are increasing returns to the aggregate production function, which in turn drive growth. In the same model, Romer also suggested that the use of partially exclusive knowledge gives the innovator a limited monopoly power, which Romer assumed to be symmetric among all firms in order to preserve a competitive market structure, in a monopolistic competition framework. Models of growth based on monopolistic competition were also developed, at around the same time, by Grossman and Helpmann. In their model in each period a new generation technology is introduced that is more efficient than the previous one: the patent system gives the innovator an exclusive right to this innovation, so that he earns rents in competition with the producers of the previous generation technology. These rents accrue to the innovator until someone else introduces the next generation technology. Models such as this are called "neo-schumpeterian", with reference to the importance that Schumpeter accorded to temporary monopoly power as a factor that motivates businesses to introduce innovations.

In these models, innovation is crucial for economic growth. Recently, some attempts have been made to include more realistic hypoteses, such as the inherent uncertainty in the discovery of new technologies, the path dependent nature of technological change, the possibility of lock-in into inferior technologies, the presence of localised technical spillovers (see for instance Redding, 1999); other authors have developed growth models from an evolutionary perspective (Metcalfe, Fonseca and Ramlogan, 2000).

2.2 Empirical literature

A vast empirical literature on innovation has fluorished starting from the 1960s. Theoretical innovation studies were not very advanced at the time and failed to provide strong hypotheses for testing; given the brittle theoretical foundation of these empirical studies and the lack of consistent hypotheses, the often contradictory nature of their results is not surpirising (Cohen, 1995). Another general problem is the variability of the indexes used to measure phenomena like "innovation" and "innovativeness" which can be seen as yet another consequence of the lack of strong theoretical foundations.

In broad terms, most empirical studies on innovation have tried to identify which factors have an effect on the "innovativeness" of the firm. In particular, the importance of the following factors has been investigated: the appropriability of the returns accruing from invention and innovation; the existence of a demand for innovation; the characteristics of markets and firms. Another important line of work focuses on modeling the processes of adoption and diffusion of innovations in the economic system. We now briefly explore each of these issues in turn, bearing in mind that the empirical literature on innovation is a broad topic and many contributions, especially the most recent ones, do not fit simply into these categories.

The characteristics of the patent system affect the extent to which a firm can protect its returns from innovation; strong patent protection will probably encourage firms to invest in the development of innovations because they know they will be able to appropriate the returns accruing from them. The hypothesis to be tested, therefore, is that of a positive relationship between the degree of protection offered by the patent system and the firm's propensity to innovate. Empirical studies on patents have dealt with issues such as: the relationship between patent length and firms' innovation intensity; optimal patent length; the reasons for which firms choose to patent; patents' success in discouraging imitation. According to a critical survey by Geroski (1995), these studies show that, in general, patents' effectiveness in stimulating innovation depends on conditions such as the existence of a legal system capable to guarantee intellectual property rights, the nature of technology, the trasmissibility of knowledge, the presence of entry barriers to the market. In some industries, patent protection is not effective in stifling imitation, and other protection mechanisms such as trade secrecy and first-mover advantage are preferred (Klevorick, Levin, Nelson and Winter, 1987).

Another element that can affect firms' propensity to innovate is the presence of involuntary knowledge spillovers between competitors: these spillovers can be enhanced by factors such as the accessibility of technical information, the opportunity to perform "reverse engineering", the possibility to invent "around" a patent, and so on. Some empirical studies have tried to provide quantitative measures of knowledge spillovers in several industries (references in Geroski, 1995), others have tried to estimate knowledge spillovers between basic and applied research (Jaffe, 1989;

Mansfield, 1995; Narin, Hamilton and Olivastro, 1997), and numerous studies are trying to quantify the spillovers between localised firms in order to evaluate the importance of geographical proximity for innovation (Jaffe, Henderson and Trajtenberg, 1993; Henderson and Jaffe, 1999; see also Feldman, 1999, who provides a detailed survey of empirical research in the field).

Some authors have also attempted to quantify the share of the general "benefits" from innovation that accrues to society compared to that accruing to the innovator. The underlying idea is that the greater the private benefits to innovation, the greater the firm's propensity to innovate. Mansfield et al (1977) found that the extent to which an innovator can appropriate the benefits of his discovery depends on the characteristics of the technology in question. Cohen (1995), in a survey article, suggests that a general consensus on the direction of the relationship between appropriability of returns and innovation has not been reached: the results depend on which industries are being considered and on which indexes are used as proxies for the relevant variables.

From the mid-1960s, numerous studies have been carried out in order to test the importance of the demand for innovations as a determinant of firms' propensity to innovate. This "market pull" hypothesis was first put forward by Schmookler (1966) who suggested that the demand for new products determined the rate and direction of innovative activity. This early work was then followed by several empirical research projects that included demand among the possible determinants of innovation (see Mowery and Rosenberg, 1979, for a critical survey of the "market pull" empirical literature). On the other hand, "technology push" approaches emphasised the importance of technological opportunities as determinants of innovation, where the concept of "technological opportunities" was meant to involve a variety of phenomena such as: the possibility to turn scientific knowledge directly into new techniques; the presence of technological interdependencies that provide specific directions for research activities; the easy exploitation of technical knowledge spillovers coming from external sources like suppliers, customers, universities, etc. (Cohen, 1995). In the '60s and '70s the debate between "market pull" and "technology push" theories was particularly lively. In general, neither of the two approaches alone have stood up to empirical verification (Cohen, 1995; Coombs, Saviotti and Walsh, 1987). Technological opportunities and market signals are now interpreted as complementary, rather than alternative, incentives to innovation (Freeman and Soete, 1997).

Other empirical studies have tried to explore the relationships between the characteristics of firms and markets and innovation.

Numerous studies have tried to test the so-called “schumpeterian” hypothesis according to which large firms are more innovative than small ones. The hypothesis tested has often been that of a positive relationship between firm (or business unit) size and R&D expenditure. Cohen (1995), whose paper is an overview of the most relevant work in this area, points out that using R&D expenditure as a proxy for innovation is misleading because this expenditure is an input, not an output, of the innovation process; moreover, empirical results in general do not support the hypothesis that bigger size means more innovation. Recent works on the empirical relationship between firm size and innovation have shown that when organizational factors are included in the model, the significance of firm size in explaining innovation decreases considerably (Francois, Favre and Negassi, 2002).

Another line of work deals with the relationship between market structure and innovation. Initially, simple causal relationships between the two were investigated. Often the relationship under study was that between R&D expenditure (used as a proxy for innovation) and market concentration, but the results obtained were inconstistent. The effect of market concentration on innovative activity proved to be weak (Kamien and Schwartz, 1982); other studies (quoted in Coombs, 1988, and in Cohen, 1995) analysed causality in the opposite direction, that is, how innovation influences market structure. More realistic results were obtained when both market structure and innovation were treated as endogenous, co-determinant variables in the context of a model of industrial development (Levin, 1981; Connolly e Hirschey, 1984; Levin e Reiss, 1988). Recent studies support the view that the nature of the technology that firms use, the innovations they introduce (radical or incremental) and the structure of the market in which they operate, are all related and change over time, for instance with the level of “maturity” of the industry. A first importart contribution by Pavitt (1984) takes the nature of a firm’s technology into account in order to explain its innovativeness and its pattern of change over time. Some recent evolutionary literature, focusing on the industrial level, has tried to explain the different structures and different patterns of development associated with sectors that employ different technologies: Breschi, Malerba and Orsenigo (2000) explain what they call “schumpeterian patterns of innovation” on the basis of the technological regimes that characterise different industries.

Other empirical analyses have investigated possible relationships between innovation and qualitative features of the firms: generally, the characteristics explored are the firms’ cash flow (a measure of their financial stability) and their degree of product diversification, however the results obtained are once again inconclusive (see references in Cohen, 1995). Firms’ access to venture capital has also been studied as a factor that could promote innovation, in that it would allow for the development of small innovative firms and the funding of research in high-tech industries (Himmelberg and Petersen, 1994; Saxenian, 1994; Scherer, 1999).

Concerning innovation adoption and diffusion models[7], the first empirical studies on innovation diffusion appeared in the 1950s and since then their number has grown enormously – twenty years ago, Sahal counted more than 2000 (see Sahal, 1981). Surveys of these works can be found in Rogers and Shoemaker (1971) who deal mainly with sociological studies, and in Stoneman (1983) and Geroski (1995) who are looking instead at the economic literature.

Most empirical studies have shown that the diffusion pattern of a technology over time (representing the proportion of users who have already adopted the technology on the total number of potential users) is sigmoid; this is the cumulative density curve of a variable whose distribution is bell-shaped (Stoneman, 1983). Researchers have then proceeded to develop models which can provide theoretical explanations for the S-curve in its many empirically-observed forms. According to the taxonomy proposed by Karshenas and Stoneman (1995), innovation diffusion models can be classified as disequilibrium and equilibrium ones. The former assume that there exists a maximum level of technology utilization and they see the diffusion pattern as a disequilibrium approach to that point. Among these models, the first ones were epidemiological (Griliches, 1957): the spread of an innovation was supposed to follow the spread of information about it, which in turn followed a process similar to that of epidemic contagion. Mansfield (1968) built on this approach, suggesting that because new technologies are inherently uncertain for their potential users, there is often a time lag in the diffusion of innovations which decreases as the number of users who have already adopted them grows. Equilibrium models, on the other hand, assume perfect information on the users' part about the new technologies and their characteristics, and derive technological diffusion patterns. Probit models (David, 1969; Davies, 1979) consider adoption choices in a population of potential users, generally firms, which differ with respect to some important characteristic (firm size, age of installed capital or market power); other models are based on game theory (Reiganum, 1981). Stoneman (1983) underlines how probit models generally assume that large firms will be the first to adopt a new technology, whereas empirical studies have shown that smaller firms sometimes adopt faster (Oster, 1982). Other authors (for instance Ireland and Stoneman, 1983) have tried to insert in their models, in addition to demand-side conditions (among which they include users'

[7] With the term "diffusion" economists indicate the way in which the economic importance of a technology, in terms of market share or output share, changes in time, generally in relation to another technology whom it replaces. With the term "adoption", instead, they are looking at the individual decisions made by the agents who buy the technology, be

expectations about the new technology), also supply-side ones, such as producers'cost functions and market structure.

As Antonelli (1999) points out, for a long time innovation diffusion has been studied as a process where in each time period a "new generation" technology is introduced that is superior to the "current" one; an important step forward was made when scholars started modelling innovation diffusion as the outcome of a complex process in which several new technologies are introduced at the same time, the competition among them is intense, and the result depends on the individual characteristics of the micro-agents who decide which technology to adopt. Important contributions to to the analytical formulation of these phenomena have been offered by Brian Arthur and Paul David. They focused on technologies characterised by increasing returns to adoption, that is, technologies where the benefit that each user derives from adopting them increases with the number of users who have already adopted the same technology. Increasing returns are due to phenomena such as network externalities, technological complementarities, learning-by-using, learning-by-doing, and economies of scale in production (Antonelli, 1999). By studying the impact of individual adoption choices on the diffusion patterns of competing technologies, David and Arthur showed how, with increasing returns, the market inevitably ends up being dominated by one technology, and not necessarily by the best one; this outcome may be irreversible (lock-in phenomenon, Arthur, 1989); there are only short and uncertain "windows of time" in which actions can be taken in order to influence the result of the process (David, 1987). The adoption pattern of the technology depends on idiosyncratic "small events" near the beginning of the process and it is therefore path-dependent (Arthur, 1994; David, 1986, 1988). Users' expectations about which technology will become dominant also have a part in influencing the result of the process, so that they can become "self-fulfilling prophecies". "Path-dependency" refers to a dynamic process where historical events have long-term consequences that are generally irreversibile; at any time, unpredictable events can take place so that the trajectory of the process cannot be foreseen (in this sense, the concept is different from that of "past dependency"). Path dependency implies irreversibility, indivisibility and structural change (Antonelli, 1999); it is a fundamental characteristic of the process of technological change. A vast literature has developed in the course of the 1990s on the topic of dynamic adoption and diffusion processes with increasing returns technologies. Recently, some interesting attempts have been made to explicitly model, in the context of innovation adoption within a finite population of agents, the agents' social organisation, which influences individual decisions (Plouraboue, Stayer, Zimmermann and Benoit, 1998; Deroian, 2002; Leydesdorff , 2001.

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they final consumers or user firms.

2.3 Evolutionary economics

Evolutionary economists mantain that their perspective is particularly appropriate for understanding situations characterised by rapid technological and institutional change (Dosi and Orsenigo, 1988). They see the economy as a process of change driven by variety in behaviours (Metcalfe, 1997) and this variety is provided by innovation. Any evolutionary process is characterised by the presence of reproductive mechanisms which guarantee the continuity in time of the entities of the population; these entities differ in at least one characteristic that is significant for selection purposes (variation principle); some entities have characteristics that are better adapted to evolutionary pressures than those of others (selection principle). Evolutionists choose as their fundamental unit of analysis the "business unit", defined as an organizational-technological unit which consists of sets of instructions that allow for an input to be transformed into an output according to specific goals, and which can often be identified with the firm. They then suggest that a firm's behaviour consists of routines that guarantee the replication of economic activities; variety is guaranteed by innovation in firm behaviour; selection is provided by competitive mechanisms in the marketplace and is stimulated by the feedback signals that firms receive from it: "innovation is a matter of differential behaviour and differential behaviour is the basis for structural change" (Metcalfe, 1997). Nelson and Winter (1982) suggest that some of the firm's routines are directed towards the exploration of new opportunities and the solution of new problems through "heuristics" and search procedures; however a conceptual distinction must be made between the search activities directed at innovation, which can be routine activities, and the results of such activities, which may lead to innovation itself.

Evolutionists have provided some interesting theoretical explanations for the cumulative nature of technological change. According to Dosi (1982), a "technological paradigm" consists of "models and patterns for finding solutions to selected technological problems, based on selected principles derived from natural sciences and on selected material technologies": the paradigm is a specific set of models and patterns which deeply influence the direction of innovative activity, while a "technological trajectory" is the effective problem solving activity that emerges from the paradigm. Nelson and Winter (1982) also pointed out that technological development often follows specific patterns, and suggested the term "technological regime" to represent, with respect to particular technologies, the set of possibilities that technology developers consider to be feasible at particular time. Over time, the "technological regime" turns into a "natural" trajectory, which defines the pattern of development of subsequent technologies in the direction indicated by the first. Breschi, Malerba and Orsenigo (2000) elaborate on the concept of "technological regime" by suggesting that it can be interpreted as representing the economic properties of a technology which influence its specific development pattern. More specifically, a "technological regime" would depend on a combination of four elements: the presence of technological opportunities, the appropriability of innovations, the cumulativity of technological development and the properties of the knowledge at the basis of innovations. Over a longer time scale, the concept of techno-economic paradigm (Perez, 1983) comprises the set of technologies that are dominant in a certain historical period, and the social and productive institutions that develop in harmony with them[8]. The concepts of technological trajectory and technological paradigm have been criticized on the grounds of fostering a deterministic view of technological and social change (for a detailed critique see Penati, 1999); however, recent contributions have attempted to introduce feedback processes, so that the technological trajectory is no longer seen simply as a natural pattern of technological development but rather as the stable outcome of adjustment processes among the properties of the technology and the market (Frenken, 2000; Leydesdorff, 2000).

Related to the evolutionary study of innovation is the debate that has developed around the so-called "long waves" of economic growth that Kondratiev (1925) first identified by examining time series data relating to France, Britain and the United States. While Kondratiev explained long waves on the basis of cycles of capital accumulation and replacement, a different explanation for this phenomenon can build on the hypothesis that innovations are not introduced in the economic system in a continuous way, but rather they arrive in clusters, which then foster periods of acceleration in aggregate growth rates, followed by slowdowns. Schumpeter had observed that innovations are not isolated random events but rather they tend to cluster in time and in particular sectors. The debate on this issue intensified in the 1970s and 1980s with the contributions of neo-schumpeterian authors such as Mensch (1979), Van Duijn (1981), Clark, Freeman and Soete (1982), who tried to find empirical support for the innovation clustering hypothesis, and in particular tried to show that fundamental innovations tend to take place at "low" points in the cycle, thus giving rise to new waves of growth. Freeman and Perez (1988) provided a somewhat different theoretical justification for the "long waves": they suggested that when an old "techno-economic

[8] A line of research which supports a similar view of technological change is the "régulation" approach, which was developed in France in the 1970s and 1980s. They introduce the concept of "régulation mode" which is wider than that of techno-economic paradigm because it indicates a regime of accumulation which comprises "the whole set of regularities which allow a general and more or less consistent evolution for capital formation, i.e. which dampen and spread over time the imbalances which permanently arise from the process itself" (Boyer, 1988). The "régulation" approach emphasises how the evolution of a technological system cannot be separated from the general economic and social system of which it is a part.

paradigm” is substituted with a new one, a period of recession may follow because the old social and institutional system does not adjust immediately to the change.

A detailed critique to the attempts to explain long waves on the basis of innovation clusters can be found in Rosenberg and Frischtak (1994), who claim that the studies do not demonstrate that there exists a causal relationship between innovation and aggregate output, nor that there are reasons for which cycles should have a certain duration or be recurrent, and they do not provide clear reasons for the fact that innovations should take place just when the cycle is at its lowest ebb. Silverberg and Verspagen (2000) have tried to evaluate the hypothesis that innovations tend to happen in clusters: the only clustering for which they found empirical support is a “random clustering” where innovations do cluster, but not periodically; moreover, these clusters do not foster an increase in the long term rate of innovative activity. They then conclude that “the authors who have argued that a long wave in economic life is driven by clusters of basic innovations have stretched the statistical evidence too far”.

2.4 Institutions and innovation

In the field of innovation studies, the theoretical importance of institutions has increased in the last decade, particularly with the development the national systems of innovation approach. It has been pointed out (Edquist and Johnson, 1997; Coriat and Weinstein, 1999) that the concept of “institution” has often been used ambiguously in this context: in its daily use, the word indicates “hierarchical structures with explicit purposes” (such as research institutes, patent offices, consultancies, and so on) while in a sociological sense “institutions” are “sets of common habits, routines, estabilished practices, rules, or laws that regulate the relations and interactions between individuals and groups”. According to Edquist and Johnson, scholars who have written on national systems of innovation have often used the word in the former sense, although the most recent contributions seem to adopt a wider definition that is close to the latter. Many contributors to the national systems of innovation approach are also evolutionary economists. The development of this line of research has thus promoted a greater integration of the concept of institutions within the evolutionary economics approach (Nelson, 1994; Nelson and Nelson, 2002).

The term “national systems of innovation” was first introduced by Freeman (1988) and Nelson (1988) who investigated how the institutional features of, respectively, Japan and United States affected these countries’ ability to introduce innovations. According to Nelson (1993), the national focus makes sense because institutions are present at a national level that create a common environment which can affect the evolution of technological change. The national systems of innovation approach became more prominent during the 1990s with the publication of two books, one edited by Richard Nelson (1993), the other by Bengt-Åke Lundvall (1992). While both texts were written from an evolutionary perspective, the authors chose different methods of analysis. The articles in Nelson's book (1993) provided empirical evidence from different countries and used a descriptive approach to compare the various national institutional contexts; the contributors to Lundvall's book (1992) instead attempted to build an analytical framework centered on the concept of "interactive learning". They suggested that innovation happens when "interactive learning" between users and producers occurs. Important elements of the national system of innovation are the firms' internal organization, the relationships among firms, the public sector, the financial system, the national education and training system, the research and development system.

The national systems of innovation literature "has more recently turned into a more eclectic and geographically neutral 'systems of innovation' approach" (Montresor, 2001): systems of innovation are in fact now being considered at different levels of analysis, from regional (Cooke, 2001), to sectoral (Breschi and Malerba, 1996; Malerba, 2000), to corporate (Coriat and Weinstein, 2000). Teubal (2002) has recently proposed a taxonomy of the positive principles that underpin the systems of innovation perspective, in order to identify some normative principles that might support technology policy recommendations.

2.5 Theories of the firm and innovation

Whereas in the 1980s the theory of the firm was dominated by transaction cost economics, primarily associated with Williamson's work, recent theories see the firm as a depositary of productive knowledge rather than as a set of contractual relationships. According to the so-called competence theory of the firm, the firm should be interpreted as a knowledge processor, in which knowledge is created rather than just managed. Over time, learning processes in the firm give rise to competences that represent "what the firm is able to do". The technological or organizational core competences of the firm are those that give it a competitive advantage, what the firm can do better than others (Hamel and Pralahad, 1990).

While the competence theory of the firm is indebted to the resource theory of the firm that originated from the work of Penrose (1959), it has found increasing support since the beginning of the 1990s, when several theoretical developments began to emphasize the role of learning and knowledge in the firm, overshadowing the emphasis on information that was dominant in the previous decade: on the one hand, the evolutionary theory of the firm (Nelson and Winter, 1982) had fostered a view of the firm as a locus of creation, combination, transformation and selection of new knowledge; on the other hand, organization theorists had started acknowledging the importance of tacit knowledge (Polanyi, 1966) as at least equally relevant for the organization as the more commonly discussed codified knowledge. When everybody has easy access to codified knowledge, the creation of unique competences and products depends on the production and utilization of tacit knowledge: producing, appropriating, sharing tacit knowledge have become strategic issues (Maskell and Malmberg, 1999). Pisano, Shuen and Teece (2000) talk about "dynamic capabilities" of the firm, which represent the firm's ability to re-configure, re-direct, transform and integrate its core competences with external resources and with strategic and complementary assets in order to respond effectively to its fast-changing environment. In this approach, then, the firms' characteristics and the sources of its competitive advantage are explained in dynamic, cognitive, relational terms. As a consequence, scholars have come to realise that the learning processes that take place in the firm, which allow it to develop its own characteristic competences, are at the root of innovation (Cantwell and Fai, 1999).

Furthermore, while in the 1980s the debate was focused mainly on the relationship (generally explored from a transaction cost perspective) between vertical and horizontal integration and innovativeness of the firm, the 1990s have seen a surge of interest for "innovation networks" (Freeman, 1991; Langlois and Robertson, 1994). This increased interest can be seen, at least in part, as a consequence of the increasing acceptance gained by the competence theory of the firm: while in transaction costs economics the firm and its environment are strictly separated, the competence theory of the firm goes beyond this distinction and studies the dynamic relationships that are internal and external to the firm, thus accounting for phenomena - such as innovation networks - that transaction cost theory would not consider. According to DeBresson (1999) innovation creation always requires the presence of a network of organizations with different competences, and it is not just a feature of modern innovation processes: networks have always been around, but economists have not been able to see them because of their bias in favour of methodological individualism. A sizable empirical literature has developed on the topic of innovation networks. Some researchers are exploring empirical evidence in order to understand the importance of networks of firms for the creation of innovations (for example, De Propris, 2000; Harabi, 2000: Ruef, 2002); others are trying to build simulations that can account for the spontaneous emergence of networks of innovative firms (Pyka and Windrum, 2000; Gilbert, Pyka and Ahrweiler, 2001).

3. The historical, sociological and cognitive determinants of innovation

3.1 The social and cognitive determinants of innovation

Nathan Rosenberg (1976) observed that - while technological change was generally treated by economists as a phenomenon of passive adjustment to economic pressures, mediated by markets and factor prices – in reality "the ultimate incentives are economic in nature, but (…) precisely because such incentives are so diffuse and general they do not explain very much in terms of the particolar sequence and timing of innovative activity". Instead, it is the content of technological knowledge that explains the actual innovation sequence, and this content cannot be formalised within economic models (1994). Rosenberg (1976; 1982; 1994) has made important contributions to our understanding of the social, technical and cognitive phenomena that drive technological change. Like evolutionary economists, Rosenberg acknowledges that technological change is cumulative; however, he stresses that social phenomena also play a very important part in influencing its qualitative characteristics. For Rosenberg, technological change does not happen randomly but it responds to "inducement mechanisms" which give it specific direction by focusing people's attention on particular aspects of the technology. These mechanisms can be technical: technologies, particularly complex ones, exhibit internal pressures and constraints that induce people to look for changes in particular directions; for instance, changes in one or more components of a technical system can create "bottlenecks" which in turn stimulate changes in other parts of that system. But technological change can also be induced by social pressures, by constraints to the use of resources that were previously freely available (Rosenberg, 1976) and by expectations about the direction of technological change itself (Rosenberg, 1982)[9]. Rosenberg also introduced the important concept of learning-by-using, that is, learning on the part of the user of new technology: especially when dealing with capital goods, learning-by-using can be a source of technological innovation.

The study of technical change as a socially determined phenomenon has been carried out by numerous historians and sociologists. According to Hughes (1987; 1994), for example, the study of technological systems - that is, systems that comprise physical artefacts, natural resources, people, organizations – allows us to appreciate how innovation processes are influenced by phenomena of various nature (social, economic, technological). Within technological systems, human components enjoy greater freedom than physical ones and provide feedback between the system's performance and its objectives, so that the former can be modified in order to achieve the latter. Hughes talks about "reverse salients", those technical or organizational parts of the system that are not in harmony with the others[10]: therefore, it is very likely that the "system-builders" will focus their attention on trying to resolve the problems that cause them. Hughes also claims that "reverse salients" usually stimulate incremental innovations, while radical innovations give rise to entirely new systems. Over time, technological systems acquire "momentum", that is, they grow propelled only by internal forces: the system involves an increasing number of people, and their interests, and it becomes more and more established and resistant to change.

According to Bijker and Pinch (1987) any technology can be developed in many variants, of which some survive over time and some do not: in order to understand what drives this selection, the analyst must focus on the problems and solutions that every technology involves and on the relevant social groups that define what constitutes a problem and what constitutes a solution with respect to a technology. A technology stabilizes (closes in) on a specific variant when the relevant social groups agree on the fact that that technological variant solves the problems they have identified. Bijker and Pinch acknowledge that *ex post* it is always possibile to reduce a multi-directional model to a linear one, where the development and diffusion of technology is seens as following a succession of stages: however, a linear approach is hardly useful if we really want to understand what are the actual processes involved in the creation of a new technology.

"Actor-network theory" (ANT) – associated with the work of Callon, Latour, Law and Akrich – sees every phenomenon (including technology) as a network of relationships (social, economic, political, mechanic, etc.) which tie human and non-human actors alike; included in this network are also the ideas that human actors have about other elements of the network and about the meaning of technology. The advantage of this approach is that it focuses attention on the network itself, a network that comprises any actor which impinges on it (Law, 1987): this eliminates the problem of distinguishing what is inside from what is outside the network, as well as the problem of focusing on a particular type of relationships (social, technical or other) because all relationships are studied, independently of their nature. This approach is perfectly symmetrical with respect to all the elements of the network: there is no distinction between human and non-human actors, social factors are not always explanatory and technological factors are not always explained.

The interest for the social determinant of technological change has also led to a re-examination of the relationship between science and technology, and between invention and innovation. Several

[9] On expectations and adoption of new technologies see also MacKenzie (1996), Lissoni (2000).
[10] Another similar concept is that of "technological guideposts" (Sahal, 1981), which drive technological change along

authors (Hughes, 1987; Mokyr, 1990; Freeman and Soete, 1997) have remarked that, while during the XIX century most inventions were achieved by individuals working independently, since the beginning of the XX century companies have begun to organize their own internal research laboratories that have then become the primary loci of inventive activity. However, the idea that invention is, or used to be, simply the result of individual “genius” has been criticised by others who underline how every inventor benefits from the pool of knowledge available in his lifetime and is conditioned by the problems that he is trying to solve (McKenzie and Wajcman, 1999); often, associating an invention with the name of one particular person does not do justice to the fact that every invention is only possible thanks to the contributions that many other people, contemporary and antecedent, have made (Usher, 1929). Most patented inventions, moreover, never find their way into the “real world” of commercial applications (Kline and Rosenberg, 1986): in order for a scientific discovery (however attained) to be implemented in a new product or process, many other factors must intervene.

Nelson and Rosenberg (1996) observe that the expression “basic research” is often used to refer to research that does not have immediate practical application; however, they point out that examples can be easily found of applied research that has led to the discovery of new natural phenomena and, conversely, of basic academic research whose results have found immediate practical application. Moreover, if it is true that technology often depends on science - because scientific knowledge is cumulative and this allows the technology designer to rely on different sources of scientific knowledge, even unrelated, in order to develop technological applications - also the contrary often holds true: science in fact depends on technology, not only because science needs appropriate technological instruments in order to carry out its investigations (Rosenberg, 1994; McKenzie and Wajcman, 1999), but also because technological progress indicates which directions of scientific research yield the highest potential payoff (Rosenberg 1982). Another reason for which it is unrealistic to see technology simply as applied science is that technology is, in itself, a body of empirical knowledge, of techniques, methods and designs: this body of knowledge often allows for technological innovations to be developed even when people are lacking the necessary scientific knowledge (Rosenberg, 1982; Mokyr, 1990).

Latour (1995) suggests that both “machines” and the facts of science are “hybrids” that people have created in order to make their local interactions universal: we are never dealing with science, technology or society but with a range of weak and strong interactions. Technology is a way to

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specific patterns.

solve the problem of constructing society on a wider scale. Also Bijker and Pinch state that no theoretical distinction is possibile between science and technology, since both are social constructions and the people who perform them tend to use any cultural resources they find appropriate, whatever their nature.

3.2 Cognition and innovation

A conventional view of invention and innovation sees the former as a cognitive phenomenon happening inside individuals' heads, while the latter is seen as the process through which invention is implemented for commercial purposes. Recent research on innovation, instead, has been moving towards greater emphasis on the cognitive and social aspects both of invention and of innovation.

On the one hand, some authors have explored the social nature of invention. In a recent article, Nightingale (1998) claims that invention is the outcome of individual cognitive processes that are embedded in social practices. He develops a model called "innovation cycle" in which invention is developed through several stages: the initial, generic problem, is actualized into a specific problem; a functional solution to this problem is imagined, which is then tested and modified until an acceptable solution is found. The actual solution is strongly influenced by the presence of a technological tradition, social and tacit in nature, which provides a "pattern" for the solution of problems.

On the other hand, recent research work is highlighting the cognitive and social dimension of innovation, which is seen as resulting from interactions among different agents, inside and outside the firm: these interactions are seen as the main locus of creation of new knowledge. Many of these studies have been developed within the field of organization theory, where a vast literature has flourished on the relationship between innovation, firm organization, tacit and codified knowledge and learning (some references were introduced in section 2.5; bibliographies can be found in Lam, 1999, and Gertler, 2001).

Numerous authors see learning in the context of interactions as a crucial source of innovation.

According to Nooteboom (1996), epistemological subjects perform cognitive activities that consist of perception, interpretation and evaluation on the basis of categories that they have developed in the course of their interactions with the social and physical environment. Cognition is, therefore, idiosyncratic and path-dependent. If the subjects' cognitive categories are identical, the relationship among them is redundant, it does not produce anything new, while if their categories are too different then they are not able to absorb each other's contribution[11]. Nooteboom's epistemologic view is compatible with the "competence view" of the firm: each firm has competences that are unique and difficult to imitate because people's cognition is unique and idiosyncratic. According to Nooteboom, we can develop a theory of innovation only after we have achieved a satisfactory theory of organization; this theory must explain how learning takes place in the firm and how industrial organization evolves from firms' interactions. In a recent work (1999) he tries to develop a model of learning and innovation in the firm. He identifies a series of processes that lead to innovation because they allow the firm to mantain continuity (exploitation) while preparing for change (exploration): the first is the "generalization" of a successful practice to a new but contiguous field; when such a practice runs into problems, it must be adapted to the new context ("differentiation"); "reciprocation" is the exchange of elements between different but parallel practices; "accommodation" represents the need to create a new practice; finally, the novel practice stabilizes in a dominant design ("consolidation"). Nooteboom suggests that this process can be modelled by borrowing the concept of "script" from cognitive science: a script is a sequence of nodes; each node represents a set of events or actions that are inserted into the script. The script coincides with the description of organizational routine that was proposed by Nelson and Winter; the technological and organizational competences of the firm can also be integrated in the model, where they can both be represented as socially constructed phenomena. With this model Nooteboom is also able to provide a new definition for radical innovation: it is an innovation that cannot be inserted in the existing user script and requires the user to adopt or develop a new script.

Ciborra and Lanzara (1999) propose a cognitive view of innovation that takes into account the institutional and organizational context within which innovation is developed. According to the authors, innovation is a process of learning new abilities: to innovate means to learn how to do different things, how to do the same things better, or in a more efficient, effective and less time-consuming way. In order to understand how innovation is generated, a distinction must be made between the daily routines of the workplace and the "formative context" within which these routines are generated and performed. The formative context is the set of institutions, images and cognitve mechanisms that individuals carry with them; it includes the things that people take for granted in their daily routines and transactions, which then become institutions. The context is "formative" because it drives people to see and do old things in innovative ways, or it entraps them

[11] Nooteboom's approach and the transaction cost economics approach reach therefore opposite conclusions: while the latter says that firms under uncertainty should integrate different activities, Nooteboom claims that the possibility to build external relationships – which foster innovation through the creation of new knowledge – is more important for the firm than the security of integration; Lundvall has also reached similar conclusions.

into habitual ways of doing things. According to Ciborra and Lanzara, therefore, social cognition has an institutional dimension and, at the same time, institutional and organizational structures have a cognitive dimension.

According to Fonseca (2002) innovation emerges in the context of interactions, when "new meanings" are produced during conversations among people. The emergence of new meanings is possibile when communication is characterised by "redundant diversity" which allows for creative "misunderstandings" to take place. Conversations of this kind require that trust be established among people and it also requires, according to Fonseca, that conversations should not be immediately finalised to economic action. This leads him to the conclusion that the process of innovation generation cannot be managed: "we are all participants in comunicative interactions having the potential for transformation, that is, innovation. As soon as we try to control innovation from an external standpoint, we simply terminate their innovation potential". Within a more structured framework, Lane and Maxfield (1997) suggest that innovations are generated in the context of "generative relationships", that is, relationships among heterogeneous agents that can induce changes in how they interpret themselves, other agents and artefacts. bringing about innovations that are generally characterized as new entities. Although the changes that result from such relationships cannot be predicted on the basis of the knowledge of the characteristics of the agents involved, Lane and Maxfield (1997) claim that it is possible to assess whether relationships have "generative potential", on the basis of five conditions. The agents involved in a potentially generative relationship must share, in their interaction, a focus on the same artifact or agent (aligned directedness). Agents must differ in terms of expertise, attributions or access to particular agents or artifacts (heterogeneity). Agents must seek to develop a recurrent pattern of interactions from which a relationship can emerge (mutual directedness); their willingness to do so depends on the attributions that each assigns to the identity of the other. In this context, mutual trust helps but is not a precondition: actually, trust may result from the interactions themselves. The agents involved must be able to carry out discursive interactions, outside the conventional exchanges that are generally confined to requests, orders, declarations (right permissions). Interactions can prove more incisive if the agents have the chance to work together on a common activity (opportunities for joint action).

Amin (2000) identifies "communities of practice" as a source of organizational learning and hence of innovation. These "communities of practice" are groups of people that are informally related on the basis of mutual experiences and interests (Brown and Duguid, 1991): they foster relationships between individuals internal and external to the firms, rather than just internal communication. Interactions among producers and users have also been recognized as a very important source of innovation (Von Hippel, 1978, 1988; Leonard Barton 1995, 1996; Lundvall, 1988, 1992).

The importance of relationships implies that a lesser distance among agents, measured along different dimensions (economic, organizational, geographic, cultural) can foster innovation. A relevant consequence of the attention that is being paid to the cognitive aspects of innovation is the renewed interest for the geographical proximity among firms as a factor that promotes the firms' innovativeness. Precisely because tacit knowedge can only be communicated through personal interactions among economic agents who share certain features (for instance, a common language, conventions and social norms, personal knowledge based on the memory of past interactions, and so on) then the geographical proximity among firms would explain the innovation dinamicity exhibited by clusters (Maskell and Malmberg, 1999; Amin and Wilkinson, 1999; Gertler, 2001; Maskell, 2001). Maskell (2001) and Maskell and Malmberg (1999) also underline the importance of institutions in supporting the creation and reproduction of knowledge, thus connecting their analysis to the regional systems of innovation approach.

Antonelli (1999) suggests a "topological" model of the economic system which includes many of the characteristics of technological change that we have indicated so far. According to Antonelli, the economic system can be represented through a multidimensional topology that takes into account the distribution of the agents and the communication flows among them. The methodologies that can be used to explore its dynamics are therefore network analysis and spatial stochastic interactions. In this model, the introduction and adoption of new technologies at the micro level originates path dependent phenomena which determine the final distribution in the topological space of the product and processes and of the characteristics of product and process innovations; technological change takes place through bottom-up processes of localised technological change in "skill based" industries and top-down invention processes in "science based" industries.

4. Concluding remarks

Numerous points of convergence can be found among the different approaches to the study of innovation that we have surveyed. Some of these reflect a more general convergence of interests and methods among different lines of research.

Innovation in the traditional microeconomic approach is seen as the application of technological and scientific knowledge to existing products and processes. Because scientific and technological knowledge is generally codified, anyone can easily access it; it is non-rival and non-excludable and this often leads to market failures. The degree of appropriability of knowledge is therefore seen as a crucial determinant of the firm's propensity to innovate, and this appropriability, in turn, is affected by such factors as the characteristics of the patent system, the presence of knowledge spillovers, the nature of the technology.

Important steps towards greater understanding of the characteristics of innovation processes have been made owing to the contributions of historians, economists and sociologists. Some of them, in fact, first highlighted phenomena such as the cumulativeness and irreversibility of technological change, the presence of material and social "focusing devices" which channel technological change in particular directions (Rosenberg, 1976, 1982; Sahal, 1981; Hughes, 1987), the definition of technological paradigms and trajectories, cognitive in nature, which also affect the direction of technological change (Nelson and Winter, 1982; Dosi, 1982), the long-term, sometimes irreversible consequences of idiosyncratic and random events (path dependency) (Arthur, 1989, 1994; David, 1987; Antonelli, 1999), the role of social factors in shaping the characteristics of technological change (Rosenberg, 1994; Mackenzie, 1996; Bjker and Pinch, 1987).

Another important set of contributions to the study of the characteristics of innovation has been offered by organization theory. During the 1990s, the view of the firm as "information processor" has been replaced by the competence theory of the firm where the firm is seen as a producer of knowledge. The important tacit dimension of knowledge in the firm (Lam, 2001; Gertler, 2001) is such that the firm develops competences that are unique, idiosyncratic and stable over time (Pralahad and Hamel, 1990). An interesting parallel can be made between the stability of a firm's competence mix and the concept of tecnological paradigm. In fact, both competences and paradigms are cognitive concepts that delimit the space of the possibile directions of technological change.

Innovation is no longer seen as simple application of codified knowledge but as a process of creation of new, often tacit, knowledge. Drawing a parallel between innovation and new knowledge helps us explain many characteristics of technological change that were mentioned earlier: knowledge itself, in fact, is characterised by path-dependency, uncertainty, localization (Maskell and Malmberg, 1999).

The increasing attention for the cognitive aspects of innovation has fostered a corresponding surge of interest for interactions among agents as sources of new knowledge: direct interaction among people is in fact the main mode of transmission and creation of tacit knowledge. Researchers have begun to study networks of innovators, that is, various forms of technological alliances which firms set up in order to develop innovations; the importance of these networks in the real world is increasing (Freeman, 1991; Mowery and Teece, 1996). One of the explanations offered for such phenomenon is that in most industrial sectors innovation nowadays requires the acquisition of external competences on the firm's part (Smith, 2000).

Sociologists and organization theorists have underlined the importance of the cognitive distance among agents in stimulating innovation (Nooteboom, 1993, 1999; Lundvall, 1992; Fonseca, 2001). Other scholars have claimed that sometimes it is geographical proximity among firms, which often implies cognitive proximity, that fosters innovation. This has led to some convergence among different lines of research, in particular among the competence theory of the firm and of the region, the national and regional systems of innovation approach, the literature on industrial districts.

One way in which we can compare different perspectives to the analysis of innovation is by examining how they see the unfolding of the process that leads to the creation of innovations. In the public discourse, a "linear" view of innovation is still dominant, where the development of an innovation is seen as a process made up of sequential stages, temporally and conceptually distinct, characterised by uni-directional causal relationships: technology is seen as the application of science; more specifically, basic research is identified with pure science, applied research with technology and the stage of "development" of new products and processes with innovation. The neoclassicals as well as many empiricists, especially those that have supported "demand pull" and "technology push" views of technological change, have been inspired by a linear vision of the innovative process. It was the analysis of the qualitative characteristics of technological change (particularly the contributions of Rosenberg, Hughes, Noble, Bijker, Pinch, Latour and the other "actor-network" theorists) that first highlighted how innovation results from dynamic interrelationships among different elements. Kline and Rosenberg (1986) first proposed that the "linear" model be substituted with a "chain-linked" model in which the different aspects of economic and scientific activity, internal and external to the firm, are linked together by multiple relationships of causality and feedback. Economic issues, technical issues, the existence of a demand for innovation, are all interdependent elements of the process of innovation generation. This model is important because it has opened the way for a systemic conception of the innovation process, which is now seen as the result of dynamic interactions among heterogeneous elements that are systemically related. The metaphor of the system is seen by many as the best tool for understanding the processes that lead to the generation of innovations.

Another way in which we can compare and connect some of the theories that we have presented concerns the role that innovation is thought to play in the economic system. Neoclassical microeconomics sees innovation as a sort of temporary adjustment mechanism; when external perturbations disturb the system's exibilibrium, an adjustment process, in the form of innovation, is immediately triggered in order to establish another equilibrium. Therefore, precisely because of its dynamic nature, innovation has a marginal role in the neoclassical framework. At the macroeconomic level, neoclassical analysis has progressively incorporated innovation into economic growth models, although this has led to the abandonment of some restrictive assumption such as that of atomistic competition, replaced by the monopolistic competition framework. Evolutionary theory, on the other hand, following Schumpeter, sees innovation as the driving force of the economy: innovation is the source of that variety of behaviour that allows the system to evolve over time. Nelson and Winter first thought that at the basis of this variety were the search routines of the firm, directed at innovation; more recently, elements of interactions and networking with other firms and institutions have been inserted in the basic evolutionary framework. The economic system is seen as driven by selection mechanisms that are not only economic but also social in nature (Leydesdorff, 2000; Frenken, 2000).

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