Notes on the Determinants of Innovation: A Multi-Perspective Analysis

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Summary

The study of innovation and technological change is an increasing field of economic enquire because innovation can be considered a major engine of growth. This paper is concerned with the determinants of innovation and technological change. Different theoretical approaches present in the literature are systematically considered. The aim of this work is to offer an overview of contributions emerging from different perspectives trying to place them in their proper theoretical framework. The paper will be divided in different subsections in which each determinant is individually treated through the presentation of the most relevant results achieved by the literature on the specific issue. Policy considerations and hints for further research are also provided.

Keywords: Determinants of innovation, Innovation and knowledge, National systems of innovation, Intellectual property rights, Technology policy

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1. Introduction

It is a broadly diffused idea among economists and policy makers that the innovative capacity and the ability to imitate new technologies adopted across regions are key factors in determining the rate of growth of an economic system (Solow, 1956; Romer, 1990; Aghion and Howitt, 1992; but also Metcalfe, 2003). Moreover, problems related to the production and the diffusion of innovations, make technology policy becoming one of the priorities in their agenda.

This work is concerned with the determinants of innovation and technological change. Trying to understand which are the conditions that affect the pace of innovation, is an obvious precondition to achieve in order to design effective policies, able to have a positive influence on the technological performance of an economy. There is a vast literature on the argument and a lot of different and, often, alternative perspectives emerge from it. The aim of this paper is to offer an overview on these contributions trying to place them in their proper theoretical framework. The paper will be divided in different subsections in which each determinant is individually considered through the presentation of the most relevant results achieved by the literature on the specific issue. Before doing this it will be useful to give some definitions in order to clarify some key concepts.

According to Joseph Schumpeter (1939), technological change is one of the major determinants of industrial change and consists of the introduction of new products (product innovation), production processes (process innovation) and management methods (organisational innovation) in an economic system. [1]

The so called Shumpeterian trilogy distinguishes technological change in three different phases: Invention, Innovation and Diffusion. The first is related to the generation of new scientific and technological ideas, while the second is referred to the development of marketable novelties i.e. the introduction of novelties in the economic system. Finally, the distribution over time and space of the adoption of innovations is the diffusion stage. However, it is important to avoid coming across a mistake i.e. to believe that technological change should be intended as a linear process. This vision was expressed in origin by the *linear model* in which there is a one-way sequence of different phases of the type Science – Technology – Production. Here the scientific activity acts as an exogenous and neutral “deus ex machina” from which depends all the innovative process (Dosi, 1983).

[1] Useful references on these general aspects are P. Stoneman(1995), C. Antonelli(1995,2003), F. Malerba (2000).

On the other hand, the chain model proposed by Klein and Rosemberg (1986), takes into account the presence of wide interrelations between the various stages of technological change process by considering information feedbacks existing along the all chain. In this way, the science and market joint contribution to the innovation process is effectively highlighted.

In order to fully understand the arguments presented in next pages, it is important to mention the distinction between radical and incremental innovation and between global and local innovation. A radical innovation represents a breakpoint with the existing products and production processes while, an incremental one, implies only an improvement of them. On the other hand, for global innovation we intend a particular event, for example the introduction of a new machinery in a production process, that occurs for the first time at a global level whether a local one refers to a similar event which happens in a defined environment, for example at a firm level, and that is already happened somewhere else.

In a recent contribution by J. Furman, M. Porter and S. Stern (2002) it has been introduced the concept of *national innovative capacity*, which is "the ability of a country to produce and commercialise a flow of innovative technology over the long term". In that paper they build up an econometric model, using panel data, in which the national innovative capacity is explained by a set of regressors representing the most significant determinants of innovation. The novelty of this new framework is that it takes inspiration from three different perspectives that emerged in the previous literature, that is what they label ideas-driven endogenous growth theory[2], the cluster-based theory of industrial competitive advantage[3] and the National Innovation Systems literature[4]. The first approach is conducted at an aggregate level and, in particular Romer growth's model(1990), focuses on the definition of an ideas production function which depends on the number of workers devoted to the development of novelties and the stock of knowledge accumulated in the past, available to ideas workers. On the other hand, Porter (1990) stresses the importance of the microeconomic environment such as the availability of innovation inputs like skilled workers, the local competitive context and the possibility to exploit cluster-level scale economies in particular when clusters are geographically concentrated. The National Innovation System approach differs from the others firstly for methodological issues.

The origin of this analytical perspective can be found in the work of economists like Kuznets (1965), Rostow (1952, 1963) and Schumpeter (1939) and in the pioneering work, in

[2] Here the main reference is Paul Romer (1990).
[3] This line of research was conducted principally by Michael Porter (1990).

the evolutionary economics field, of Nelson and Winter (1982) further developed by Dosi et al. (1988). It is a new framework of analysis for the economics of innovation in which, the equilibrium perspective of standard neoclassical theory, is challenged. This means that competition is not perceived from the viewpoint of an equilibrium state of economic agents and markets, but as a selection process emerging from the different behaviour of heterogeneous agents. Moreover, a further peculiarity of the National Innovation System literature is that its attention is focused on the analysis of the role played by institutions and public actors in determining the national innovative capacity. In this view institutions are seen, in general, as aimed at reducing uncertainty and represent a way to sustain accumulation and diffusion of knowledge. Differences in institutional and policy choices regarding universities, financial and patent systems, public research laboratories and R&D subsidies are perceived as key factors in shaping the rate of innovation.

The relevance of the work by Furman et al. (2002), is that they shed light on the differences but also on the complementarities of those three approaches trying to develop a model consistent with all of them. Having this kind of approach in mind we will try, in the next pages, to enter in the analysis of a single determinant believing that, taken all together, the three perspectives are able to shed light on the understanding of technological dynamics. It is in fact our opinion that such a multi-perspective analysis will help the reader to deal with the complexity of the innovation phenomenon.

In next pages, we will not be able to deal with the analysis of the determinants of innovation keeping separate the three literature framework before highlighted. In fact, they often share common ideas about the key drivers of innovation, even if these are perceived from different perspectives. However, the specific contribution of each framework will be, as much as possible, systematically emphasized.

2. Intellectual Property Rights and Innovation.

This section deals with the analysis of the relationship between patents and innovation. We will show that, given the peculiar features of inventive activity, the system of property right protection may affect the pace of innovation.

[4] This concept was introduced for the first time in the literature by C. Freeman (1987) and developed by Lundvall(1988,1998),Nelson(1993), Edquist and McKelvey (2000), Malerba (2002) and Carlsson et al. (2002).

As we have already seen, scientific knowledge is often involved in the production of innovation but, the early contributions of economists like R. Nelson (1959) and K. Arrow (1962), pointed out that knowledge shares some typical characteristics of public goods such indivisibility, non rivalry and the impossibility to exclude other agents from the use of that sort of information[5] . Given that reproduction costs for information are very low, it is possible to increase the number of users of that specific knowledge at marginal costs near to zero. Furthermore, as the number of consumer increases, the availability of a particular knowledge to former users is not affected.

In the absence of legal protection, who develops new knowledge is not able to sell it without losing the derived monopolistic power because the buyer (if there is one considering also problems deriving from the presence of asymmetric information[6]), can easily reproduce the acquired information and sell it again. The creation of new knowledge is obviously a case in which agent's behaviour affects positively the welfare of other agents. Hence, the introduction of new knowledge produces *positive externalities* in the market. This fact was also confirmed, for example, by the empirical analysis conducted by Mansfield et al. (1977) in which they proved that there is, in general, high positive difference between social and private internal rate of return of R&D investments.

Those particular characteristics of knowledge[7] creates huge difficulties in terms of the ability of market forces to produce a Pareto efficient allocation of resources devoted to innovative activities. For such reasons patent protection, that is in turn a way through which is possible to internalise the external effect above mentioned, is seen as a key driver of the rate of technological change in an economic system[8].

A patent is a right granted to the inventor for a given period of time that allows just him to exploit commercial revenues deriving from the application of his own invention. Patents help the entry in markets especially for small and medium sized firms which are less able to protect their innovations in alternative ways, and support investments devoted to the introduction of radical innovations characterised by a high degree of uncertainty, elevated costs and long time lasting between the invention stage and the market introduction of innovation.

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[5] It is necessary to mention that Dosi (1988) and Dosi et al. (1988) noticed that great part of knowledge is tacit and localized so that it cannot be seen entirely as a public good.
[6] On this point, see for example Arrow (1962a).
[7] On the concept of knowledge and its governance see Antonelli (2004).
[8] Recently a new role of patents as a determinant of innovation has been proposed. They represent in fact a way to reduce transaction costs in the knowledge markets because patents can be used to signal the quality of knowledge embodied in a specific organization (Antonelli, 2004).

This argument emerges clearly in models, that according to Furman et al.(2002) we call ideas-driven endogenous growth models. As an example Romer(1986,1990) and Lucas(1988), propose models in which the notion of technological externalities is introduced. Here firm's knowledge is assumed to be a public good, hence when new knowledge is discovered it spreads across the economy because spillover effects occur. Intellectual property right protection is needed because it is the way through which ex-ante incentives to inventive activities are provided. Along with this view, Barro and Sala-i-Martin (1999) assume explicitly that the inventor gains a monopoly power on the invention produced through the patent system.

In designing an appropriate system of patent protection we have to deal with two different kinds of trade-offs. The first one is between static and dynamic efficiency while, the second one is between development and diffusion of innovations.

The first trade off emerges from the fact that, through the patent system, a monopolistic power is granted to the inventor allowing him to earn monopoly rents. This is of course a source of inefficiency from a static point of view in fact, the presence of a difference between price and marginal costs, produces a deadweight loss in social welfare. On the other hand, we noticed that many innovations may not occur in the absence of a patent system and this will hamper the dynamic efficiency of an economy. It is interesting to note that Schumpeter (1942) went beyond this trade off arguing that pure profits that an innovator can collect are not a rent from a dynamic perspective.

Turning to the second trade off, Nordhaus (1969) noticed that the number of innovations tends to grow as the protection accorded to the innovator increases because great part of the externalities produced are internalised, but the diffusion of an innovation through the economy is at the same time increasingly limited.

Hence, the core of patent policy problems is to find the right combination of length and depth of protection that assure the right equilibrium between the two types of efficiency and between production and diffusion of innovations. A relevant contribution in the patent literature is the article of Gilbert and Shapiro (1990). They build up a model which predicts that, when a single innovation context is considered, the optimal patent regime consists in maximising the duration of patents. Of course, their result is not applicable to the case of a base technology that can be used to develop further innovations. If this is the case, a legal protection is needed because otherwise the innovative firm tends to postpone the introduction of the new technology until it is completely refined, determining a delay in the availability of new products and processes in the market and negative consequences in terms of the diffusion stage. This kind of analysis can be found in Matutes et al. (1996) who, comparing different patent regimes, find that the best one consists in granting protection to the new technology developer only for some applications deriving from it.

In the literature,[9] there is no general agreement on which is actually the optimal patent system design. Different combinations of length and scope can be conceived and, differences in the intellectual property rights across countries gives a clear evidence of the lack of agreement among scholars and policy makers over the patent policy that should be implemented.

The NIS literature deals as well with appropriability problems and intellectual property rights. However, in this framework, knowledge is perceived as prevalently tacit (not codified) and localized meaning that it cannot be seen entirely as a public good (Dosi, 1988; Dosi et al., 1988). This does not mean that there are not appropriability problems but that the foundation of technology policy does not entirely reseed in market failure problems due to the presence of externalities. Nevertheless, patents can be considered a determinant of the pace of innovation because they are part of the rules and institutions forming a National System of Innovation. Differences in those rules and institutions create divergence in the innovative capacity across countries (Lundvall, 1988, Malerba, 2002).

Another source of disagreement in the literature is the actual relevance of patents as an instrument for intellectual property protection. Corporate espionage and reverse engineering can make patent protection[10] useless and, for this reason, firms have in general multiple ways to protect an innovative technology. On this point the empirical analysis conducted by Levin et al. (1987), showed that many firms do not consider patents as an effective measure of protection.

In conclusion, there exist an important relationship between intellectual property rights and innovation, but it is important to stress how industries differ widely in the extent in which patents can be considered effective. The huge empirical literature[11] on the argument, pointed out that there are industries in which patents are intensively used and represent a key driver of the pace of innovation because, there, knowledge can be properly seen as a public good.

[9] Important scholar's contributions are for example Scotchmer and Green (1990), Scotchmer (1996) and O'Donoghue et al. (1998), Jaffe (2000). Klemperer (1990) and Van Dijk and Cayseele (1994) analyses focused on the range of patent protection in a context of product differentiation models.

[10] On this point, it is also important to consider the possibility to "invent around" patents without breaking any laws.

[11] Sherer et al. (1959) conducted an early enquire revealing differences on patenting behaviour across industries. Brower and Kleinknecht (1999) found a firm's propensity to patent differs across sectors and depends on the firm size and on the innovation nature. Further econometric evidence about Levin et al (1987) hypothesis has been proposed by Shankerman(1991).

Pharmaceutical industry is considered a classical example in which patents are an important measure of protection that influences positively the amount of innovative efforts in that industry (Lacetera and Orsenigo, 2001; Lanjouw and Cockburn, 2000). Conversely, there are other sectors in which knowledge is more tacit and localized so that firms find other means of appropriability limiting the importance of patents in shaping the rate and direction of technological change.

3. Market Structure and Innovation.

This section focuses on the analysis of the relationship between market structure and innovation. The question here addressed is if an economic environment characterised by the presence of big companies and a certain level of market concentration performs better, in terms of dynamic efficiency, than a context of perfect competition. Seminal contributions by J. Shumpeter and K. Arrow can be considered the two pillars of this debate.

Great part of the literature among the determinants of innovation, particularly in the Industrial Organization framework, focuses on the two well known Schumpeterian hypotheses (Schumpeter, 1942). The first deals with the relationship between innovation and monopoly power and stresses the idea that concentrated market structure boosts innovative activity, while, the second, is concerned with the relationship between firm size and the attitude to invest in innovative activities. In the Shumpeter's (1942) view[12], monopolists have the possibility to attract more qualified scientist and technicians and have, in general, less financial constraints. R&D investments are characterised by a lower probability of success than investment in physical capital, in contrast, their potential revenues are usually very high (Sherer et al.2000). Therefore, they are more likely to be performed by firms able to bear risky projects and having the possibility to protect and finance their investments. Firms can use their current market power in order to obtain resources that can be devoted to R&D. The eventual output of this process, allows firms to preserve their market power, earn extra-profits that reward the original R&D investment and give the possibility to continue the innovative process.

[12] A really interesting and exhaustive exposition of Shumpeter thought and of the subsequent related literature is in Scherer (1992). Cayseele (1998) performs a more recent review of contributions on the relationship between market structure and innovation.

In contrast with Shumpeter's ideas, Arrow (1962a) found that perfect competition is the environment, which gives the major incentives to innovation[13]. In Arrow`s model a monopolistic firm appears to invest in R&D less than the competitive one. The economic rationale of this result is that, a quote of the monopolist rents earned after the introduction of an innovation, are already warranted to him before the innovative process has occurred. On the other hand, under perfect competition, it is actually the introduction of an innovation that produces all rents so, in that context, incentives to invest in R&D are greater. In other words, a monopolist gains less than a new entrant from the introduction of an innovation because the monopolist will replace part of his existing profits whether for the entrant such profits are completely new.

In the Shumpeterian tradition, Nelson and Winter in their "An Evolutionary Theory of Economic Change"(1982) show the results of their simulations of the evolution of an industrial system in which emerges that productivity tends to grow with a reduction in market concentration. Moreover, R&D spending seems to be greater when the number of firms present in a given industry is not too large.

Kamien and Schwartz (1972, 1976) developed an intermediate position between the two. They investigate a model in which by considering market structure as an exogenous variable, it is possible to study how R&D spending varies with it. They pointed out that innovation does not increase monotonically with concentration but, intermediate market environments between perfect competition and monopoly, are more likely to produce the best conditions to perform innovative activities. Furthermore, they found that the key determinant in determining the pace of innovation is not concentration but effective rivalry. High rivalry implies that, after an innovation has been introduced, the imitation process from rivals begins very rapidly conducting to a fast reduction of extra-profits earned by the innovative firm.

The debate on market structure and innovation acquired new vitality with the emergence of some important contribution from Dasgupta and Stiglitz (1980 a,b), Sah and Stiglitz (1987) and Dasgupta(1988). In these articles was reached and discussed in detail a central result, which is the invariance theorem according to which, the number of competing firm is irrelevant to the innovation process and there will be always just one or no innovator. The invariance theorem holds, of course, under certain restrictive conditions but, as the Modigliani Miller theorem in the finance literature, it can be considered a useful benchmark. In fact it has

[13] Greenstein and Ramey (1998) re-examine Arrow (1962) and prove that a monopolistic market in the old product gives greater incentive to innovative activities than competition in a context of vertically differentiated product innovations.

been a valid starting point for later enquires dealing with a context of asymmetric information. As an example Sutton(1991, 1998) who proposed the so called bounds approach, investigated R&D competition in the case in which the invariance theorem's hypotheses are not fulfilled, considering the long term co-evolution of market concentration, firms size distribution and innovative behaviour.

The theoretical debate above reviewed reaches important results but it is far to be concluded so it will be useful to analyse the evidence that has emerged up to now from data.

The empirical literature on the relationship between market structure, firm size and innovation is extensive but, again, there is still diffuse disagreement among scholars on the message provided by data and on the reliability of the results obtained. Scherer (1983) found that, according to Schumpeter ideas, larger firms provide better conditions to invest in new technologies. Although there are big differences across industries, Scherer (1984) estimated that innovative activities tend to increase almost linearly with firm size. As soon as new data became available for the US, Acs and Audretsch (1990) discovered that they were inconsistent with the schumpeterian hypothesis revealing that small firms performs more innovation per employee. Such a result was criticized by Cohen and Klepper (1992) who noticed that it is not sufficient to count the number of innovations because they can deeply differ in quality. Another important study conducted by Gerosky (1990) investigated empirically the relation between innovation and market structure finding that there is an inverse relation between concentration and the rate of investments in innovative activities. Cohen and Levin (1989) and more recently Blundell et al.(1999) found results consistent with Gerosky(1990). On the other hand, a recent contribution by Aghion et al.(2002), provides evidence of the hypothesis of a U-shaped relationship between competition and innovation. According to this view, competition effects tends to be more relevant for low level of product market rivalry, whether Schumpeterian effects prevail in a high competitive and with low level of concentration market environment. These findings maybe suggest that a moderate level of market power can help the development and the introduction of new technologies. What is interesting to note here is that numerous studies stressed that these patterns vary significantly across sectors and depend on other industry level factors (Acs and Audretsch, 1990).

Summing up, many scholars both empirically and theoretically oriented investigated the point with contrasting results. However it appears clearly that market structure and firm size, considered in industry and market specific context, can affect deeply the pace of innovation so further research is needed in order to design industrial and antitrust policies aimed at stimulating innovation and growth.

4. Financial structure, corporate governance and innovation

This section will be divided in two parts and is aimed at giving some hints on the possible relations occurring between corporate governance, financial structure and innovation.

The first question here addressed is if different corporate governance systems may have divergent results in terms of innovative performance while the second is related to the understanding of which is the role of financial systems in determining the pace of technological change.

The separation between corporate ownership and control generates conflicts between managers and shareholders; in fact, the two can have different interests and objectives. The presence of asymmetric information, determines the necessity to use some control instruments aimed at reducing the divergence between their goals. Corporate governance consists in such kind of mechanisms. Different governance systems produce different effects on innovative activity and, their analysis can help to understand different national patterns of innovation (Tylecote and Conesa, 1999).

R&D investments tend to boost the divergence between the interests of the principal (shareholders) and the agent (managers) because they are characterised by a high degree of uncertainty but also high potential returns. Shareholders, in fact, are attracted by investments in innovative activities because of their high potential returns and because they can spread risk among their portfolio of investments, in contrast, the utility of managers is closely related to the outcome of the project. Hence, managers will be more attracted by R&D projects associated with a low risk level and, for this reason; if corporate governance systems are ineffective the pace of innovation might be negatively affected (Munari and Sobrero, 2003). According to Munari and Sobrero(2003), the nature of the control system (strategic or financial control[14]), the type of principal (which can be distinguished by the level of stock concentration) and the characteristics of the board (insider or outsider directors), have a

[14] The latter distinction was proposed by Hoskisson and Hitt(1988). Roughly speaking, strategic control is characterized by the use of long term performance indicators and requires consistent flows of information between managers and shareholders, whereas financial control relies on objective, firm indipendent criteria.

relevant role in shaping the rate of innovative activities within firms. In particular, they discuss in details the following propositions:

1) Strategic control appears to be more complete and appropriate than financial control in dealing with innovative and fast evolving environments because, within it, long-term strategically relevant criteria are used.

2) Stock ownership concentration has a positive influence on R&D expenditures because it allows a major control on manager's decisions and reduces their risk aversion. In fact Owner's knowledge of firms activities and their monitoring capabilities tend to increase with concentration.

3) The composition of the board of directors appears to be relevant in the process of resource allocation devoted to innovative activities. Insiders seem to be better suited as decision-makers than independent directors are because they have appropriate information about firm's activities and this is fruitful to enhance innovation.

Now we turn to the analysis of the role of financial systems in high innovative contexts. As we have already noticed in the discussion about market structure and innovation, large firms have financial advantages in R&D investments because they can rely on superior sources of internal finance. Moral Hazard and adverse selection phenomena seem to be particularly pervasive when we deal with innovative investments. Moreover, in the context of R&D investments, there might be high bankruptcy costs because of the inability to sell R&D assets at a fair price because they are strongly specific and difficult to resell. These conditions are in contrast with the assumptions[15] of Modigliani Miller theorem (1958) which states that firm's capital structure does not affect the decision to invest so that, on the margin, investments in R&D should have the same price of the others. Therefore a strong divergence between the cost of internal and external finance and between the cost of investments in R&D and in physical capital may well arise. Kamien amd Schwartz (1978) pointed out that R&D expenses depends crucially on the availability of internal resources. Also Hall (1992) and Himmelberg and Petersen (1994) argue that the rate of innovation might be sensitive to financial factors[16]. It seems in fact that, not only less developed markets which are not

[15] The theorem assumes infact that there is no asymmetric information so that problems of adverse selection and moral hazard are not taken into account. Moreover, the absence of bankruptcy and default is assumed.

[16] There is an extensive literature on cash constraints and R&D investments. Fazzari, Hubbard and Petersen(1988) proposed, as a measure of the level of a firm financial constraints, the sensitivity of investments to cash-flow. A number of empirical studies, verified that innovative firms tend to be more cash constrained and

capable to offer the diversity of capital instruments needed to come close to the market completeness, but also UK and US markets produce "finance gaps" that may largely affect R&D spending because firms might be financially constrained. Differences across countries in the completeness of markets for finance, in the legal treatment of bankruptcy as well in the bank lending regime, in government policies for credit market and in monetary policy[17], are capable to determine differences in countries innovative capacity (Canepa and Stoneman, 2002).

In conclusion, once again, institutional and organisational variables seem to be relevant in shaping the pace of technological change. Different credit and corporate governance systems produce diverse results in terms of dynamic efficiency. However there is no general agreement in the literature so a clear policy advice cannot be given, but it is sure that policy makers, managers and shareholders should keep in mind these results.

5. Geography and innovation

This section is devoted to the analysis of the effect of industries geographical concentration on technological change. In order to assess how local considerations may affect the pace of innovation, we will briefly present four different theoretical perspectives that deal with this issue such as the Marshall-Arrow-Romer (MAR) view, the contributions of Jacobs(1969), Porter (1990,1998) and the Regional Innovation System framework[18].

The seminal work by Marshall (1920) further restated by Arrow (1962 a,b) and Romer (1986, 1990), claimed that geographical agglomeration of industries produces knowledge externalities which can have positive effects on the rate of innovation and economic growth.

Arrow (1962 a) shed light on the particular characteristics of the knowledge good and on the idea that knowledge spills over. The questioned point is that because great part of knowledge is tacit and localised, spillover effects are spatially bounded (Antonelli, 1999). To clear the point it is useful to distinguish between the concepts of "information" and "knowledge". The first is easy to be codified and, especially considering the current evolution of Information and Communication Technologies, can be transmitted at very low marginal

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that there is a positive relationship between cash-flow and R&D investments (see Hao and Jaffe, 1993; Mulkay, Hall and Mairesse, 2000; Hall, 2002). These results seem to be in line with the theoretical considerations expressed above.

[17] Schiantarelli (1996) provides support to the hypothesis that the strength of financial constraints varies with monetary policy. A monetary restriction leading to lower net worth produces an increase of the external finance premium and it can lead a reduction of bank loans.

[18] A good reference on these issues is Audretsch and Feldman (2003)

costs while, the second, cannot be codified or formalized so that his marginal cost of transportation raises with distance. It is for such reasons that Von Hipple (1994) argued that face to face and repeated interactions among different economic agents, is the most effective way in transmitting knowledge producing positive externalities. Hence, physical proximity enhances flows of technological knowledge spreading across entrepreneurs, engineers and workers[19].

The view expressed by the MAR model is that knowledge spillovers are enhanced by the presence of a strong concentration of a single industry in a given area. Here it is stressed the argument that innovation is facilitated when local actors share common activities because they belong to the same sector. In fact it is argued that communications, and knowledge transmission are less expensive in a context of a single concentrated industry with respect to the case of diversified industries. A corollary of this argument is that local monopoly is to be considered a more conducive environment for innovation because companies can internalise the spillover effects deriving by the production of new knowledge.

According to this perspective, it emerges a clear policy implication i.e. governments should stimulate a growing local concentration of a single industry without hampering the emergence of local market power.

Opposite conclusions can be derived by the analysis of Jacobs thought. In fact, she believes that the major source of knowledge spillovers comes from the interaction of actors belonging to different industries. Industry diversity within a given region is the key driver of technological externalities and innovation. The diversity of skills, expertise, experiences, needs and the easiness of human relationships offered by a local context, is seen as a major source of promoting innovation and growth. Hence, with the work of Jacobs, a second type of externalities emerges by considering spillovers across different industries.

The role of knowledge spillovers produced by geographically concentrated industries was also analyzed by Porter (1990), who agrees with the MAR view about the positive effect of industry geographical concentration. However, in contrast with MAR model he stressed the role of strong competition between local firms within the same industry in determining the pace of innovation.

Porter (1998, p. 78) defines clusters as a "geographic concentration of interconnected companies and institution in a particular field". According to Porter, clusters affect competition by increasing the productivity of companies sited in a certain area, by running the

[19] See Baptista (2001) for an analysis of the effects of geographical proximity and technology diffusion.

rate and the direction of technological change and, finally, by encouraging the entry of new firms in the market. The advantages deriving from clustering can be divided into demand and supply side components. On the first side, the presence of a strong local demand deriving from related firms and the possibility to establish long-lasting relationships with customers, seem to be rather important benefits deriving from clusters. Customer requirements and feedbacks can, in fact, give relevant flows of information that can be used to derive new ideas for innovation. On the supply side, geographical concentrated firms belonging to the same industry can have access to a pool of skilled and high experienced workers with low recruiting costs. On the other hand, knowledge exchange between workers belonging to different industries but sharing the same scientific and technology base affect positively the innovative activity. Moreover Porter (1998) highlights that, talented people having different backgrounds, can be easily attracted because a cluster reduces the risk of relocation for employees. A second advantage is that it is easier to find high quality related inputs at low costs. Innovative activities are associated with high level of uncertainty, which can be reduced through the presence of a local network of innovators that allows agents to share similar experiences and ease the exploitation of new solutions to problems (Feldman, 1993).

In the definition of clusters given by Porter(1998) it emerges a role played by local institutions in shaping the external environment in which different agents interact in order to produce innovative efforts. The importance of the local institutional framework for innovation has been particularly stressed by what we called the National Innovation System approach through the notion of Regional Innovation System (RIS) (Cooke et al. 1997, 1998).

A RIS can be defined as a local system in which firms, other organizations and institutions are involved in interactive learning activities aimed at producing and developing innovations. Local institutional and organisational routines, social conventions promote systemic interaction around the exploitation of new ideas and the use of new technologies. Hence, in this perspective, local public intervention through the correct design of proper knowledge infrastructures promote technology production and diffusion by favouring the emergence of flows of knowledge and technology spillovers.

From the empirical point of view, three major areas of analysis can be conceived. These are aimed at assessing the importance of knowledge spillovers at local level, testing the hypothesis that, given the presence of local externalities, clustered firms are more likely to be engaged in innovative efforts and, finally, at discovering which is the most important source of externalities, diversity or a single industry concentration.

The first result to be cited is that provided by Jaffe (1989) and Acs et al. (1992) who dealt with measurement issues related to knowledge spillovers. By modifying the knowledge production function in order to take into account geographical effects, they found strong evidence of the importance of knowledge spillovers due to the presence of local university, public research centres and industry R&D laboratories.

On the second point Audretsch and Feldman (1996), using the Small Business Administration Innovation Citation Data, gave evidence supporting the idea that firms with a high innovative propensity tend to cluster more than firms belonging to more traditional sectors. Similar results are founded by Baptista and Swann (1998) who, using a database of innovations in the UK, give a positive answer to the question risen in the title of their article which is: “Do firms in clusters innovate more?”.

Finally, Sherer (1982) found that a great part of inventions in a given industry is used in other industries confirming the argument proposed by Jacobs. These results are confirmed by Glaeser et al. (1992) who, through the analysis of a data set on geographical concentration and competition in 170 of the largest US cities over the period 1956-87, gave evidence supporting Jacobs’ point of view and by Feldman and Audretsch (1999). The latter proved that the presence of different and complementary industries within the same region is more conducive to innovative activities than the existence of a single industry specialization.

In conclusion, what it is important to stress is that if we consider innovation as resulting from the interplay between generic knowledge and learning processes occurring in a localized context (Antonelli, 1995b), geography, proximity and location seems to be vital for innovation. If information flows produce increasing returns (Romer, 1986, 1990), but such flows are geographically bounded (Marshall, 1920; Krugman 1991), then they can explain part of the differences experienced in the rate of growth of economies[20].

Though more research is needed in this field of enquire. In particular, the identification of different types of knowledge spillovers and of mechanisms through which they emerge are two important goals for future research.

6. Demand and innovation

[20] It should be noted that these results seems to be robust to the introduction and the diffusion of new information technologies that facilitate flows of information. It has been claimed that in cognitive process, local interactions

In this section, we will discuss the importance of demand considerations when the innovation process is analysed. We will briefly present the analysis of the so called demand-pull hypothesis proposed by Schmookler considering as well, how Schmookler's thought was re-examined by the subsequent economic literature. Moreover, we will try to show how this argument can be extended at the aggregate level.

From the analysis conducted up to this point, the role of demand side factors has been almost neglected. Economic theory seemed to be more concerned with the analysis of supply side factors enhancing innovation and this fact is maybe due to the importance assumed in the literature by the technology push model, which describes the innovation process as entirely deriving from an exogenous advancement in scientific and technological knowledge. In this model, market considerations are not taken into account and there is no relation between technological change and demand. Market is seen as capable of absorbing passively all the introduced innovations.

However, there has been an influential contribution in the literature by Schmookler (1966) who, in particular at micro-level, studied the relationship between market demand and the rate and direction of technological change.

According to this author, technological change is not driven by scientific discoveries but it is the existence of demand for a particular invention to really matter. Scientific knowledge is still important because it determines what Schmookler calls the "inventive potential", but, essentially, market forces choose which invention will be actually realised[21]. Therefore, innovative activities tend to react to the presence of an expected profitability deriving from a market demand expansion which is, actually, the real incentive to innovation. Schmookler analyses both theoretically and empirically these issues, considering consumption and investment goods market as well. He concludes that the number of inventions in a given field tends to vary over time with sales in the related class of products. Therefore, differences in the number of invention across distinct product classes in the same period can be explained directly with variations in sales (see Schmookler, 1966, p114).

The demand-pull hypothesis was restated by many later contributions. Here we mention an important one performed by Gilpin(1975), who considered market demand as the primary determinant of successful innovation. Such kind of literature was reviewed and criticised, in

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and personal contacts display a relevant role and that ICT can help to explain the success of certain local systems. For a discussion on this issue, see Rallet and Torre (2000) , Audretsch (2000) and Antonelli (2003).

[21] On this point Schmookler (Invention and Economic Growth, 1966, p.112) writes: " The idea that the inventor is a man possessed by an idea and driven for months or years to develop it regardless of its market value,

particular on the empirical ground, by Mowery and Rosemberg (1979), Scherer (1982) and later by Kleinknecht and Verspagen(1990). These articles share the idea that the empirical evidence in favour of the demand-pull hypothesis is less robust than what was claimed in advance. Data used by Schmookler seem, in fact, not to be representative of the US economy therefore, the hypothesis was tested again using a broader set of data which confirms the existence of a positive correlation between demand and innovation even if it turns out to be less strong than Schmookler would have expected.

Finally, it is interesting to note that the relationship between demand and innovation can be extended at the macro-level, in fact, macroeconomic conditions are likely to affect the rate of innovative activities (Kaldor, 1957; Shleifer, 1986).

Gerosky and Walters (1995) give an important contribution on this issue showing that innovations tend to have a pro-cyclic behaviour and that demand granger cause innovation[22]. According to Gerosky and Walters, the economic explanation of this phenomenon is twofold. Firstly, markets have a limited ability to absorb new products in a given period so that, when a demand expansion is registered, this capacity tends to grow making the introduction of innovation more profitable. On the other hand, appropriability problems are associated to innovative activities so that firms often have a limited time to gain profits from the introduction of a novelty. It is for this reason that innovations are more likely to appear in periods characterised by a growing demand trend. Hence, since macroeconomic conditions can affect the expected profitability of innovative investments, it is possible to argue that governments approach to macroeconomic policies can have important effects on technological change and growth. Therefore, in considering the opportunity of restrictive policies it seems necessary to take into account their effects on the pace of innovation.

We believe that the analysis of demand considerations in the study of innovation and technological change is at a very early stage and that future research efforts should be done in order to improve our comprehension of these issues[23]. Two principal research questions should be considered in order to look at the relationship between demand and innovation from both sides. The first is related to the assessment of the relevance of the demand-pull hypothesis through theoretical and empirical analysis considering also new advancements in the formulation of models for innovation. The second should be addressed to understand the

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probably holds for some inventors. It is certainly the kind of inventor imagined by cartoonist, but it hardly describes the typical inventor. His creations find a commercial market too often for it to be true."

[22] Kleinknecht (1996) gives evidence of the existence of a positive relationship between demand and R&D investments.

effects of innovation on each component of the effective demand such as consumption, investments and exports. In this way, it will be possible to have significant advancements both in theory and from a policy perspective.

7. Human capital and innovation

This section is devoted to the analysis of the contribution of human capital to technological change and economic growth.

In models that we label ideas-driven the level of human capital, which can be represented by the level of schooling, skills and competencies of a given population, is seen as a key determinant of economic growth (Lucas, 1988; Mankiw, Romer and Weil, 1992). In Lucas (1988), investments in human capital produce positive externalities that enhance the economic system's productivity and foster his growth's rate. This can be explained because technological change is positively affected by the average level of human capital which determines, as Schultz (1975) argued, the ability of individuals to adapt to an environment characterized by technological dynamics.

Nelson and Phelps (1966) gave a seminal contribution in the study of the interaction between human capital and technological change. Roughly speaking, the intuition is that different levels of human capital determine differences across countries in the technology adopted and affect the way in which those technologies are used. Recently Acemoglu and Zilibotti (2001), build a model in which they found explicitly that a country with less skilled workers would have greater difficulties in implementing effectively technologies belonging to the innovation possibilities frontier, because of the derived lack of absorptive capacity.

A second argument in favour of the importance of human capital for innovation has been proposed by Roy (1997) who points out that in most models of endogenous growth there is a linear relation between the number of researchers and the rate of technological progress, while, in reality, negative externalities due to congestion effects may appear. In fact, it is possible to argue that, if the number of researchers per project increases beyond a certain level, congestion externalities reduce productivity of the average researcher. This problem tend to be less stringent if the number of ideas and of the related projects increases as well as the number of researchers but that is possible only if the level of human capital quality is higher.

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[23] Similar conclusions have clearly emerged from the symposium held in Jena (1997). The results are published by the Journal of Evolutionary Economics (2001) vol.11.

From a different perspective, the NIS literature reaches very similar results. Here the educative system is seen as part of the set of organisations and institutions composing the National System of Innovation. Advanced countries and less developed countries (LDC) differ deeply in the average level of schooling of their populations. LDC are in fact characterised by low level of participation to high degree of instruction and, in addition, a large number of their high skilled workers leave the country in order to have greater personal opportunities[24].

From the innovation point of view, it is important to stress that the educative system and in particular universities are aimed at diffusing base knowledge, giving technical and scientific competencies and finally at promoting and developing research in their laboratories. Furthermore, the NIS approach stresses the importance of interconnections between universities and the productive system and underlines the success obtained by USA in promoting such kind of collaborations (Montobbio, 2000).

The empirical literature presents some evidence in favour of a positive role of human capital in shaping the pace of innovation. As an example Benhabib and Spiegel (1993), using cross country data, do not reject the presence of an additional source of influence of human capital on economic growth due to the interaction with technology. Cross-country data are used as well by Hall and Jones (1999) who detect a strong correlation between human capital and TFP.

In conclusions it is important to stress that, as Lucas (1988) showed, the private return of investments in human capital is inferior to the social one. So, if as we have argued human capital is a relevant driver of innovation and economic growth, public intervention is obviously needed in this field.

Technology policy, regulation and innovation

From the review, it emerges clearly that the theoretical foundations of technology policy are different for what we call ideas driven endogenous growth theories and National Innovation System approach.

From the first perspective market failures originated by the presence of externalities, uncertainty and problems related to asymmetric information strongly affect decisions to invest in innovative activities creating conditions for public intervention (Martin and Scott, 2000).

[24] This phenomenon is known in the literature as *brain drain.*

Incentives and subsidies (David et al, 2000), the patent system (Levin et al.,1987), the strength of antitrust policy Porter (2001), the promotion of Research Joint Ventures (Cassiman, 2000), diffusion policies (Gerosky, 2000), the design of credit system (Canepa and Stoneman, 2002), the improvement of human capital (Lucas, 1988), are some of the instruments that policy makers can use to enhance innovation.

In contrast, the National Innovation System approach goes beyond market failures rationale for technology policy and stress the importance of the institutional framework of an economy in shaping the pace of innovation (Metcalfe, 1995). The system of institutions[25] has to be designed in order to promote the interaction between private firms, public research institute and other key private and public actors.

However, the relevance of the state in driving innovation cannot be confined to technology policy. In fact, the state plays an "autonomous" role through the effect of other policy measures adopted to obtain other policy goals. As an example, regulation is a way through which governments can influence the pace of innovation. To impose standards rules and other form of economic instruments means changing constraints and creating new incentives faced by firms taking decisions aimed at maximising their profits. This will have effects also on choices regarding innovative activities.

Here we will consider the analysis of the consequences on innovation of a particular example of regulation that is environmental regulation. The interaction between environmental policy and innovative activities has been a source of an interesting debate among economist (Corral, 2002). The point is that profit maximising firms do not consider reducing pollution as a private objective because of the presence of standard externality problems. Therefore, governments have to design appropriate policy instruments that, by changing external economic conditions for companies, are capable to influence the rate and direction of technological change. At a first sight, the performance of the economic system in which such policies are implemented seems to be definitely harmed. Anyway, it is possible to argue that flows of innovation produced in reaction to environmental policies allow a country to become a net exporter of environmental technologies[26]. The idea in his most strong formulation is that the shock produced by a new regulation creates an external pressure on firms, which are fostered to create new product and processes that affect positively the dynamic behaviour of that economy and hence his social welfare. Porter and van der Linde

[25] With the term institution we consider regulations, laws, market exchange rules, contracts, education system social and ethic values.

[26] This is known in the literature as the "Porter hypothesis".

(1995) found evidence supporting this hypothesis even if they conclude that environmental regulation has to be designed properly i.e. be, according to the definition of Jaffe et al.(2002), “technology forcing” in order to actually obtain the claimed results. On the other hand Jaffe and Palmer (1997) empirical analysis shows that there is a positive correlation between green regulation and R&D expenditure, but the same is not true for patents production. Finally, Newell et al.(1999) by considering the effects of energy-efficiency standards, found evidence that they were responsible of a considerable amount of innovation.

The autonomous impact on technological change due to the presence of the state of course is not limited to regulation activities. The dimension of welfare state is for sure another variable able to affect innovation. It has been claimed that a larger public intervention, by creating huge government bureaucracies, can hamper the pace of innovation because most talented people tend to become rent seekers (Murphy et al., 1991). On the other hand, the welfare state is a way through which uncertainty is reduced and this has positive effects on investments in innovative activities (Leon, 2003).

The debate on issue related to the importance of the role of the state in determining the pace of innovation is still open. Future research is needed for a better comprehension of the theory and the practice of technology policy. Furthermore, particular attention should be devoted to study in detail the effects of the other forms of public intervention on innovation in order to take into account dynamic efficiency consideration when policies are implemented.

8. Conclusions

In this paper, we reviewed the most relevant determinants of innovation. What has emerged is that innovation is a complex and multifaceted phenomenon and that a large amount of factors tends to influence it. The presence of many difficulties in studying innovation is confirmed by the fact that diverse theoretical approaches coexist in the economic literature and, in fact, to present the analysis of the determinants of innovation, it has been necessary to consider all these different perspectives. However, we believe that they share common opinions on the importance of technological change for economic growth. This large *consensus* is enlightened by the importance attributed to public intervention in promoting innovation and technological change at a policy level. In this sense, the outcome of the european councils held in Lisbona (2000) and in Barcelona (2002) confirms that the common strategy of european partners is to increase R&D expenditure up to 3% of GDP in order to sustain growth.

However, to increase R&D spending is not sufficient. According to what emerges from this review, an effective sustain to innovation derives from a set of policies oriented at designing a proper environment for innovative activities both at a national and at a local level.

From the first point of view, it has been underlined for example the importance of patents, market structure, human capital and demand considerations in determining the pace of innovation.

We discussed the analysis of the economics of intellectual property right protection showing how there is no general agreement on which is the best patent policy to promote innovation. We showed also that there are differences among industries concerning the effects of patents on technological change patterns. A better understanding of these issues is an obvious goal for future research.

Furthermore, it has been claimed that innovation is related to market structure. Even if economists produced relevant theoretical advancements in this field, it is still not clear which market environment performs better in terms of innovation. However, the debate has been useful in order to show how dynamic considerations should be taken into account by antitrust authorities. A promising field of enquire is to analyse the effects of alliances, mergers and acquisitions and other forms of collaboration on innovation from an antitrust perspective.

In the review emerges the importance of human capital to perform innovative activities. On this point, there is general agreement in the literature in particular, investments in scientific and technological education seem to be conducive to a better employment of human resources devoted to produce innovation.

Finally, we showed that, in the promotion of technological change, not only supply factors matter. The demand-pull hypothesis shed light on the importance of market considerations in the study of innovative dynamics. Future research should be addressed to study both sides of the relationship between demand and innovation. In particular, the analysis of the effects of innovation on demand has been almost neglected in the literature.

In the paper we stressed how technology policy has to deal also with the local dimension of innovation. The presence of spatially bounded knowledge spillovers suggests, in fact, that great part of innovative activities takes place at local level. Hence, regional technology policies have to be designed in order to shape the local environment, which is better suited to spur innovation. Further research is needed for the correct identification of different types of technological spillovers and for a better definition of the concept of Regional Innovation Systems.

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