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PECUNIARY EXTERNALITIES: THE CONVERGENCE OF DIRECTED TECHNOLOGICAL CHANGE AND THE EMERGENCE OF INNOVATION SYSTEMS

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PECUNIARY EXTERNALITIES: THE CONVERGENCE OF DIRECTED TECHNOLOGICAL CHANGE AND THE EMERGENCE OF INNOVATION SYSTEMS[1]

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ABSTRACT. The new understanding of the characteristics of knowledge indivisibility and knowledge appropriability makes it possible to appreciate the key role pecuniary externalities play both in the generation and in the exploitation of technological knowledge. Pecuniary externalities affect access to external knowledge and its localized appropriation, by the intensive use of idiosyncratic factors and the introduction of biased technological change. Their combined effect shapes the convergence of the directed features of the knowledge generated at the firm level and explains the path dependent emergence of local and technological innovation systems and the dynamics of innovation cascades.

KEY WORDS: PECUNIARY KNOWLEDGE EXTERNALITIES; KNOWLEDGE COMPLEMENTARITY; LOCALIZED APPROPRIABILITY; DIRECTION OF TECHNOLOGICAL CHANGE; CONVERGENCE; PATH DEPENDENCE; EMERGENCE; INNOVATION SYSTEMS.

JEL CLASSIFICATION: O31

1. INTRODUCTION

The aim of this paper is to explore the role of pecuniary externalities, as distinct from technological externalities, in shaping the direction, as distinct from the rate, of technological change, and to understand the dynamics of the convergent processes of knowledge generation and exploitation that lead to the emergence of geographical and technological systems of innovation.

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Pecuniary externalities have attracted little attention in the economics of innovation while a large body of empirical and theoretical research has been based upon the notion of technological externalities.

The new analyses of the characteristics of knowledge indivisibility and appropriability make it possible to understand that the conditions and costs of external knowledge and idiosyncratic inputs have a role to play as key factors in shaping the intentional strategies of firms about the direction of their technology. These strategies lead to the introduction of directional technological knowledge that is influenced by the conditions at which the external sources of complementary technological knowledge are locally available and biased towards the intensive use of local, idiosyncratic production factors in order to increase its generation, appropriability and exploitation.

The application of the notion of pecuniary externalities to the economics of knowledge provides a coherent framework able to understand the emergence of innovation systems created by the regional and sectoral convergence of the localized strategies of knowledge generation and exploitation by many firms.

2. THE ROLE OF PECUNIARY EXTERNALITIES IN THE GENNERATION AND EXPLOITATION OF TECHNOLOGICAL KNOWLEDGE

As is well known, Marshallian literature has identified two quite different types of externalities: a) technological externalities and b) pecuniary externalities. Technological externalities consist in direct interdependence among producers. Pecuniary externalities consist in indirect interdependence. In the former case the interdependence is not mediated by market mechanisms. In the latter, instead, interdependence takes place via the effects on the price system (Viner, 1931; Meade, 1952; Scitovsky, 1954).

In the words of Scitovsky technological external economies apply when “The producer’s output may be influenced by the action of persons more directly and in other ways than through their offer of services used and demand for products produced by the firm. This is the counterpart of the previous case, and its main instance is inventions that facilitate production and become available to producers without charge” (p. 144).

According to Scitovsky (1954), pecuniary external economies consist in 'interdependence among producers through the market mechanism" (p.146).[2] There are positive pecuniary externalities when the market price of production factors happens to be lower than equilibrium levels because of the effects of market interactions among firms in the growth process.

Pecuniary externalities have long been a fruitful tool to analize the relationship between structural change and growth. They have been used to understand the effects of the interplay between industries. In analyzing the dynamics of the division of labor, increasing demand by downstream industries favors increasing levels of division of labor in upstream industries. This, in turn, leads to higher levels of specialization and the introduction of innovations that eventually result in lower prices, in intermediary markets, for capital goods and other intermediary inputs. The growth in demand from downstream industries makes it possible to increase the division of labour in upstream and lateral industries. In this case, pecuniary externalities stem from the effects of the dynamics of demand-led growth. Triggering effects along vertical transmission mechanisms may be both positive and negative. The poor supply of advanced intermediary inputs by upstream industries may cause development traps (Young, 1928; Rosenstein Rodan, 1943; Kaldor, 1981).

More recently pecuniary externalities have been applied to study the diffusion of new technologies within filieres. Ciccone and Matsuyama (1996) show that the limited availability of specialized inputs may force the producers of downstream users to adopt, as distinct from generate, technology which are too labor intensive technologies. Arora, Fosfuri and Gambardella (2001b) study the mechanisms by means of which the growth of specialized upstream suppliers in developed countries improves access to technology and lower investment costs for downstream users in developing countries in the chemical industry.

Pecuniary externalities play an important role in the model of Aghion and Howitt (1992) that implements the Schumpeterian notion of creative destruction with a multisectoral quality ladder approach. Innovations consist in new intermediary inputs and engender transient monopolistic profits. New technologies, in fact, destroy the competitive advantage of the previous generations of innovators. At each point in time there is a direct and negative relationship between the current levels of research

[2] As Scitovsky (1954) notes: "This latter type of interdependence may be called pecuniary external economies to distinguish it from technological external economies of direct interdependence" (p.146).

funded by firms and the future levels of monopoly profits. The profitability of innovations affects directly their price. In this context an equilibrium solution can be found where the derived demand for innovations matches their supply. Hence the model is able to endogenize the levels of monopoly profits and the rates of introduction of innovations. The flows of pecuniary externalities that stem from the provision of new inputs that embody technological innovations to downstream sectors explain the increase of total factor productivity growth at the system level[3].

In these analyses, however, the users of technological knowledge generated and made available through market transactions by upstream specialized suppliers are very much passive. Consistent with standard microeconomics, agents are not able to react creatively to the stimulations provided by upstream activities and to intentionally generate their technological knowledge, and to change their technology.

So far, the notion of pecuniary externalities has been rarely applied to provide an understanding of the generation, as distinct from application, of technological knowledge and the direction, as distinct from the rate, of technological change. The literature has explored more systematically the consequences of knowledge non-appropriability and non-divisibility in terms of 'direct interdependence' non-mediated by the market mechanism, hence building almost exclusively on the notion of 'technological externalities'.

Pecuniary knowledge externalities become relevant as soon as: a) firms are credited with the creative capability to intentionally generate technological knowledge and to introduce technological changes that are consistent with their specific and contextual conditions and b) the active role of knowledge users is appreciated. In order to command new technological knowledge, generated by third parties, and take advantage of it, users need to perform specific activities that involve specific resources. This is true for the adopters and imitators of new products and processes when technological knowledge is embodied, for the buyers of patents and licenses when knowledge is disembodied, and for the preceptors of knowledge spillovers. In all cases users can access external knowledge only at a cost: such costs have an effect on the technological

[3] Quite surprisingly little attention has been given to study the implications of the model. The effects of the 'equilibrium' amount of innovations introduced in a given upstream industry in terms of total factor productivity in downstream industries and hence at the system level, should be larger, the greater the centrality of the industry in the flows of inter-industrial exchanges. Moreover the indirect effects should be considered next to the direct ones. Working along these lines the 'old' notion of *key* sectors would easily find new support.

choices of firms. Hence the need for pecuniary knowledge externalities (David and Rosenbloom, 1990).

An understanding of pecuniary externalities makes it possible to consider the effects, on the emerging and intentional direction of technological change, of a) the lower relative prices of specific knowledge inputs b) other intermediary production factors. In both cases such price levels are determined by the idiosyncratic characteristics of the localized regional, historical, institutional and industrial context.

The characteristics of the context into which firms are localized are especially important in terms of pecuniary knowledge externalities in shaping the direction of technological change. The notion of pecuniary knowledge externalities makes it possible to integrate into a single framework the analysis of the direction of technological change, as shaped by the role of the actual costs of the indispensable external knowledge inputs in the generation of new knowledge and by the effects of the prices of other intermediary inputs that it is convenient to bundle with new knowledge so as to increase its appropriability.

In both cases firms have a clear incentive to search for the potential complementarities between internal and external factors and characterize intentionally their innovative strategies so as to implement the interface between internal and external factors, achieve dynamic complementarities and increase their productivity and profitability. Let us analyze these aspects in more details.

2.2. PECUNIARY EXTERNALITIES IN KNOWLEDGE GENERATION

Traditional analysis led by the contributions of Nelson (1959) and Arrow (1962) and implemented by the methodology elaborated by Griliches (1979 and 1992) and Jaffe (1986), rests upon the notion of knowledge as a public good and consequently applies the notion of technological externalities. In this approach knowledge spills over and no interaction between ‘inventors’ and ‘imitators’ or ‘knowledge producers’ and knowledge users’ is necessary. Such knowledge externalities stem from a number of key characteristics of technological knowledge such as non-divisibility, non-appropriability, non-rivalry in use, non-excludability. Such pervasive technological externalities in the generation and exploitation of technological knowledge make it difficult for the market place to provide incentives and to organize the production and dissemination of knowledge. There is a wide-ranging literature exploring the implications in terms of market failure and articulated the need for public subsidies.

If knowledge is a public good or, as recently described in the new growth theory, a quasi-public good, the notion of ‘technological externalities’ can apply. At least a fraction of the technological knowledge generated by each firm can be considered as an unpaid factor that enters the production function of the other firms. Imitators can take advantage of knowledge generated by third parties: inventors can retain only a share of the stream of economic benefits that stem from its economic use (Grossman and Helpman, 1994).

In the last decade, this analytical framework has been questioned by: A) the discovery of knowledge governance costs, B) the new understanding of knowledge complementarity as distinct from knowledge cumulability, C) the discovery of the key role of knowledge as both an input and an output in an intentional process of knowledge generation.

A) Progressively the evidence gathered in the empirical literature has shown that the acquisition of technological knowledge by both users and imitators is not free. Knowledge does not spill over spontaneously: its acquisition requires some dedicated resources. Imitation costs are relevant (Mansfield, Schwartz and Wagner, 1981) as well as absorption costs (Cohen and Levinthal, 1990; Griffith, Redding and Van Reenen, 2003). The characteristics of the system, into which knowledge flows, matter in terms knowledge governance costs described as transaction, interaction and communication costs (Nelson, 1993; Antonelli, 2006b).

This literature shows that technological externalities are not an appropriate tool of analysis: they do not apply for the acquisition of external knowledge. Dedicated interaction and specific resources are necessary if the knowledge that spills over is to be exploited. External knowledge has a cost: it cannot be treated as a free factor. Here the application of the notion of pecuniary externalities, as distinct from ‘technological externalities’ becomes relevant. It is clear in fact that using existing external knowledge incurs a cost, although it is often below its marginal productivity. Because of the intrinsic non-exhaustibility and non-divisibility of knowledge, cost levels can be lower than the cost of early generation, at least in specific and positive geographic, historic, institutional and sectoral contexts (Breschi and Malerba, 2005; Bresnahan and Gambardella, 2004).

B) Much attention has been paid to the analysis of knowledge indivisibility articulated in terms of cumulability, that is diachronic indivisibility: new vintages of knowledge build upon previous advances. Recent advances in the economics of knowledge have made it possible to better appreciate the role of synchronic knowledge indivisibility. The notion of knowledge complementarity has been elaborated in terms of the interdependence between different modules of contemporary knowledge generated, at the same time, by different agents and possibly in different fields. The legacy of Hayek (1945) finds new support: technological knowledge is viewed as being dispersed and fragmented into a variety of complementary and yet specific and idiosyncratic applications and contexts. In such a new framework knowledge is viewed as a collective activity (Antonelli, 2001 and 2007).

A systemic approach to understanding what determines the rate and the direction of technological change is progressively implemented. In such an approach the innovative capability of firms is strongly influenced by the characteristics of national innovation systems articulated in technological, industrial and regional subsystems and based upon networks of interaction and communication into which the dissemination and access to technological knowledge takes place (Freeman, 1991; Patel and Pavitt, 1994)

C) Technological knowledge is an input for the production of other goods and an input for the production of new technological knowledge. Hence, technological knowledge enters the production function of both new goods and further knowledge. The role of knowledge as an input in turn adds a new element to understand the intrinsic complementarity between external and internal sources of knowledge for the production of new knowledge. Because of non-excludability non-exhaustibility, reproduction costs are far lower than generation costs (David, 1993; Arora, Fosfuri and Gambardella, 2001a).

The generation of new knowledge is the specific outcome of an intentional action and requires the integration of four distinct and specific activities: internal learning, formal research and development activities, and the acquisition of external tacit and codified knowledge. Each of them is indispensable. Firms that have no access to external knowledge and cannot take advantage of essential complementary knowledge inputs can generate very little, if any new knowledge at all, even if internal learning and systematic research and development activities provide major contributions. No firm, in fact, can innovate in isolation (Antonelli, 2007).

These advances have important implications for our understanding of the effects of the local context on the costs and the characteristics of the technological knowledge being generated by the firm. First, and most important, for a given budget, firms that can access cheaper external knowledge can generate a larger amount of knowledge. The unit costs of the new knowledge generated in a fertile knowledge environment are clearly lower than the unit costs of the knowledge generated in a 'hostile' ambient where there is a single firm that can rely almost exclusively on its own internal competence.

Secondly, firms can select the characteristics of the technological knowledge they generate, according to the characteristics of the ambient in which they are embedded. As a consequence the knowledge generated with a strong content of external localized inputs, is cheaper and has a stronger idiosyncratic and contextual character (Nooteboom, 2003 and 2004).

Firms can select the 'best' mix of knowledge inputs depending on the levels of knowledge governance costs, networking and absorption costs, the costs of purchasing external codified knowledge and the costs of internal research and learning activities. It is clear, for instance, that when and where, access to external knowledge is difficult, firms will rely more on internal research and learning activities. On the other hand, when and where pecuniary knowledge externalities matter, when, in other words, the total costs of external knowledge for perspective users, including purchasing and governance costs, are lower than its marginal productivity as is the case in average conditions, firms will rely less on internal learning and research activities and will direct their research strategies and implement its complementarity with the research activities of other firms so as to take advantage of the characteristics of the local knowledge pools (Pisano, 1990; Patrucco, 2009).

In short, pecuniary externalities is a fertile tool of analysis that, makes it possible to understand what determines the effects of the different levels of costs of external knowledge as an essential input. External knowledge does not spill over freely. External knowledge can be accessed at specific and well identifiable costs that vary according to the different characteristics of the local ambient.

2.3 PECUNIARY EXTERNALITIES IN KNOWLEDGE EXPLOITATION

Following the approach elaborated by Nelson (1959) and Arrow (1962) the analysis of knowledge appropriability has mainly been developed considering knowledge as an economic good per se. This line of analysis had led to the identification of a number of key characteristics of technological knowledge such as non-divisibility, non-rivalry in use, non-excludability and hence non-appropriability. Non-appropriability means that imitators can benefit freely of the new knowledge. The market place is not able to provide the incentives for the generation of the correct amount of knowledge. The basic tools of economics make it clear that knowledge, as a good per se, is a public good.

This situation is quite different, however, when the appropriability and exploitation of embodied knowledge are considered (March, 1991). Technological knowledge can be appropriated and exploited effectively through downstream integration by incumbents who can take advantage of existing barriers to entry and hence to imitation (Schumpeter, 1942). The bundling of knowledge with other assets that are under a firm's exclusive control becomes an effective strategy to appropriate technological knowledge better and hence to exploit it (Teece, 1986).

An important step forward can be made when the role of production factors, external to the firm, but idiosyncratic because they are available only in a specific context, is appreciated. Localized appropriability becomes relevant as it is the result of embodying knowledge into downstream activities and is characterized by the very intensive use of production factors that are external to the firm, and both idiosyncratic and locally abundant. Bundling knowledge with other production factors, which are idiosyncratic and localized to an extent that imitators and competitors cannot easily access, makes localized appropriability possible. Identifying and developing local and idiosyncratic resources which firms find are convenient to use intensively becomes a clear and strong focusing device for firms to align their research activities[4].

[4] Following a well established line of analysis of technological change at the macroeconomic level it is well known that the intensive use of more abundant and hence cheaper production factors leads to a larger increase in productivity (Kennedy, 1964; Samuelson, 1965; Ruttan, 1997; Acemoglou, 2002). Yet little attempt has been made, so far, to integrate this approach -centered upon an analysis of the aggregate direction of technological change- with an analysis of how the conditions which determine the use of knowledge act as an incentive towards the selection of knowledge generation strategies at the firm and regional level. When the endowments of both tangible and intangible inputs differ, the direction of technological change towards the exploitation of local pecuniary externalities based upon the intensive use of locally abundant factors has a strong effect on the results in terms of performance both at the level of the economic system and at the level of the firm (Antonelli, 2006a).

In a static context, when only technical substitution is considered, producers have a clear incentive to use the production factors that are characterized by pecuniary externality more intensively. Hence, the factor intensity of such inputs will be higher in some specific clusters than in others. In a dynamic context where technology is endogenous, innovators have a strong incentive to direct the introduction of new technologies so as to increase the intensity of production factors that are available at prices that are below their marginal productivity. Consequently, in a dynamic context, the input intensity of the production factors that offer pecuniary externalities will be much higher than in a static context. Technological change works as a meta-substitution process.

The more specific the technology introduced by innovators is, i.e. the more it makes an intensive use of idiosyncratic production factors that are specific to innovators possible, the lower the chances that newcomers, even when and if they succeed in understanding the new technological knowledge and imitate the new technology, will be able to match the production costs of innovators and hence reduce their competitive advantage. In such a market place the competitive advantage of innovators is based more on the biased mix of idiosyncratic production factors that have shaped the direction of technological change, than on the exclusive command of proprietary technological knowledge. Even if new competitors can imitate the new idiosyncratic and localized technology, their production process will be less effective than that of the innovators because of differences in the costs of production factors.

Innovators who rely on idiosyncratic production factors can command a cost advantage upon which long lasting barriers to entry and to mobility can be built. Each innovator becomes the local monopolist in a well-defined market niche. The size of the niche depends upon the specification of the products with respect to the preferences of consumers and upon the cross price elasticity with respect to other similar products, which, in turn, are built around the idiosyncratic competences of other competitors. Innovators will fix strategic prices in the niche according to the ease of mobility and entry of the competitors in a broader basket of niches which includes the demand of similar customers.

In short, when the generation of new knowledge is directed towards the introduction of new biased technologies that consist in the intensive use of locally abundant production factors aimed at reducing production costs, the local social value of technological knowledge is larger. The private share of such a larger social value is larger when directed technological change, biased towards the intensive use of pecuniary externalities engendered by local idiosyncratic production factors, as this makes it possible to exploit the new technological knowledge better by means of barriers to entry and imitation. Such barriers prevent the economic rents which stem from their introduction being dissipated and hence increase de facto knowledge appropriability.

The search for new, more effective, uses of locally abundant production factors is a powerful alignment mechanism for the research strategies of innovators and a strong incentive to the generation of directed technological knowledge. Biased production technology that makes the most intensive use of locally abundant, and hence cheaper production factors, is more efficient, and profitable as it engenders systematic cost asymmetries that are long lasting, as long as competitors do not have access to the same factor markets.

Pecuniary externalities are important in shaping the direction of knowledge generation because of their effects in terms of exploitation. The relative abundance of key idiosyncratic inputs, that other competitors cannot access in the same conditions, and hence lower-than-average market prices provide firms with the opportunity to increase the appropriability of their knowledge as long as it is able to use them intensively.

3. THE CONVERGENCE OF DIRECTED TECHNOLOGICAL CHANGE AND THE EMERGENCE OF INNOVATION SYSTEMS

An understanding of the constraints and opportunities provided by pecuniary externalities stemming from horizontal knowledge indivisibility and localized appropriability makes it possible to elaborate in a single framework, an analysis of the incentives that contextual and localized factors exert in shaping the direction and the characteristics of new knowledge generated by firms and to describe the path dependent dynamics of the convergent processes that lead to the emergence of regional and sectoral systems of innovation.

An understanding of the effects of pecuniary knowledge externalities in shaping the rate and the direction of technological change makes it possible to explain at the same time why the technological paths of firms converge towards local pools of complementary knowledge pools and why structured systems of innovation based upon the local availability of distinctive sources of both tangible and intangible inputs emerge. (Malerba, 2005; Quèrè, 2008).

Let us start from a population of heterogeneous and idiosyncratic firms, distributed in different regions that have access to different sources of knowledge and factor markets and have well defined location in knowledge space. Each firm, exposed to a mismatch between beliefs and related plans, and the eventual factor and market conditions, is pushed to generate new knowledge and to introduce new technologies. This creative reaction requires dedicated activities: the development of internal learning, carrying out formal research and development activities, and the acquisition of external knowledge, both tacit and codified. Such activities involve assessing specific costs such as the costs of the coordination of the development of internal learning, the knowledge transaction costs necessary to search and purchase codified knowledge in the markets for knowledge and the networking costs, necessary to implement the acquisition of external knowledge, both codified and tacit. Even tacit external knowledge does not spill over freely: its acquisition is itself the result of intentional activities. Relevant absorption costs add to the actual purchasing costs of external knowledge. The selection of the kind of technological knowledge is affected both by the conditions for its generation and by the conditions for its exploitation. Each firm has a clear incentive to direct the generation of new technological knowledge towards applications that enable it to combine its internal competence with the knowledge inputs that are locally abundant and that have a strong idiosyncratic character.

Each firm engaged in generating new knowledge and appropriating its benefits in terms of extra-profits, discovers that the convergent alignment of its internal research activities with the complementary research activities of other firms, co-localized in both geographical and knowledge space, is a powerful factor of competitive strength. It is immediately clear in fact that the lower the unit costs of external knowledge are, the larger is both the amount of knowledge that the firm is able to generate and the larger is its localization in a specific context. A firm that is located in a conducive knowledge environment, and is able to identify and access the local pools of knowledge at low cost, is induced to take advantage of it and hence to base the generation of its new knowledge in the characteristics of its environment.

When firms are able to align their research strategies so as to take advantage of locally abundant knowledge, the amount of knowledge generated is larger. Consistently, in the downstream applications firms can rely upon a larger increase in efficiency with the same budget available to fund the generation of new knowledge. The amount of external knowledge that has been used in the knowledge generation process has a direct bearing not only upon the amount of knowledge being generated and hence on the efficiency shift engendered in the production process, but also on its characteristics. Firms that rely more upon external knowledge are more likely to produce complementary knowledge.

Let us now consider the effects of the direction of technological knowledge in terms of knowledge exploitation. When factors are not equally abundant in each local factor market, it is clear that the unit costs of goods manufactured by the intensive use of locally abundant factors are lower than the costs of goods manufactured with inputs that are available to every firm at the same price. In addition, we see that the two production processes differ in efficiency because a larger amount of knowledge has been generated by the firms that have a better access to external knowledge and are better able to take advantage of it with the introduction of a bias in the direction of their knowledge. The working of the two mechanisms is consistent and clearly the average costs of the goods that are manufactured using an idiosyncratic technology are lower than the average costs of the goods that are manufactured using a generic technology.

Finally, we must consider the price at which the goods that are manufactured using the new technologies can be sold. The products manufactured with a more idiosyncratic technology, that use locally abundant factors more intensively – this includes factors which are internal to the firm, and not available at the same conditions to competitors, enjoy systematic cost asymmetries with respect to imitators and hence can benefit from substantial barriers to entry and to mobility. In product markets characterized by monopolistic competition, incumbents protected by barriers to entry and to mobility, can fix high prices for their products, far higher than those of competitors. This is not the case when technological change is generic. In such cases every firm can use production factors that are not idiosyncratic. Hence, new competitors can imitate the new technology and their entry drives prices down to competitive levels. Clearly the prices of products manufactured with a higher intensity of idiosyncratic inputs are higher than the prices of the products manufactured with a low intensity of idiosyncratic inputs.

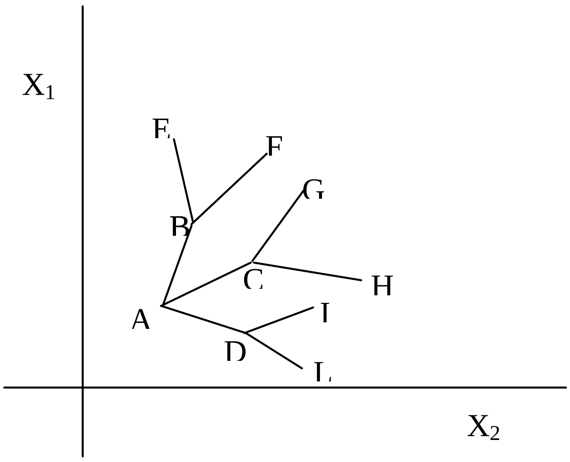
Firms which are able to select their technological innovations so as to introduce a bias in favor of the creation and subsequent intensive use of idiosyncratic production factors have a larger mark-up for four reasons: a) lower research costs, b) lower production costs, c) higher product prices, d) barriers to entry and imitation lasting for a longer length of time.

As Figure 1 shows, each firm directs the generation of technological knowledge in a simple Lancastrian knowledge space with two characteristics (X_1 and X_2) depending on the opportunities to benefit from the locally available pecuniary knowledge externalities (Lancaster, 1971). At time 1 each firm moving from point A directs its technological strategy either towards B, C, or D depending on the conditions of the external context. In turn, once rooted in either point, new possible directions can be chosen, within corridors defined by the firm's internal characteristics which include the preceding path. Points E or F will be attained if the firm were 'arrived' in point B at time 2; points G or H, instead will be chosen by a firm which happened to find itself at point C.

Every firm's technological path will reflect the characteristics of both its own internal quasi-irreversibilities and learning processes and the local context. The initial conditions play a key role in defining the context of action. The external context however, at each point in time, has powerful effects on the dynamics. The direction of the process is constrained by the initial conditions, but at each point in time it can change. The past limits, at each point in time, the range of possible directions. Path dependence consists in the continual redefinition of such a limited range of possible directions, and the convergence of each firm's research strategies can gain momentum.

INSERT FIGURE 1 ABOUT HERE

FIGURE 1. THE DIRECTION OF THE GENERATION OF KNOWLEDGE

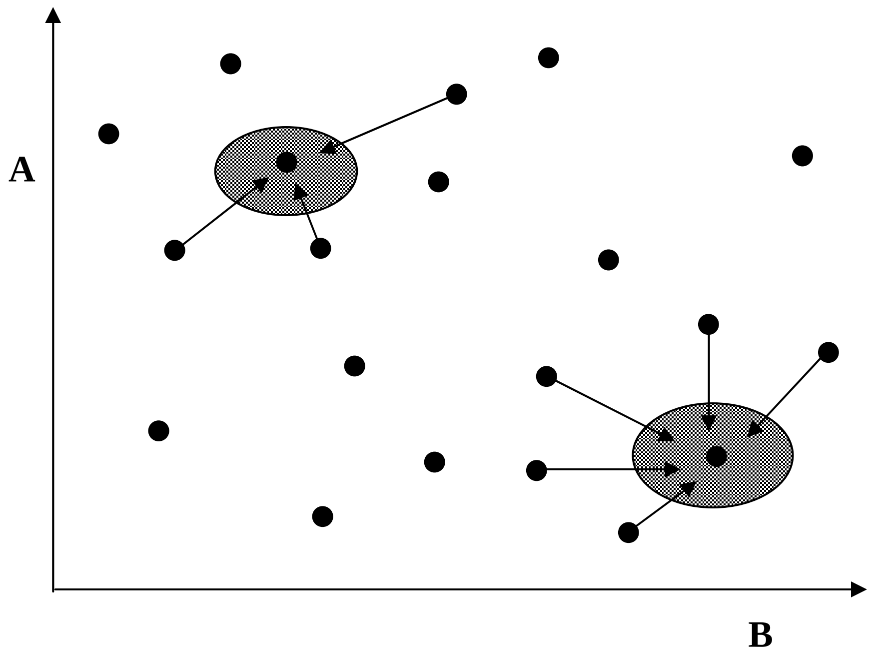


Strong incentives favor the convergence of each firm's research projects. Positive feedback is likely to reinforce the process as the effort to increase the complementarity of each firm's research activity creates local pools of knowledge which, in turn, increase the possibility to access external knowledge. At the same time increasing awareness of the opportunities for better knowledge exploitation provided by the intensive use of locally abundant and idiosyncratic production factors increases the intentional convergence of knowledge generation strategies towards a common direction shaped by the collective identification of the local idiosyncratic inputs. At the population level, the effects of individual convergence are reinforced by selection mechanisms. The success of the localized knowledge exploitation strategies acts as a powerful focusing mechanism that, through selection processes, favors the survival and growth of firms that have selected convergent paths of knowledge generation and exploitation.

Innovation systems emerge, articulated in technological districts and clusters, when the generation of new technological knowledge is reinforced by the emerging structure of complementarities based on communication channels provided by the intentional research strategies of firms that discover new sources of complementarities and move within the knowledge space. In special circumstances the emergence of innovation systems empowered by highly performing network structures that have emerged through the collective dynamics of a myriad of agents in search of potential complementarities may lead to Schumpeterian gales of innovations. Local and sectoral systems of innovation can be seen as nodes of communication channels that are the result of an endogenous process of emergence that shares the complex dynamics of Internet network creation (Pastor–Satorras and Vespignani, 2004; Antonelli, 2007).

As Figure 2 shows, each firm is rooted in a well defined location in a Lancastrian knowledge space represented for the sake of simplicity by two characteristics: A and B. Each firm is able to move in such a knowledge space and generate new knowledge taking advantage of increased proximity and reinforced communication channels with other firms clustering in nodes (the shaded regions) where potential knowledge complementarities can be better understood. As a result, new systems of innovation based upon nodes of coherent knowledge complementarity emerge (and others decay) while the direction of technological knowledge is shaped by the emergent collective convergence of the research strategy of each firm (David, Foray, Dalle, 1995).

INSERT FIGURE 2 ABOUT HERE
FIGURE 2 THE EMERGENCE OF INNOVATION SYSTEMS



Pecuniary externalities however are neither exogenous nor, by definition, static. Convergent dynamics may exhibit both positive and negative effects. On the one hand, the amount of external knowledge available within the district keeps increasing and its costs are lower and lower. On the other hand, however, knowledge governance costs may increase along with the number of firms accessing the same knowledge pools because of congestion effects in coordination. Density may have negative effects in terms of reduced knowledge appropriability: the case of excess clustering can occur when proximity favors the uncontrolled leakage of proprietary knowledge within the local system. In the same way the price of idiosyncratic inputs may increase with the increasing levels of their derived demand as shaped by the introduction of directional technological change.

The dynamics of the process reflects the interplay between the positive and negative changes of the levels of pecuniary externalities both in knowledge generation and knowledge exploitation. The convergence of the direction of technological change and the emergence of innovation systems in geographical and technological space occurs as long as the raising levels of knowledge governance costs, and the raising prices for the idiosyncratic inputs do not cancel out net positive pecuniary externalities. Innovation systems emerge depending on the relative weights of the positive and negative pecuniary externalities[5]. Specific factors such as the characteristics of the technological knowledge, the

[5] In specific contexts the interplay can lead to logistic processes of emergence with S-shaped dynamic processes that identify critical masses.

types of competition in product and factor markets, the institutional context can all cause innovation systems to emerge and decline (Beaudry and Breschi, 2003) [6].

At each point in time the emergence of new innovation systems may be blocked by a number of countervailing forces. The process is far from being past dependent: it is shaped, at each point in time by the ability of the actors to contrast the dissipation of pecuniary externalities. Both at the firm and the regional level these processes are likely to occur with a strong non-ergodic and sequential stratification (David, 1994). The path dependent dynamics stems from the interplay between past dependence and intentional action. The internal stock of knowledge acquired through learning by each firm together with the features of the local pools of knowledge and of the economic structure are the past dependent components as at each point in time they are the result of historic accumulation. The amount of knowledge being generated, the direction of technological change being introduced, the levels of knowledge governance costs and the price of locally idiosyncratic production factors are, at each point in time, the result of the intentional action of agents. Hence they provide the opportunities for intentional action to change the original path. At each point in time the intentional action of the embedded agents adds a new layer to the original structure: the original shape exerts an effect that the new layers can modify, depending on their thickness and density. Each firm in fact is able to interact with the system and to change it. This occurs at different levels: by introducing changes to the structural conditions and the topology of the system's communication channels, with the introduction of organizational innovations in knowledge governance mechanisms, and by changes in the factor markets due to innovations that change the supply of the idiosyncratic production factors. The emergence of innovation systems is the result of continual feedback between the structure of the system and the innovative action of its agents.

4. IMPLICATIONS AND APPLICATIONS

This analysis has a few important implications. An understanding of the key role of pecuniary knowledge externalities available in the localized context where technological knowledge is being generated makes it possible to be aware of the specific forms of knowledge complementarities among firms. Much empirical analysis has explored the relations between the variety of economic activities interpreting them

[6] Once more the analysis of Internet shows striking similarities between the dynamics of communication systems and the emergence and decline of systems of innovation. See D'Ignazio and Giovannetti, (2006).

as a source of Jacobs externalities. A step forward is necessary in order to qualify the kind of variety. Jacobs externalities can be considered as economies of scope at the regional level. A wide-ranging literature in the theory of the firm has shown that some combinations of production processes characterized by technological complementarity do yield increasing returns (Milgrom and Roberts, 1995). Other contributions, such as in the case of uncorrelated diversification, can actually yield negative returns to variety. In a similar way the analysis of pecuniary knowledge externalities and directed technological change suggests that ‘positive’ and ‘negative’ Jacobs externalities can be identified. Positive Jacobs externalities emerge when the competence and the technological knowledge being generated converge and set off actual horizontal complementarities. The distinction between related and unrelated variety both in knowledge and geographical space becomes crucial (Frenken, Van Oort, Verburg, 2007).

An analysis of the flows of pecuniary externalities between industries within vertical filieres makes it possible to understand the dynamics of innovation cascades. Introducing technological innovations in upstream activities provides new idiosyncratic factors when and if proximity in regional and knowledge space between users and producers gives downstream firms privileged access to the new products, especially if they can be used as production factors. The supply of new idiosyncratic inputs by upstream producers pushes downstream users to direct their technological change towards their intensive use in order to increase knowledge appropriability. The increased derived demand for their products activates demand pull effects upon the rate and direction of technological change in upstream industries.

The notion of innovation cascades can contribute to the long-standing debate about Marshall and Jacobs externalities. Innovation cascades are the result of the interaction between Jacobs and Marshall externalities. At each point in time in fact Jacobs pecuniary externalities in knowledge generation stem from the horizontal complementarity among firms active in a well-defined variety of industries. Such complementarity leads to the introduction of innovations that affect downstream industries. The introduction of innovations in upstream industries in fact affects the factor markets for perspective downstream users. At this point Marshall externalities play a role. Downstream firms have an incentive to try and take advantage of the localized availability of innovations supplied by upstream activities. Pecuniary externalities in knowledge exploitation occur along vertical filieres. Actually vertical filieres are the result of downstream users introducing directed technological change in an attempt to exploit pecuniary externalities through the introduction of directed technological knowledge that leads to the intensive use of new inputs so as to increase the chances of appropriation. Innovation cascades are the result of the dynamic complementarity among intra-industrial and inter-industrial externalities (Van der Panne and Van Beers, 2006).

Fransman (2007) provides clear evidence regarding the key role of vertical and horizontal knowledge complementarity in an emerging information and communication system. The innovation capabilities of firms within each layer are conditioned by the flows of technological knowledge that occur within each layer and between layers embodied in the advanced inputs supplied by upstream providers and vice-versa. The supply of pecuniary knowledge externalities by upstream innovators provides the opportunities for the creation of new activities in downstream applications. Innovative users in turn push upstream producers to introduce further innovations[7].

The framework elaborated so far provides the basic elements to understand not only the persistent growth of many ‘traditional’ sectors organized in industrial districts, but also the growth dynamics of many new knowledge districts of knowledge-intensive business suppliers based upon skilled manpower. The interplay between pecuniary externalities in knowledge generation and knowledge exploitation provides the context into which small firms with low levels of formalized R&D activities are able to introduce fast rates of innovation based upon the horizontal complementarity between their own knowledge base and the systematic direction of the new technologies towards the use of locally abundant production factors supplied by upstream innovators. The growth of the Italian industry in the second part of the XX century, with special reference to the industries of general machinery, machine tools, food, garments, textiles, furniture, jewelry, leather, tiles and other ceramic products, shows how the reciprocal access to the local pools of the competence and expertise of designers, marketing experts and stylists provides opportunities to increase the capability to generate technological knowledge. The growth of upstream niches specializing in the supply of high quality and dedicated inputs ranging from machinery to intermediary inputs designed to support downstream production provides the second leg to the dynamics. The local supply of capital and intermediary inputs gave downstream users the opportunity to increase the exploitation of the new knowledge being generated as well as the opportunity to take advantage of intensive user-producers interactions. The creation, through

[7] This analysis reveals how the well-known ‘infant industry’ argument can be enriched: the lack of advanced upstream suppliers can inhibit or delay the birth of new downstream industries.

innovation cascades, of vertical filieres articulated in an increasing numbers of layers of specialized activities has been the ultimate result of such a dynamics of converging technological change. The paradox of low levels of R&D activities and huge increases in total factor productivity levels seems solved: as a matter of fact such an organization of industrial and technological activity is far more knowledge-intensive than aggregate statistics can measure (Antonelli and Barbiellini Amidei, 2007).

Quite the same dynamics seems to apply to the new clusters of knowledge intensive business services such as is found in the legal, logistics, software, entertainment, cultural, finance, engineering industries. Here again, firms activate the convergence of their knowledge generation activities in an effort to take advantage of the local pools of collective knowledge and direct the exploitation of the new knowledge being generated towards the intensive usage of locally abundant and yet idiosyncratic production factors. In turn, the supply of such locally abundant factors is the result of the rapid pace at which innovations are introduced by firms in upstream industries that rely upon pecuniary knowledge externalities based upon enforced knowledge complementarities. The process eventually leads to the emergence of an articulated structure of layers of vertical and horizontal complementarity among highly specialized service firms. There are high levels of vertical flows of exchanges among layers and horizontal knowledge interaction within each layer within intermediary markets (Bresnahan, Gambardella and Saxenian, 2001; Vicente and Suire, 2007).

5. CONCLUSIONS

The distinction between pecuniary and technological externalities in the economics of knowledge and innovation is fruitful. It suggests that an understanding of the characteristics of the knowledge and geographical space into which firms are rooted plays a key role in the implementation of successful strategies for the localized generation and exploitation of knowledge. Pecuniary externalities make it possible to understand the role played by external factors in shaping the direction of technological change. An awareness of the distinction between pecuniary externalities and technological externalities in the economics of knowledge suggests that an understanding of the whole range of characteristics of the region into which firms are rooted -including the structure of knowledge governance mechanisms, the local factor markets and the vertical structure of interindustrial relations- plays a key role in the implementation of successful strategies for localized knowledge generation and exploitation.

When, rather than focusing only on the diachronic building of knowledge, the role of the synchronic integration of knowledge, dispersed among a variety of agents, is considered, pecuniary knowledge externalities stemming from the localized complementarity of agents, emerges as a crucial factor in shaping the generation of new knowledge.

Strong positive effects, in terms of reduced knowledge generation costs stemming from knowledge complementarity, reduced production costs engendered by the ensuing directed technological innovations that make an intensive use of locally abundant factors and increased knowledge localized appropriability based upon the use of idiosyncratic –either locally available or internally created- production factors, provide a clear incentive to direct the generation of new knowledge depending on the local knowledge networks and endowments. This strategy can exert positive effects not only on the growth of firms but also upon regions and industries able to implement the local pools of collective knowledge by means of effective knowledge governance mechanisms.

The dynamics of the process can continue as long as institutional and organizational changes are introduced so as to counteract the decline in the levels of pecuniary externalities stemming from low knowledge governance costs and relative abundance of idiosyncratic inputs. The continual recreation of pecuniary knowledge externalities is crucial for the process to keep momentum.

The localized context of action emerges as a fundamental aspect of the innovation process, one that makes it possible to understand that a variety of paths to innovation can exist successfully. An understanding of the key role of the localized context where technological knowledge is being generated and exploited opens up new horizons of empirical enquiry regarding the variety of types of knowledge that different groups of firms, active in different contexts, have an incentive to generate.

Depending on the local endowments, articulated in material inputs, skills and mechanisms of knowledge governance, firms have clear incentives to identify and implement a specific typology of technological knowledge and the ensuing technological innovations. In a heterogeneous system, where local endowments differ, firms do not compete on the same knowledge frontier but, instead, have a strong incentive to identify the kind of technological knowledge that is more appropriate to their own specific conditions and traditions. Such specific conditions are not only internal to each firm, as the resource-based theory of the firm argues, but also external. Consequently, a variety of localized paths to technological change are likely to emerge and consolidate. Firms based in countries and regions with a stronger scientific infrastructure have an advantage in the introduction of science-based technologies. This is not necessarily the case for firms based in countries where the endowment of human capital is lower or different. The distinction between skills acquired on-the-job and skills based upon formal education, for instance, has important consequences. The specific characteristics of the industrial structure also play a major role here. Firms based in countries and regions specialized in capital goods have a structure of incentives to align their knowledge generating activities that differ from that of firms based in countries specialized in supplying final goods. In the globalized learning economy, regions have a strong incentive to pursue dedicated and specialized knowledge strategies based upon their own endowments in terms of both knowledge generation and knowledge exploitation mechanisms (Scott and Storper, 2007).

Pecuniary knowledge externalities are a crucial tool to understand the complex dynamics of network creation that underlies the path dependent emergence of local and sectoral innovation systems as well as the dynamics of innovation cascades. Thus pecuniary knowledge externalities are an important tool in implementing an articulated economics of complexity.

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