Via Po, 53 – 10124 Torino (Italy)
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THE EMBEDDED GENERATION OF KNOWLEDGE: CONTEXTUAL SPILLOVERS AND LOCALIZED APPROPRIABILITY

Cristiano Antonelli

Dipartimento di Economia "S. Cognetti de Martiis"

Laboratorio di Economia dell'Innovazione "Franco Momigliano"

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THE EMBEDDED GENERATION OF KNOWLEDGE: CONTEXTUAL SPILLOVERS AND LOCALIZED APPROPRIABILITY[1]

CRISTIANO ANTONELLI

UNIVERSITA' DI TORINO
LABORATORIO DI ECONOMIA DELL'INNOVAZIONE
DIPARTIMENTO DI ECONOMIA

ABSTRACT. The new understanding about the characteristics of knowledge indivisibility and knowledge appropriability stresses the key role of external factors both in the generation and exploitation of technological knowledge. The combined effect of internal learning, external knowledge and the conditions for embodied appropriation associated to the intensive use of idiosyncratic factors by means of the introduction of biased technological change, provides key inputs to understanding the path dependent stratification of the directed features of the knowledge generated by firms as the basis for building their distinctive competences and the economic success of regions.

KEY WORDS: KNOWLEDGE COMPLEMENTARITY AND EMBODIED APPROPRIABILITY; DIRECTION OF TECHNOLOGICAL CHANGE; PATH DEPENDENCE; STRATIFICATION.

JEL CLASSIFICATION: O31

1. INTRODUCTION

The new analysis of the characteristics of knowledge indivisibility and appropriability makes it possible to appreciate the key role of external idiosyncratic factors in shaping the intentional strategy of firms about the direction of technology strategies. These strategies lead to the introduction of directional technological change based upon the identification and combination of the external sources of complementary technological knowledge and of the idiosyncratic production factors that is convenient to use intensively both to reduce production costs and to increase the markup.

The generation of new knowledge is viewed as the result of an intentional conduct induced by a specific process that can be successfully implemented only when a number of key conditions apply. Learning and research and development activities are a necessary, but not sufficient condition for the generation of new knowledge. External factors play a key role both in the intentional generation and exploitation of

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technological and organizational knowledge. The combined effect of internal learning, external knowledge and the conditions for exploitation associated to the intensive use of idiosyncratic factors by means of the introduction of biased technological change provides key inputs to understanding the path dependent features of the knowledge generated by the firm properly embedded in the local context and of successful regional growth.

In this paper the role of knowledge indivisibility and appropriability, respectively in the generation and exploitation of new knowledge, is discussed in section 2. Specifically Section 2.1 explores the implications of knowledge indivisibility for the generation of new knowledge. Section 2.2 elaborates the implications of knowledge appropriability in terms of the exploitation of a directional knowledge that makes it possible an intensive use of idiosyncratic production factors and hence obtain both a reduction in production costs and an increase in the levels and duration of transient rents. Section 3 provides a simple model that brings together in a single framework the two lines of analysis and spells out the basic methodology for the identification of the focusing mechanisms that shape the direction of the inventive activity of firms. Section 4 explores some of the implications of the analysis in terms of the variety of possible kinds of technological knowledge according to the characteristics of the local contexts and stresses the path dependent aspects of this dynamic process. The conclusions highlight the role of the selective generation and exploitation of knowledge, as a strategy towards the creation and exploitation of the distinctive competence of firms and regions.

2. THE NEW ECONOMICS OF KNOWLEDGE INDIVISIBILITY AND APPROPRIABILITY

The economics of knowledge has made substantial progress in recent years and has provided a new and better understanding of the characteristics and implications of knowledge as an economic activity. The appreciation of knowledge indivisibility has led to a better assessment of the role of external knowledge. The new analysis of knowledge appropriability, based upon the conditions of usage and application to downstream production processes, has shed new light upon the incentives to bias technological change towards the intensive use of idiosyncratic production factors. The combined appreciation of these two characteristics becomes a powerful tool to understand the criteria by means of which firms select the direction of the generation of new technological knowledge. Let us analyze them in detail.

2.1 THE ROLE OF KNOWLEDGE INDIVISIBILITY IN THE INTENTIONAL GENERATION OF NEW KNOWLEDGE

Following the analytical track initiated by Nelson (1959) and Arrow (1962) the analysis of knowledge indivisibility has been mainly articulated in terms of diachronic indivisibility: new vintages of knowledge build upon the 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 (Griliches, 1992).

This new thinking about knowledge indivisibility has been reinforced by the understanding that knowledge is not only an output but also an input. Knowledge generated in a specific field and at a specific time for a dedicated purpose is an output. It is also, however, an essential input into the generation of other knowledge both synchronically e.g. in other complementary fields at the same time and diachronically, e.g. cumulatively either in the same or in other fields (David, 1993; Stiglitz, 1994).

As a consequence it is now clear that no firm can command all the knowledge that is necessary to generate new knowledge. Knowledge external to the firm, at each point in time, is a necessary and relevant complement to knowledge internal to the firm, in order to generate new knowledge. Because of the intrinsic indivisibility of technological knowledge, the successful generation of new knowledge depends upon the access to external knowledge (Antonelli, 2001).

The generation of new knowledge is the specific outcome of an intentional conduct and requires four distinct and specific activities: internal learning, formal research and development activities, and the acquisition of external tacit and codified knowledge (See Table 1). 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 no 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, 2005 and 2006b).

External knowledge can be accessed by means of a variety of tools, ranging from transactions in the markets for knowledge to an array of interaction modes with public research centers, customers, suppliers and competitors including the hiring of qualified personnel embodying the competence acquired by means of learning in other companies, the creation of technological clubs and technological platforms, acquisition of new high-tech companies and mergers with other firms in order to acquire specific knowledge modules (Arora, Fosfuri and Gambardella, 1994; Amin and Cohendet, 2005).

The acquisition of external knowledge is made difficult by relevant transaction, networking and absorption costs. The cognitive distance among agents, the complementarity in competence and research agenda, the levels of trust, the institutional setting, the quality of knowledge governance mechanisms put in place, are key factors. When external knowledge is available, at low total costs that include the sheer costs of the purchase of knowledge and knowledge transaction and networking costs, the firm needs to manage the absorption and inclusion of external knowledge into the research process. External knowledge is only potentially useful: systematic efforts have to be done in order to take advantage of such possibilities. Only when a corporation is able to fully combine all the learning and research activities conducted within its boundaries with the relevant sources of external knowledge, both tacit and codified, new knowledge can be successfully generated (Cohen and Levinthal, 1990; Teece, 2000).

TABLE 1: MODES OF PRODUCTION OF NEW TECHNOLOGICAL KNOWLEDGE

	TACIT KNOWLEDGE	CODIFIED KNOWLEDGE
INTERNAL KNOWLEDGE	**LEARNING**	**RESEARCH & DEVELOPMENT**
EXTERNAL KNOWLEDGE	**NETWORKING INTERACTIONS WITH CUSTOMERS, RIVALS, ACADEMICS AND SUPPLIERS; HIRING OF QUALIFIED PERSONNEL**	**KNOWLEDGE TRANSACTIONS WITH KIBS AND UNIVERSITIES; PURCHASE OF PATENTS AND LICENCIES IN THE MARKETS FOR KNOWLEDGE; MERGERS & ACQUISITIONS OF HIGH TECH START-UPS**

According to the levels of knowledge transaction, networking and absorption costs, the sheer purchasing costs of external codified knowledge and the costs of internal research and learning activities, firms can select the 'best' mix of knowledge inputs. It is clear, for instance, that when and where external knowledge is cheap, both because of low purchasing costs in the markets for codified knowledge, low knowledge transaction and networking costs, firms will rely less on internal learning and research activities. On the opposite, when and where, the access to external knowledge is difficult, firm will rely more on internal research and learning activities (Pisano, 1990)[2].

This approach has two important implications about the costs and the characteristics of the technological knowledge being generated by the firm. First, and most important, for a given budget, firms that have access to 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' context by a single firm that can rely almost exclusively on its own internal competence[3].

Second, firms select the characteristics of the technological knowledge they can generate, according to the characteristics of the context into which they are embedded. As a consequence the knowledge generated with a strong content of external localized inputs, has a stronger idiosyncratic and contextual character (Nooteboom, 2003 and 2004). When external knowledge is less available and absorption costs are high, firms generate less knowledge and rely more on internal research efforts. Occasionally, however, they can succeed in implementing a technological knowledge that has a stronger scientific content and applies to a larger variety of technical solutions. Generic knowledge has a wider scope of applicability and generality.

2.2. THE ROLE OF EMBODIED APPROPRIABILITY IN THE EXPLOITATION OF KNOWLEDGE

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[2] This analysis provides a clue to understanding the puzzling evidence about the low levels of formal research activities of firms localized in fertile and dynamic technological districts. Here the notion of localization acquires a strong geographic, cognitive and institutional character.

[3] It is important to stress once more that in our approach the firm cannot rely exclusively on its internal competence and internal research activities because of the intrinsic complementarity and the limited substitutability between external and internals sources of knowledge

Following the approach elaborated by Nelson (1959) and Arrow (1962) the analysis of knowledge appropriability has been mainly developed considering knowledge as an economic good per se. Disembodied knowledge can be appropriated both because of high levels of 'natural' appropriability and the effects of strong and effective intellectual property right regimes. In such circumstances firms have a strong incentive to produce knowledge as a product per se. Markets for knowledge can emerge and regular knowledge transactions can take place with the well-known positive effects in terms of division of labor, specialization and efficiency (Arora, Fosfuri and Galbardella, 2001; Guilhon, 2004). When knowledge is characterized by low levels of natural appropriability that are poorly served by intellectual property rights, embodied appropriability becomes relevant.

Following a well established line of analysis of technological change at the system 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, 1998). Yet little attempt has been made, so far, to integrate this approach -centered upon the analysis of the aggregate direction of technological change- with the analysis of the conditions of usage of knowledge as an incentive towards the selection of knowledge generation strategies at the firm and regional level. The direction of technological change 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, 2003 and 2006a).

It has been well known for quite a long time that knowledge generation is a localized joint-product of manufacturing where learning by doing and learning by using play a key role (Atkinson and Stiglitz, 1969; Rosenberg, 1976; Antonelli, 1995). It is now more and more clear that also knowledge exploitation is a joint-product of manufacturing activities. The conditions of knowledge usage affect sharply its appropriability: the notion of embodied appropriability has important consequences (Antonelli, 2003).

The identification and valorization of local and idiosyncratic resources that it is convenient to use intensively becomes a clear and strong focusing device along which firms can align their research activities. The conditions for exploitation of knowledge feed back on the generation of new technological knowledge (March, 1991; Nooteboom, 2003).

Knowledge can be exploited and better appropriated when its application and usage impinge upon selective production factors characterized by asymmetric access conditions. The productivity of new technological knowledge, when applied to the actual production process, and the appropriability of the economic value stemming from its use, are much influenced respectively by the relative price and the conditions of access to the production factors being used. Firms that are able to identify idiosyncratic production factors upon which they exert a specific control that enables low purchasing costs, can direct the introduction of new technologies so as to increase their role in their production process, and make an intensive use. The local social value of directed technological change is higher. When such local factors are idiosyncratic and other firms cannot use them at the same conditions, innovators are able to extract much higher rents from their knowledge generation activities for much a longer period of time. In this case the innovator can increase the private value of the innovation[4].

Schumpeterian market dynamics provides the basic elements to fully understand the mechanism at work. Since 'The theory of economic development' by Joseph Schumpeter it is well known that innovators can take advantage of a monopoly power that is, however, transient. Extra profits associated with the introduction of successful innovations stimulate the imitative entry of newcomers. Increased competition drives price-cost margins to minimum levels.

In this context, the more specific is the technology introduced by innovators, i.e. the more it makes possible an intensive use of idiosyncratic production factors that are specific to innovators, and the less likely is the possibility that newcomers, even when and if they succeed in grasping 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 innovators because of the differences in the costs of production factors.

Innovators relying 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. The latter 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 the broader basket of niches competing for the demand of similar customers and the levels of cross price elasticity, that is the mobility of customers across the different niches.

In sum, 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 so as to reduce production costs, the local social value of technological knowledge is larger. The private share of such a larger social value, is larger when barriers to entry and imitation, based upon the intensive use of idiosyncratic production factors, prevent the dissipation of the economic rents stemming from their introduction and hence increase de facto knowledge appropriability.

[4] The quest for idiosyncratic inputs can take place both internally and externally. Building upon Edith Penrose, in fact, we see that firms have an incentive to generate internal production factors that are idiosyncratic because they are the result of a specific learning process: as such are difficult to replicate for other agents which do not share the very same historic process of growth. Stretching the argument elaborated by Edith Penrose we argue that the identification and exploitation of distinctive external factors that other firms cannot access easily at the same price, have similar effects at the regional level in terms of incentives and focusing mechanisms upon the direction of technological knowledge. This is all the more true and interesting in a globalized economy where firms localized in different factor markets compete on quasi-homogenous global product markets.

The new understanding of the role of knowledge embodied appropriability leads to a new appreciation of the idiosyncratic character of production inputs and its productive and competitive effects. 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. The 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, when competitors have not access to the same factor markets.

3. THE EMERGENCE OF THE DIRECTION OF TECHNOLOGICAL CHANGE

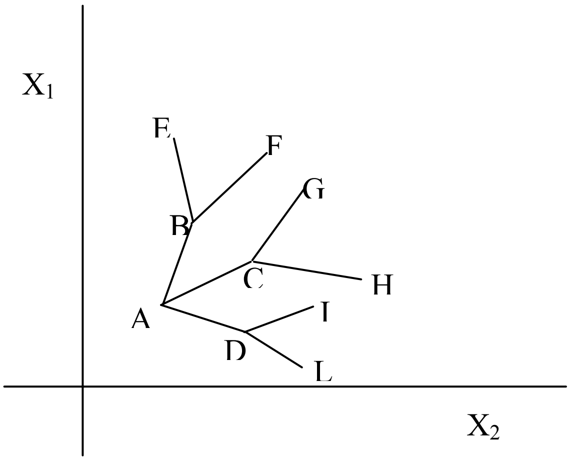
The appreciation of the constraints and opportunities provided by knowledge indivisibility and embodied appropriability makes it possible to frame in a single framework the analysis of the incentives that contextual and localized factors exert in shaping the direction and the characteristics of the new knowledge generated by firms.

Although learning localizes the cognitive base of firms in a limited spectrum from the original focal point of activity, there are still many possible directions along which the generation of new technological knowledge can be aligned. The choice among an actual array of possible knowledge modules becomes a crucial issue. As a matter of fact at each point in time the firm has in front a variety of possible directions towards which the creative activities can be ordered. Each needs to be assessed and the relative profitability needs to be valued both from the viewpoint of the costs of introduction and the revenue stemming from its application.

As Table 2 shows at each point in time the learning firm has the opportunity to move in a Lancastrian (Lancaster, 1971) space of knowledge characteristics and related technological characteristics, branching out from the original point A to a variety of points B, C, D. Each of the new points exhibits an improvement and a change and it is the result of the generation of new technological knowledge and of the introduction of new technologies. In the subsequent unit of time, t_2 the learning firm has again opportunity to further branch out from the new points B, C, D towards the points E and F if it had reached point B at time t_1 , the points G and H, if it had reached point C at time t_1 , and points I and L if it had reached point D at time t_1 . The theory of the firm, so far, is able to explain retrospectively why and how the learning firm has moved from any of such points to the next and indeed, each of the points generated sequentially, is related to the previous vintages by clear elements of cumulability along a technological trajectory. The direction of the selected trajectory however can be identified only ex-post. From an ex-ante perspective the theory of the firm does not supply any strong analytical support to elaborate possible hypotheses about the direction of the future steps (Dosi, Nelson, Winter, 2000).

INSERT TABLE 2 ABOUT HERE

FIGURE 1. THE DIRECTION OF THE GENERATION OF KNOWLEDGE



Here an important step forward can be made if the factors that constraint the selection of the direction of the sequential steps and act as focusing mechanisms are identified and analyzed within a single framework. The new characteristics of knowledge indivisibility and appropriability –e.g. knowledge complementarity and embodied appropriability- make it possible to identify such focusing mechanisms. Our basic argument can be spelled out as follows: firms have an incentive to direct the generation of new knowledge according to the contextual spillovers of complementary knowledge and the localized conditions of embodied appropriability.

The analysis of knowledge indivisibility has made clear how relevant is the access to external knowledge. The analysis of knowledge appropriability as a joint-product of manufacturing has stressed the key role of the intensive usage, by means of the introduction of biased technological changes, of local and idiosyncratic production factors. The combination of these two and complementary arguments makes it possible to identify in the local context a powerful focusing mechanism of the direction of new technological knowledge.

Let us start from a population of heterogeneous firms, distributed in different regions that have access to different sources of knowledge and factor markets. 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 valorisation of internal learning, the conduct of formal research and development activities, and the acquisition of external knowledge, both tacit and codified. Such activities entail the assessment of specific costs such as the costs of the coordination of the valorisation of internal learning, the knowledge transaction costs necessary to 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 freely in the air: its acquisition is itself the result of intentional activities. Relevant absorption costs add to the actual costs of external knowledge[5]. 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

[5] Absorption costs of external knowledge do matter and affect the research strategies of firms. When technological knowledge has high absorption costs firms will rely more upon internal inputs (Griffith, Redding, Van Reenen, 2003).

has a clear incentive to direct the generation of new technological knowledge towards applications that make it possible to make an intensive use of locally and internally abundant factors that have a strong idiosyncratic character. In so doing, in fact, firms can generate more knowledge, produce at lower costs and take advantage of barriers to imitation based on idiosyncratic production conditions.

In a heterogeneous population of firms engaged in the effort to generate new knowledge and appropriate its benefits in terms of extra-profits, each firm can discover that the alignment of their internal research activities along the complementarity with the research activities of other firms co-localized and the identification of the local idiosyncratic production factors is a powerful factor of competitive strength. The creation of distinctive competences requires the systematic exploitation of the characteristics of the local context. For the same token a consistent directionality of technological knowledge is the collective result of a process of convergence of co-localized firms able to integrate their own specific competence with the features of the local context. This analysis can be understood as a discovery process articulated upon the sequence of three steps.

Localized learning is the basis for the generation of new knowledge. As such it consists of enriched techniques, typically found in the technical region where each firm is localized. Other basic sources of knowledge enter the knowledge production function: research and development, external codified and external tacit knowledge. The costs equation includes the costs of internal research and learning activities, including coordination costs, the total costs of external codified knowledge, including knowledge transaction and networking costs for external tacit knowledge.

We shall assume that each firm has a budget available to fund activities for the generation of new knowledge[6]. Let us specify the following knowledge production function and knowledge cost equation:

(1) $KN = (R\&D\&L^{a}, EK^{b})$,
(2) $TCK = (jR\&D\&L + zEK)$,

where KN is the knowledge generated, R&D&L are the internal research, development and learning activities to generate new knowledge, j are their unit costs; EK is the external knowledge and z its unit cost that includes the pecuniary costs of purchase, when possible, and the costs of knowledge transaction, networking and absorption activities that are necessary in order to acquire and use it.

With standard maximization procedures it is immediately clear that the lower are the unit costs of external knowledge and the larger is both the amount of knowledge that the firm is able to generate and the larger is its localization in the specific context[7]. A

[6] See Antonelli (1995) for the full specification of the inducement mechanism within the context of the localized technological change approach.

[7] The identification of the best mix of inputs depends upon the specific form of the knowledge production function. When the notion of partial substitution built into the traditional Cobb-Douglas specification is recalled, however, it is clear that standard maximization procedures make it possible to identify the 'best' mix of knowledge inputs, provided that the shape of the envelop curve which defines the region where substitution is possible, reflects properly the large size of the regions where complementarity among knowledge inputs apply.

firm that is located in a conducive knowledge environment, and is able to identify and access the local pools of knowledge at low costs, is induced to take advantage of it and hence to root the generation of its new knowledge in the characteristics of the environment into which it is based (Nelson, 1982; Patrucco, 2008)[8].

It is clear that the amount of knowledge generated when $z<j$ and firms are able to align their research strategies so as to take advantage of locally abundant knowledge, is larger. Consistently in the downstream applications firms can rely upon a larger increase in efficiency with the same amount of budget available to fund the generation of new knowledge. The amount of knowledge generated has a direct effect upon the general efficiency of the production function:

(3) $A = l\,(KN)$,

where A measures the general efficiency of the production function, i.e. the neutral shift towards the origins of the map of isoquants. It is clear that the larger is KN and the larger the shift effect A. Firms that are able to take advantage of the local pools of collective knowledge can produce at lower costs.

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 shift efficiency engendered in the production process, but also on its characteristics. Firms that rely more upon internal knowledge are more likely to produce generic knowledge. Firms that rely more upon external knowledge are more likely to produce idiosyncratic knowledge.

This amounts to saying that the generation of idiosyncratic technological knowledge leads to the introduction of idiosyncratic technological change that shapes the production function in such a way that the output elasticity of idiosyncratic production factors (I) is much higher than the output elasticity of generic production factors (G). This is convenient when, for the innovating firm, locally abundant production factors are available at a price (r) that is lower than the price of the other production factors (p): i.e. when $r<p$. Conversely the introduction of generic technological change has no effect on the ratio of output elasticities. In other words the generation of (more) generic knowledge leads to the introduction of a (more) neutral technological change with no modifications in the output elasticity of the production factors G and I.

To make this point clear let us consider a standard production function prior to the introduction of the new technology:

(4) $Y(t) = (I^E\ G^F)$,

where I and G are respectively the idiosyncratic and generic inputs; E and F measure their output elasticities.

[8] The argument becomes stronger when the efficiency of external knowledge is larger than that of research and development activities ($a>b$), but holds even when the efficiency of internal research and development activities is larger than that of external knowledge ($a<b$).

After the introduction of respectively generic and idiosyncratic, hence biased, technological changes, the new alternative production functions can be specified as it follows:

(5) $Y(t+1)_g = A\ (I^u\ G^v)$,
(6) $Y(t+1)_I = A\ (I^s\ G^t)$,
(7) $C = rI + pG$,
where at time t+1 after the introduction of the new technology, Y_I is the production process that uses idiosyncratic technological knowledge and Y_g is the production process that uses generic technological knowledge; u, v. s, and t measure the different output elasticities with u=E; s>E, and possibly, s>t when r<p.

Let us now consider the effects of the alternative directions 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 the goods manufactured by means of an intensive use of locally abundant factors are lower than the costs of the goods manufactured with inputs that are available to every firm at the same price. On the top of this, we see that the efficiency of the two production processes differs because of the larger amount of knowledge that 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 costs of the goods that have been manufactured with an idiosyncratic technology (CY_I) are lower than the costs of the goods that have been manufactured with a generic technology (CY_G):

(8) $CY_I < CY_g$.

Finally, we consider the price at which the goods that have been manufactured with the new technologies can be sold. The products manufactured with a more idiosyncratic technology, that make a more intensive use of the locally abundant factors, including those internal to the firm, that not available at the same conditions to competitors, enjoy systematic cost asymmetries with respect to imitators and hence can take advantage of 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 they products, far higher than those of competitors. This is not the case when technological change is generic: every firm can use production factors that are not idiosyncratic. Hence new competitors can imitate the new technology and their entry drives the prices to competitive levels. Clearly the prices of products manufactured with a higher intensity of idiosyncratic inputs (P_I) are higher than the prices of the products manufactured with a low intensity of idiosyncratic inputs (P_G). Search processes might also be directed towards those knowledge outcomes that are much easier to protect through IPRs. Rivette and Kline (1999) offer some examples of firms that have chosen product designs much easier to patent. The possibility of protecting knowledge through formal property rights is also a powerful driver of the process of knowledge generation[9]. In these circumstances, moreover, the mark-ups of idiosyncratic-intensive firms are likely to last longer.

[9] I owe these remarks to one of the anonymous referees,

Equations (5) and (6) can be combined into the traditional frontier of possible production:

(9) $Y_G = e\ (Y_I)$

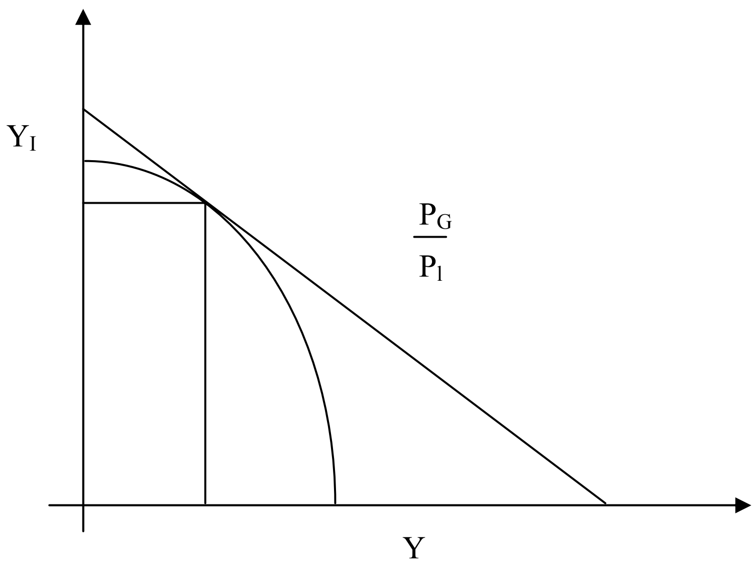
The solution to the optimization problem is easily found with an isorevenue that defines the possible revenues that can be earned with the alternative production functions considered. The slope of the isorevenue measures the ratio of the prices of the products manufactured with a new generic technology (P_G) to the prices of the products manufactured with a new localized technology (P_I). The equilibrium is found where:

(10) $d\ Y_g / d\ Y_l = P_I / P_G$

Clearly there are stronger incentives to select the mix with more biased technologies, than generic ones. A simple geometric exposition can help to grasp the point. As it is shown in Table 3, the shape of frontier of production possibilities which considers the trade-off between the levels of output Y_l which can be attained with the introduction of a new technology that makes intensive use of locally abundant and idiosyncratic production factors and the levels of output Y_G that can be attained with the introduction of a new technology which use generic production factors, is clearly asymmetric. Moreover the slope of the isorevenue, much smaller than 1, reflects the positive effects for innovators of the price asymmetry with respect to imitators, which have not access to the same idiosyncratic production factors. Optimization clearly favors the introduction of a mix of technologies based upon the intensive use of locally abundant and idiosyncratic production factors.

Firms 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 because of four factors: a) lower research costs, b) lower production costs, c) higher product prices, d) barriers to entry and imitation lasting for a longer stretch of time.

TABLE 3. OUTPUT AND REVENUE MAXIMIZING INCENTIVES TO MAKE INTENSIVE USE OF IDIOSYNCRATIC INNOVATIONS



In sum, the generation of technological knowledge and the eventual technological change is directed by: a) the conditions of access to local pools of external knowledge and participation in commons of collective knowledge where interactions and transactions are shaped by proximity; b) the costs-reducing use of locally abundant production factors; c) the profit-increasing use of local idiosyncratic production factors. According to the value and weights of these parameters the characteristics of new knowledge and the direction of technological change (See Table 1) can be assessed ex ante.

4. IMPLICATIONS FOR EMPIRICAL ANALYSIS AND TECHNOLOGY POLICY

The implications of the analysis are far reaching. The analytical frame suggests that the appreciation of the characteristics of the region into which firms are rooted plays a key role in the implementation of successful knowledge strategies.

For the firm this implies that the identification and exploitation of the sources of external knowledge and of the idiosyncratic production factors that is more convenient to use intensively, contributes to shape the technology strategy. The analysis of localized spillovers and contextual appropriability becomes a key component in the creation and exploitation of the distinctive competence of the firm. For the region this provides basic guidance for understanding the factors upon which a successful technology policy can be implemented.

The appreciation of the key role of the regional context where technological knowledge is being generated opens new prospects of empirical enquiry about the variety of types of knowledge that different groups of firms, localized in different contexts, have an incentive to generate. The key role of the direction of technological change, as a fundamental aspect of the innovation process, makes it possible to understand that a variety of paths to innovation can persist successfully.

According to the local endowments, articulated in material inputs, skills and mechanisms of knowledge governance, firms have clear incentives to identify 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, on the opposite, have a strong incentive to identify the kind of technological knowledge that is better appropriated 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 contends, but also external. As a consequence, a variety of paths to technological change is 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 final goods. In the globalizing 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 (Archibugi and Lundvall, 2001).

The well-known positive effects of the division of innovative labor in terms of specialization, trade and increased efficiency, that are possible at the firm level when knowledge has high levels of 'natural' appropriability and intellectual property rights are effective, can be reaped, even when the 'natural' appropriability of knowledge is low, in a global economy, at the regional level. This is possible when and if the local commons of collective knowledge are implemented and enriched within regions by the consistent research strategy of firms able to understand the key role of contextual spillovers and localized embodied appropriability so as to generate and introduce, with the support of local government, technological knowledge and hence technological innovations with a strong local content and a clear directionality.

Both at the firm and the regional level these processes are likely to take place with a strong non-ergodic and sequential stratification (David, 1994). At each point in time, each firm, based in a region where knowledge transaction, networking and absorption costs are low, is induced to take advantage of available external knowledge and hence to select a direction for the generation of new knowledge that reflects the proximity to firms localized nearby both in spatial, cognitive and technological space. Additional flows of external complementary knowledge become available in the same space and reinforce the process. At the same time better knowledge governance mechanisms are likely to be implemented and stronger communication channels among firms are likely to emerge. Moreover the systematic implementation of complementary research strategies is likely to have positive effects on knowledge absorption costs for each firm. Larger and more accessible commons of collective knowledge consolidate and push innovating firms to rely more systematically upon external knowledge. The process is further reinforced by the selective use of idiosyncratic production factors. A larger derived demand for local factors is likely to favor their additional supply with further benefits in terms of specialization, especially when distinctive skills are a core, idiosyncratic input[10].

This new progress in the analysis of the effects of the characteristics of technological knowledge helps grasping its path dependent dynamics (David, 2000). The new thinking on knowledge indivisibility stresses the role of the external environment in the form of the conditions of access to the local pools of collective knowledge. The new thinking on knowledge appropriability stresses the role of exploitation as a joint-product of manufacturing and hence of biased technological change. The path dependent dynamics stems from the interplay between past dependence and intentional action. Learning together with the features of the local pools of knowledge and of the economic structure are the past dependent components as they are at each point in time the result of historic accumulation. The interaction of agents with the existing past dependent features, in terms of the amount of knowledge and the direction of technological change being generated, 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 however the new layers can modify, according to their thickness and density.

At each point in time the generation of new knowledge by each firm is influenced by the dynamics of internal learning, by the structure of local interactions that shape the access to the knowledge generated within the system and by the structure of local endowments. Each firm, however, is able to interact with the system and change it. This takes place at three levels: by changing the amount of knowledge made available to the other firms, by changing the structural conditions of the systems in terms of knowledge governance mechanisms and topology of communication channels, and by changing the factor markets by means of changes in the derived demand for production factors.

5. CONCLUSIONS

The new understanding of knowledge indivisibility and knowledge appropriability provides important clues to assessing the selection of the direction of technological knowledge.

The generation of new knowledge is not the automatic and spontaneous product of internal learning processes. Internal learning is a necessary, but not sufficient condition for the generation of new knowledge.

Because of intrinsic knowledge indivisibility both in terms of knowledge cumulability and complementarity and its twin character of both an input and an output, the acquisition of technological knowledge external to each firm is a necessary and indispensable activity in the generation of new knowledge. Hence firms are pushed to select the generation of new knowledge so as to make the best use of external knowledge that is available within the local knowledge networks. When 'natural' knowledge appropriability is low, innovating firms have a strong incentive towards the generation of technological knowledge that makes possible the introduction of an

[10] It seems worth noting that the process can be harmed by the reduction in variety and the consequent decline in creative opportunities. This can become an important guideline for local knowledge policies.

intentional biased direction of technological change. The intensive use of locally and possibly internal production factors, that are highly idiosyncratic and hence cheaper for a limited number of users, favors both the productivity of new biased technologies and their profitability because reduces the risks of imitation by rivals who have not access to the same factor markets. Such inputs are made idiosyncratic to the innovating firm by the selection of locational factors and their intentional creation. In so doing firms build an embodied appropriability. Embodied appropriability adds to the appropriability provided by the intellectual property right regime.

Strong positive effects in terms of reduced knowledge generation costs stemming from knowledge complementarity, reduced production costs engendered by the ensuing technological innovations that make an intensive use of locally abundant factors and increased knowledge embodied 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 according to the local knowledge networks and endowments. This strategy can exert positive effects not only on the growth of firms but also upon regions able to implement the local pools of collective knowledge by means of effective knowledge governance mechanisms.

As a consequence, technological knowledge acquires a strong idiosyncratic character that is indeed influenced by the internal learning processes, but also by the local structure of knowledge interactions and the characteristics of local factor and product markets.

6. REFERENCES

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