PAPERS on Economics & Evolution

MAX-PLANCK-GESELLSCHAFT

0709

Localized Technological Knowledge: Pecuniary Knowledge Externalities And Appropriability

by

Cristiano Antonelli

The *Papers on Economics and Evolution* are edited by the Evolutionary Economics Group, MPI Jena. For editorial correspondence, please contact: evopapers@econ.mpg.de

ISSN 1430-4716

Max Planck Institute of Economics
Evolutionary Economics Group
Kahlaische Str. 10
07745 Jena, Germany
Fax: ++49-3641-686868

LOCALIZED TECHNOLOGICAL KNOWLEDGE: PECUNIARY KNOWLEDGE EXTERNALITIES AND APPROPRIABILITY[1]

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

ABSTRACT.
Recent advances in the economics of knowledge highlight the key role of pecuniary knowledge externalities in explaining the system dynamics of total factor productivity growth. When non-exhaustible technological knowledge is an input both in the production of new goods and of further knowledge, and the acquisition of external knowledge, as a non-disposable input in the production of new knowledge, is not free, pecuniary externalities, as opposed to technological externalities, provide an important clue to understanding the key role of knowledge governance mechanisms in assessing the rate of growth of total factor productivity and economic systems at large. The negative effects upon appropriability limit the advantages of agglomeration.

KEY-WORDS:
TECHNOLOGICAL KNOWLEDGE, PECUNIARY EXTERNALITIES, KNOWLEDGE GOVERNANCE, KNOWLEDGE APPROPRIABILITY.

JEL-CODE: O33

---

[1] Preliminary versions of this paper have been discussed at the Workshop "Regional technological trajectories. Theoretical backgrounds and empirical observations" organized by the Max Planck Institute Evolutionary Economics Group, Jena, Germany, September 27-29, 2007 and at working seminars of the European project EURODITE. I acknowledge the comments of many colleagues and the funding of the University of Torino Research Grants and of the European Union Directorate for Research, within the context of the Integrated Project EURODITE (Regional Trajectories to the Knowledge Economy: A Dynamic Model) Contract nr° 006187 (CIT3), in progress at the Fondazione Rosselli.

1. INTRODUCTION

The literature on knowledge spillovers has been growing exponentially in the recent years. Firms, clustering in geographic and knowledge space take advantage of knowledge spillovers and grow much faster than isolated firms. This literature has elaborated the Marshallian understanding of technological externalities where knowledge is a production factor spilling in the atmosphere of industrial districts. In this perspective technological knowledge is expected to spill freely in the atmosphere, with no costs for perspective users neither to acquire nor to use it: knowledge can be acquired with no transaction and communication costs.

The new growth theory has further elaborated this literature with the distinction between generic and specific technological knowledge. Generic technological knowledge is germane to a variety of uses, while specific technological knowledge is embodied in production processes and routines: as such it has strong idiosyncratic features. Specific knowledge can be appropriated by 'inventors'; generic knowledge instead retains the typical features of the Arrovian public good. The appropriability of specific knowledge provides sufficient incentives for investment in knowledge generating activities. The assumption about the intrinsic complementarity between generic and specific knowledge is the basic engine of the process. Innovators generate generic knowledge while are engaged in the introduction of new specific knowledge embodied in new products and new processes. The production of specific knowledge takes advantage of the collective availability of generic one. The spillover of generic knowledge helps the generation of new specific knowledge by third parties and yet does not reduce the incentives to the generation of new knowledge for the strong appropriability of the specific applications. Each firm has unlimited access to the spillovers of generic knowledge that can be used with no efforts. According to the new growth theory, the unconditional and unconstrained access to generic technological knowledge leads to the spontaneous and ubiquitous increase of total factor productivity and hence the automatic growth of output (Romer, 1990; Jones, 2002).

As a matter of fact the Marshallian analysis of the notion of externalities is much more articulated. Two quite different types of externalities have been identified in the Marshallian literature: a) technological externalities and b) pecuniary externalities. Technological externalities consist of direct interdependence among producers. Pecuniary externalities consist of indirect interdependence. In the former case the interdependence is not mediated by the market mechanisms. In the latter, instead, interdependence takes place via the effects on the price system. Pecuniary externalities exert an effect on the price of production factors and the price of products. Positive pecuniary externalities are found when the latter are below the equilibrium level and the former above.

More precisely, technological externalities take place when unpaid production factors enter the production function of users. Pecuniary externalities affect the production function as well as the cost and the revenue function. Pecuniary externalities apply when the prices of both products and factors differ from equilibrium levels and reflect the effects of external forces.

It seems now clear that the new growth theory and the large empirical literature initiated by Zvi Griliches with the notion of technological spillovers elaborate upon the notion of ‘technological externalities’. This paper explores an alternative analytical path, based upon the notion of pecuniary externalities. Pecuniary externalities provide a novel and fruitful tool to understand the relationship between the generation of technological knowledge, economic growth and total factor productivity growth. So far it has found little application, as the literature has explored more systematically the consequences of knowledge non-appropriability in terms of ‘direct interdependence’ non-mediated by the market mechanism.

The new evidence about the costs of acquisition of external knowledge (Arrow, 1969), the identification of the dual role of technological knowledge elaborated by David (1993), and the new understanding about technological knowledge as a distributed factor (Hayek, 1945). Let us consider them in turn.

Much empirical evidence confirms the early analysis of Kenneth Arrow (1969). The acquisition of technological knowledge requires some dedicated resources. Technological knowledge spills in the atmosphere, but is use entails some costs. Imitation costs are relevant as much as knowledge governance costs articulated in transaction, interaction and communication costs. Because of the intrinsic non-exhaustibility of knowledge, however, the costs of existing knowledge are far below the costs of its generation. Even after the proper assessment of knowledge governance costs it becomes more and more evident that their levels can be lower than the costs of early generation, at least in specific and positive geographic, historic, institutional and sectoral contexts (Antonelli, 2001).

The understanding of the key role of knowledge as an input in the production of new knowledge (David, 1993) adds new elements to understanding the intrinsic complementarity between external and internal sources of knowledge for the production of new knowledge. The legacy of Hayek (1945) finds new support: technological knowledge is viewed as dispersed and fragmented into a variety of complementary and yet specific and idiosyncratic applications and contexts.

In such a new context, where knowledge is viewed as a collective activity, the application of the notion of pecuniary externalities to the economics of knowledge makes it possible:

A) to qualify the systemic characteristics that favor the generation of technological knowledge. Agglomeration within technological systems both in geographical and technological space, favors the generation of new knowledge only in specific contexts where and when positive knowledge externalities that knowledge as an input make available at costs that are lower than equilibrium levels are not offset by negative externalities that reduce the price that knowledge as an output can command in market exchanges. Such circumstances in fact do not hold everywhere and at all time, but only in highly idiosyncratic conditions (Antonelli, 2005); and
B) to appreciate the negative effects of excess proximity within geographical and technological clusters in terms of reduced levels of knowledge appropriability and hence reduction of the prices for the products that embody new proprietary knowledge

The rest of the paper is organized as it follows. Section 2 provides an account of the working of positive knowledge pecuniary externalities and highlight the role of agglomeration as a factor that reduce the costs of external technological knowledge as a production factor for the generation of new knowledge. Section 3 shows how agglomeration has a direct effect on appropriability and hence lead to negative pecuniary knowledge and the price of knowledge as an output. Section 4 elaborates a simple model that shows how only net positive pecuniary knowledge externalities have a direct effect in terms of total factor productivity growth. The conclusions summarize the main findings and put them in a perspective that specifies the role of public policy.

2. EXTERNAL KNOWLEDGE AS A PRODUCTION FACTOR

In order to produce new knowledge, external knowledge, that is knowledge possessed by other parties, has a crucial role. In the generation of knowledge firms act as 'integrators' of internal skills and competence with external sources of knowledge.

The 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. The access conditions to external knowledge are a key conditional factor in assessing the chances of generation of new knowledge. 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. 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 combined with research and development activities, provides major contributions. Also the opposite is true. Firms that do not perform any knowledge generating activity but have access to rich knowledge commons can generate no new knowledge.

In order to generate new knowledge, firms need to combine and integrate internal sources of knowledge such as intramuros research and development activities and learning processes with the systematic use of external knowledge as a primary input for the general production of new knowledge. No firm, in fact, can innovate in isolation. External knowledge is an essential input into the generation of new knowledge. External knowledge can substitute internal sources of knowledge only to a limited extent: full-fledged substitutability between internal and external knowledge cannot apply. Unconstrained complementarity however also appears inappropriate. Building on the large empirical evidence about the role of external knowledge, the hypothesis of a constrained multiplicative relationship can be articulated. External and internal knowledge, both in their tacit and codified form, are complementary inputs where none is disposable. The ratio of internal to external knowledge however seems relevant. Neither can firms generate new knowledge relying only on external or internal knowledge as the single input. With an appropriate ratio of internal to external knowledge instead internal knowledge and external knowledge inputs enter into a constrained multiplicative production function. Both below and above the threshold of the appropriate combination of the complementary inputs the firm cannot achieve the maximum output (Patrucco, 2008).

Because of the intrinsic indivisibility of technological knowledge, the successful generation of new knowledge depends upon the access to external knowledge. External knowledge is only potentially useful: systematic efforts have to be done in order to take advantage of such possibilities. To do so, firms rely on knowledge exploration strategies to identify the sources of knowledge, to assess whether and how to rely upon external or internal knowledge in the production of new knowledge one. Only when a firm is able to fully coordinate all the relevant 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. Knowledge procurement is as relevant as intramuros research activities in the generation of new knowledge. The purchase of patents and licenses in knowledge markets by means of knowledge transactions, however, is by no means the single source of external knowledge. External knowledge can be accessed also by means of a variety of other tools, including the hiring of qualified personnel embodying the competence acquired by means of learning in other companies and an array of interaction modes with public research centers, customers, suppliers and competitors.

The acquisition of external knowledge is expensive both in terms of actual purchasing costs and in terms of knowledge governance costs. Knowledge governance costs include all knowledge transaction, communication and networking costs. Knowledge transaction costs are the costs associated with the exploration activities in the markets for disembodied knowledge such as search, screening, processing, and contracting. As it is well known the assessment of the actual quality of the knowledge can be difficult when the vendor bears the risks of opportunistic behavior and dangerous disclosure.

The acquisition of external knowledge requires qualified interactions with other agents: dedicated efforts are necessary to create the institutional context into which external knowledge can be acquired. The capability of agents to access external technological knowledge depends on the fabric of institutional relations and shared codes of understanding which help to reducing information asymmetries, reducing the scope for opportunistic behavior and building a context into which reciprocity, constructed trust and generative relationship can be implemented (Cohen and Levinthal, 1990).

Knowledge communication is necessary when knowledge is dispersed and fragmented, retained by a myriad of heterogeneous agents, and yet characterized by high levels of indivisibility with important potential benefits in terms of externalities stemming from its integration and recombination. Yet knowledge communication is not automatic. On the opposite, it is the result of much intentional activity designed to create a context conducive to combine variety and complementarity.

Systematic networking is necessary to establish knowledge communication flows. The network structure of the system plays a key role in shaping the flows of knowledge communication and hence the availability of external knowledge. Specific, dedicated networking activities are necessary in order to manage the flows of knowledge that are not internal to each firm and yet cannot be reduced to arm's length transactions. Networking activities make knowledge interactions, as distinct from knowledge transactions, possible. Networking activities are a well specific –indispensable- ingredient of the basic governance of knowledge (Freeman, 1991).

Firms often rely on networking interactions with other independent parties, to increase the proprietary control of their knowledge, to acquire external knowledge and to better exploit it. External knowledge can be acquired by taking advantage of the spillovers from the academic activities, and from localization in the proximity of other firms. Qualified user-producers interactions, both upstream, with suppliers, and downstream, with customers, are the source of key inputs into the production of new knowledge. Knowledge search and utilization is better implemented within networks of interactions based upon constructed and repeated interactions, qualified by contractual relations. The array of networking tools is ever increasing and includes both formal and informal mechanisms. Joint ventures, dedicated research clubs, sponsored spin-offs, patent-thicketing, technological platforms, cross-licensing, and in-house outsourcing are the main types of formal cooperative tools. Co-localization within technological districts and membership into epistemic communities are typical forms of networking procedures (Antonelli, 2006).

Our basic assumption here is that the levels of knowledge governance costs have a key role in assessing the actual levels of the total costs for the perspective users of external knowledge (Arrow, 1969).

The understanding of the costs of external knowledge has important implications about the direction and the amount of technological knowledge being generated by the firm. When efficient markets for knowledge are available, the selection of knowledge activities that firms retain within their boundaries is much more effective. The scrutiny for the inclusion of knowledge generating activities and of their eventual valorization is in fact much more selective. The exploration for external sources of knowledge and knowledge outsourcing becomes common practice. Firms can rely on external providers for specific bits of complementary knowledge. Knowledge outsourcing on the demand side matches the supply of specialized knowledge intensive business service firms. Universities and other public research centers can complement their top-down research activities finalized to the production of scientific knowledge with the provision of elements of technological knowledge to business firms.

The stronger are pecuniary knowledge externalities and the stronger the incentives for firms to select the characteristics of the technological knowledge they can generate, according to the characteristics of the context into which they are embedded. A variety of factors affect this process: the cognitive distance among agents, the complementarity in competence and research agenda, the levels of trust, the institutional setting. Geographic proximity plays a key role.

Firms that have access to cheaper external knowledge, can generate a larger amount of knowledge with a given amount of resources available to fund research activities. The unit costs of knowledge generated in a conducive environment are clearly lower than the unit costs of the knowledge generated in a ‘hostile’ context by a single firm able to rely almost exclusively on its own internal competence.

This analysis has many important implications about the role of the local context into which firms are embedded. 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, and low knowledge governance costs, firms will rely less on internal learning and research activities. On the opposite, when and where, the access conditions to external knowledge are less easy, firm will rely more on internal research and learning activities. 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 (Antonelli, 2008).

3. APPROPRIABILITY AND NON-RIVALRY IN KNOWLEDGE EXCHANGE

Pecuniary knowledge externalities are not always and exclusively positive. Agglomeration in geographical and technological space, respectively within technological clusters and technological systems has negative effects that are seldom identified. The density of firms accessing the same knowledge pools may have negative consequences in terms of reduced appropriability of technological knowledge. The clustering of firms in the same region favors the uncontrolled mobility of qualified workers and hence the leakage of sensitive information and competence. The likelihood of informal contacts among workers of different companies is increased and favored by repeated interactions and the complementarity and interdependence of research activities. Once more firms are exposed to the uncontrolled loss of proprietary knowledge.

As Kenneth Arrow (1962) has pointed out knowledge is indeed characterized by non-rivalry is use. While two or more parties cannot share the simultaneous usage of the same tangible good, repeated usage of knowledge by many parties at the same time is possible. Each user does not deprive or limit the conditions of usage of other parties.

Knowledge however is characterized by substantial rivalry in exchange. Firms can extract substantial monopolistic rents from the exclusive command of original and unprecedented technological knowledge. The innovative firm can charge monopolistic prices upon products that embody new technological knowledge as long as it is able to retain its exclusive command.

Non-rivalry in use and non-rivalry in exchange coincide only when perfect competition applies. But perfect competition applies only when all firms have access to all technological knowledge available with no restriction. When the access to knowledge is restricted perfect competition no longer applies. Knowledge holders have a clear incentive to delay the dissemination and leakage of knowledge to third parties.

In Schumpeterian competition non-rivalry in use and non-rivalry in exchange differ widely. As it is well known in fact the exclusive command of proprietary technological knowledge impedes imitation and hence stretches the duration of monopolistic rents.

The access to the same pools of knowledge reduces the costs of external knowledge as an input into the generation of new knowledge, but reduces also its appropriability.

4. PECUNIARY KNOWLEDGE EXTERNALITIES AT WORK: A SIMPLE MODEL

The production of goods is the result of a transformation process that combines tangible inputs with Following Nelson (1982) we can specify a knowledge production function. External knowledge is a non-disposable input for nobody can command all the knowledge available at any point in time. Internal and external knowledge are complementary inputs that it is necessary to combine in order to produce new technological knowledge[2].

The unit costs of internal knowledge consist in the market price for the resources that are necessary to perform research and development activities. The costs of external knowledge consist in the resources that are necessary to screening, understanding, purchasing and acquiring knowledge possessed by other agents in the system, including non trivial efforts in terms of knowledge communication in terms of reception and absorption activities and knowledge networking. Such technological knowledge does not spill freely in the air. Dedicated activities are necessary in order to identify and acquire it. Moreover additional resources are necessary in order to make a new use of it. The acquisition of external knowledge is not free: in fact pecuniary externalities apply instead of technological externalities.

There are conducive contexts characterized by high quality knowledge governance mechanism in which, because of knowledge-non-exhaustibility, the costs of reproduction of technological knowledge are far below the costs of generation. Because of pecuniary knowledge externalities, the costs of external knowledge (u) are lower than the costs of internal sources of new knowledge (p) and below equilibrium levels (u*). The latter would hold if and when knowledge was a normal economic good.

[2] In our case, the production and costs functions of knowledge can be stylized as it follows:
(1) $T = (IK^a \ EK^b)$ with $a+b = 1$
(2) $C = pIK + uEK$
Where T represents new technological knowledge generated with constant returns to scale by means of internal knowledge (IK) and external knowledge (EK). Here p and u represent their respective unit costs.

Insert table 1 about here

Pecuniary knowledge externalities are found within economic systems where the costs of external knowledge are below equilibrium levels. Pecuniary knowledge externalities are found when and where knowledge reproduction costs differ sharply from generation costs and knowledge governance at the system levels is effective and the efficiency of knowledge governance mechanisms is high. It is important to stress again here how important are knowledge governance costs. When knowledge governance costs are high, the actual costs of external knowledge are close to "equilibrium" levels. Hence there are no pecuniary knowledge externalities. When knowledge governance costs are high there are actual knowledge spillovers and new growth dynamics cannot take place.

When pecuniary knowledge externalities apply, the maximizing firm will find the equilibrium in point B and produce a larger quantity of knowledge (T). The equilibrium technique will consist of a larger use of external knowledge with respect to internal knowledge. In a system characterized by positive pecuniary knowledge externalities, the firm will produce more technological knowledge than in a system where external knowledge has higher costs.

With positive pecuniary knowledge externalities in the upstream production of technological knowledge, the costs of technological knowledge generated by the firm are below equilibrium level: $s < s^*$.

This has important implications with respect to the output that the firm will produce. As it is shown in Figure 2, because of the upstream positive effects of external knowledge available at costs that are below equilibrium levels, the firm will be able to generate technological knowledge at lower costs and hence to produce a larger quantity of Y. The firm will select in fact the equilibrium point E, instead of F where the firm that has no access to pecuniary knowledge externalities would go. The equilibrium in E implies a smaller demand for the bundle of tangible inputs (I), a more intensive use of the technology (T) and a larger output Y. As a matter of fact the amount of excess output dY generated by the firm that can take advantage of positive pecuniary knowledge externalities can be considered the residual, that is the excess output that cannot be explained in equilibrium conditions[3].

Insert figure 2 about here

Total factor productivity growth can be explained by means of positive pecuniary knowledge externalities because knowledge is a production factor both for the production of goods and for the generation of further knowledge and it is characterized by non-exhaustibility and its production function is shaped by the complementarity between external and internal sources knowledge.

The working of pecuniary knowledge externalities is compatible with equilibrium conditions at the firm level while at the aggregate the system is far from equilibrium. As long as pecuniary knowledge externalities are found, the typical system dynamics, stemming from the positive feedback generated by knowledge non-exhaustibility and knowledge complementarity, implemented by good knowledge governance mechanisms, are at work at the system level.

The characteristics of the system in terms of knowledge governance mechanisms and hence the levels of knowledge transaction, communication and interaction costs are crucial to assess the long-term viability of the system dynamics. The analysis so far has not taken into account the negative effects of the number of agents that are active in the same knowledge pool and share basic knowledge complementarities upon the levels of knowledge appropriability and hence the price for the products that embody new technological knowledge.

When such effects are taken into account we see that pecuniary knowledge externalities have a twin effect. On the one hand they reduce the costs for external knowledge and consequently, via the increase in

---

[3] Following Griliches (1979) technological knowledge enters directly a standard Cobb-Douglas production function with constant returns to scale:

(3) $Y = (I^f T^g)$ where $f+g=1$
(4) $C = cI + sT$
(5) $dY/Y= A$

Where for the sake of simplicity I is a bundle of tangible inputs, c are their costs, T is technological knowledge and s its cost and A measures total factor productivity growth stemming from pecuniary knowledge externalities.

total factor productivity, the costs of goods. On the other they affect the price at which the goods that incorporate the new knowledge can be sold. Net pecuniary externalities depend upon the combined effects of positive and negative pecuniary knowledge externalities[4].

The specific form of interplay between the positive effects on the costs of external knowledge and the negative effects on knowledge appropriability can acquire a quadratic form. In such circumstances the dynamics of the process will follow a S-shaped path.[5]

Insert figure 3 about here

Net pecuniary knowledge externalities provide the incentive to enter the knowledge pools. Entry will take place as long as they are positive. The flow of entry will take a quadratic shape and accelerated flows of entry are likely to take place in the proximity of the optimum size of the cluster. Beyond that level firms will enter at a reduced pace. Entry will stop as soon as the negative effects of reduced knowledge appropriability will be larger than the positive effects in terms of reduced costs of external knowledge

It is clear in fact that agglomeration is no longer an unconstrained recipe. The size of the local knowledge pools can be too little or too large. There is also, according to specific conditions, an 'optimum' size of the local pools of knowledge.

[4] It is easy to derive the formal conditions to identify the optimum size of the local pools of knowledge. We know that the value of output depends on the quantity and its price P:

(6) $Y = PQ$

The price at which the good that embodies new knowledge is sold is influenced by the number N of firms that have access to the same knowledge pool:

(7) $P = P^* / z(N)$

We know that the cost of the output is influenced by the costs of external knowledge which in turn is affected by the same number of firms N:

(8) $C = C^* / v(N)$

(9) $dY/dN = dC/dN / dp/ dN$

[5] Formally we see that the dynamics of net positive externalities as dependent upon the number N of firms may take a quadratic shape:

(10) $dN(t) = n (N(t) – (N^2(t))$

In such circumstances the entry process of new agents in the system may follow a shaped process. In fact equation (10) admits the standard logistic equation as a solution.

5. CONCLUSIONS AND POLICY IMPLICATIONS

Technological and scientific knowledge is a collective, highly imperfect and heterogeneous activity. First of all it is not only an output, but also an input, an essential intermediary factor of production that is relevant both in the generation of new technological knowledge and in the generation of other goods. The dynamic efficiency of each firm and of the system at large depends upon the factors affecting the generation and dissemination of knowledge.

The identification of the dual characteristics of technological knowledge as both an output and an input in the production of other goods and in the production of further knowledge, together with the understanding of the intrinsic complementarity between external and internal sources of knowledge, both non-disposable inputs in the generation of new knowledge, make it possible to apply the notion of pecuniary externalities in a novel context.

Pecuniary knowledge externalities are a powerful analytical tool that applies to the analysis of external knowledge as a necessary and yet costly production factor into the generation of new knowledge. The use of the notion of 'technological' externalities is consistent with the view that external knowledge falls from heaven like manna and spills freely in the atmosphere.

Pecuniary knowledge externalities are not always and universally positive. Agglomeration within geographic and technological clusters can yield negative consequences in terms of reduced appropriability of proprietary knowledge. Agglomeration within clusters yield positive effects only when the effects of pecuniary knowledge externalities upon the costs of external knowledge are stronger than the effects of pecuniary knowledge externalities upon the prices of the goods that embody new technological knowledge. A clear case for excess agglomeration has been identified in terms of reduced knowledge appropriability. Uncontrolled leakage and reduced exclusivity of proprietary knowledge can impede the long-term sustainability of such a process of self-propelling growth.

The quality of knowledge governance mechanisms that include the assessment of intellectual property right regimes is crucial for the actual viability of public policies based upon knowledge externalities.

Such results call attention upon the role of a public knowledge policy. The need for an economic policy regarding the production and dissemination of knowledge seems stronger than ever. Spontaneous knowledge governance mechanisms need to be complemented by a public policy. The implementation of the institutional set up by means of policy actions that reduce uncertainty and create information, so as to reduce the effects of bounded rationality and information loads, seems to be a viable strategy to reduce the divide between profit maximization and social welfare. Public policy can reduce the major limits of the knowledge governance system so as to favor a more effective system of producing and circulating knowledge with interventions aimed at increasing the amount of information each agent has access to.

Public knowledge policies can play a key role in encouraging dynamic coordination among the variety of heterogeneous players involved in the generation of knowledge as a complex and collective process. The State can favor the activity of interface bodies that have the specific mission to increase the dissemination of scientific knowledge and its communication to potential users. The creation of such interface agencies can increase the efficiency of the workings of the knowledge governance systems. Public interface agencies can help to identify the supply buried in the stocks of knowledge, often in the public domain, in Universities and other public research centers, and awaken demand for its application. The role of public interface agencies is to push the academic community towards the market place and selected segments of the business community towards the academic one. Small firms are not even present in the knowledge markets. The minimum threshold of performance or research activity is often beyond the size possible for single small companies.

Moreover the State can specialize in the direct supply of knowledge, by means of University and Public research centers, especially when it has high levels of fungeability, that is to say, knowledge with a wide range of applications in a broad array of activities and high levels of incremental enrichment. Public implementation of the access conditions to such knowledge, viewed as an essential facility, is the key to dynamic efficiency in the generation of new knowledge.

6. REFERENCES

Antonelli, C. (2006), The business governance of localized knowledge: An information economics approach to the economics of knowledge, *Industry and Innovation* 13, 227-261.

Antonelli, C. (2007a), The system dynamics of collective knowledge: From gradualism and saltationism to punctuated change , *Journal of Economic Behavior and Organization* 62, 215-236.

Antonelli, C. (2007b), Pecuniary knowledge externalities and the emergence of directed technological change and innovation systems, submitted to *Industrial and Corporate Change*

Antonelli, C. (2007c), Localized appropriability: Pecuniary externalities in knowledge exploitation, submitted to *Technology Analysis and Strategic Management*

Antonelli, C. (2008), *Localized technological change: Towards the economics of complexity*, Routledge, London.

Arrow, K. J. (1962), Economic welfare and the allocation of resources for invention, in Nelson, R. R. (ed.) *The rate and direction of inventive activity: Economic and social factors*, Princeton University Press for N.B.E.R., Princeton, pp. 609-625.

Arrow, K. J. (1969), Classificatory notes on the production and transmission of technical knowledge, *American Economic Review* 59, 29-35.

Cohen, W.M., Levinthal, D.A. (1989), Innovation and learning: The two faces of R&D, *Economic Journal* 99, 569-596.

Cohen, W.M., Levinthal, D.A. (1990), Absorptive capacity: A new perspective on learning and innovation, *Administrative Science Quarterly* 35, 128-152.

David, P.A. (1993), Knowledge property and the system dynamics of technological change, *Proceedings of the World Bank Annual Conference on Development Economics*, The World Bank, Washington.

Feldman, M.P. (1999), The new economics of innovation spillovers and agglomeration: A review of empirical studies, *Economics of Innovation and New Technology* 8, 5-26.

Freeman, C. (1991), Networks of innovators: A synthesis of research issues, *Research Policy* 20, 499-514.

Griliches, Z. (1979), Issues in assessing the contribution of research and development to productivity growth, *Bell Journal of Economics* 10, 92-116.

Hayek, F.A. (1945), The use of knowledge in society, *American Economic Review* 35, 519-530.

Jones, C.I. (2002), *Introduction to economic growth*, Norton, New York, (2nd edition).

Nelson, R.R. (1982), The role of knowledge in R&D efficiency, *Quarterly Journal of Economics* 97, 453-470.

Nelson, R. R., Winter S.G. (1982), *An evolutionary theory of economic change*, The Belknap Press of Harvard University Press, Cambridge,

Romer, P.M. (1986), Increasing returns and long-run economic growth, *Journal of Political Economy* 94, 1002-37.

Romer, P.M. (1990), Endogenous technological change, *Journal of Political Economy* 98, S71-102.

Romer, P.M. (1994), The origins of endogenous growth, *Journal of Economic Perspectives* 8, 3-22.

Patrucco, P.P. (2008), Collective knowledge production, costs and the dynamics of technological systems, *Economics of Innovation and New Technology* 17, forthcoming.

Scitovsky, T. (1954), Two concepts of external economies, *Journal of Political Economy* 62, 143-151.

Stiglitz, J.E. (2000), The contributions of the economics of information to twentieth century economics, *Quarterly Journal of Economics* 115, 1441-1478.

Stiglitz, J.E. (2002), Information and the change in the paradigm in economics, *American Economic Review* 92, 460-502.

FIGURE 1.THE NELSON KNOWLEDGE PRODUCTION FUNCTION

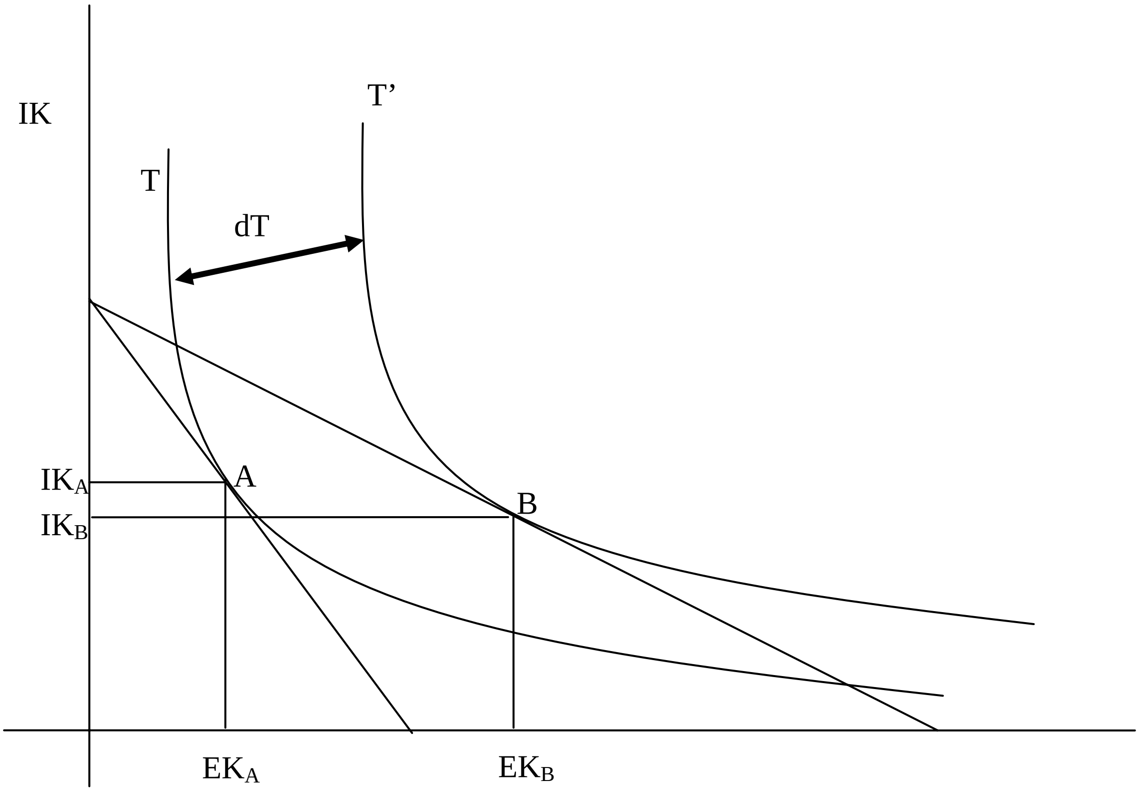

FIGURE 2. THE GRILICHES PRODUCTION FUNCTION

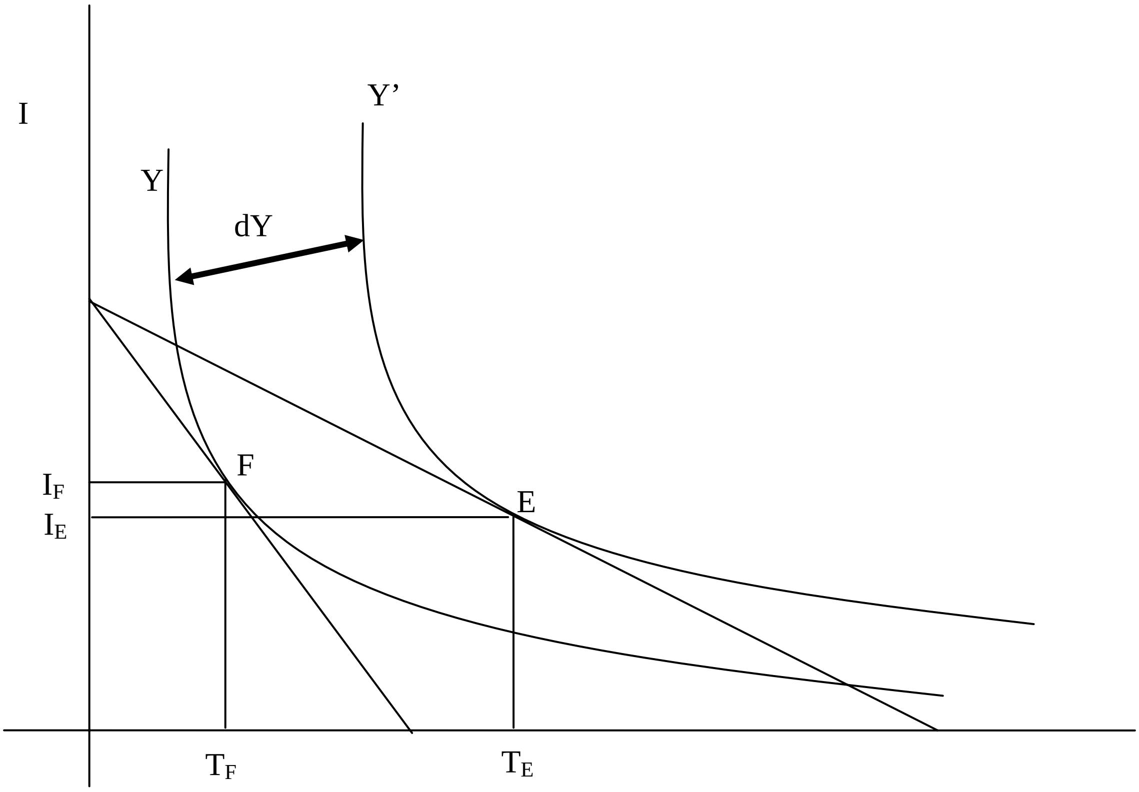

FIGURE 3. THE DYNAMICS OF THE PECUNIARY KNOWLEDGE EXTERNALITIES TRADE-OFF AND THE S-SHAPED DIFFUSION PROCESS OF INNOVATION SYSTEMS