department of economics
"S. Cognetti de Martiis"

Via Po, 53 – 10124 Torino (Italy)
Tel. (+39) 011 6702704 - Fax (+39) 011 6702762
URL: http//www.de.unito.it

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PECUNIARY KNOWLEDGE EXTERNALITIES AND THE SYSTEM DYNAMICS OF GROWTH

Cristiano Antonelli

Dipartimento di Economia "S. Cognetti de Martiis"

Laboratorio di Economia dell'Innovazione "Franco Momigliano"

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PECUNIARY KNOWLEDGE EXTERNALITIES AND THE SYSTEM DYNAMICS OF GROWTH[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.

KEY-WORDS: TECHNOLOGICAL KNOWLEDGE, PECUNIARY EXTERNALITIES, KNOWLEDGE GOVERNANCE, TOTAL FACTOR PRODUCTIVITY GROWTH.

JEL-CODE: O33

1. INTRODUCTION

The economics of knowledge has made substantial progress since the path breaking contributions of Kenneth Arrow (1962). The Arrovian analysis had identified a number of key characteristics of technological knowledge as an economic good such as non-divisibility, non-appropriability, non-rivalry in use, non-excludability. A large literature explored their implications in terms of market failure and articulated the role of the State in the provision of knowledge as a public good.

In a second step, economic analysis has identified in bottom-up learning processes a major source of technological knowledge. Tacit knowledge complements the top-down contributions of scientific breakthroughs.

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Because of its embedded and idiosyncratic character, knowledge can be partly appropriated and hence it is considered a quasi-private good (Nelson and Winter, 1982). The identification of the tacit and hence specific components of knowledge provides the foundations for the new growth theory. The new growth theory builds in fact upon the distinction between generic technological knowledge 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 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. According to the new growth theory, the collective access to technological knowledge leads to the increase of total factor productivity and hence the growth of output (Romer, 1990; Jones, 2002).

The new growth theory has enriched and articulated the Marshallian understanding of technological externalities where knowledge is a production factor spilling in the atmosphere of industrial districts. In this perspective the distinction between specific and generic knowledge is crucial. While specific knowledge is embedded in organizations, generic knowledge is expected to spill freely in the atmosphere, with no costs for perspective users neither to acquire nor to use it. Intellectual property rights have no effects on generic knowledge and there are no knowledge governance costs: knowledge can be acquired with no transaction and communication costs (Romer, 1989 and 1994).

A third step in the economics of knowledge has emerged with: a) the new evidence about the costs of acquisition of external knowledge (Arrow, 1969), b) the identification of the dual role of technological knowledge elaborated by David (1993), and c) 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 empirical evidence about the costs of external knowledge is reinforced by the new understanding of knowledge as both an output and input. According to David (1993) technological knowledge is not only an output, but also an input. More precisely technological knowledge is an input into the production of other goods and an input into 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 new element of understanding about 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, it seems appropriate to reconsider the notion of externalities. As a matter of fact, on the supply side, two quite different types of externalities have been identified: 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. Positive pecuniary externalities reduce the price of production factors below the equilibrium level.

Following the analysis of externalities provided by Scitovsky (1954), it seems now clear that the new growth theory elaborates upon the notion of ‘technological externalities’. Technological externalities take place when technological knowledge is considered as an unpaid production factor that enters the production function.[2]

This paper explores an alternative analytical path, based upon the notion of pecuniary externalities. Pecuniary externalities apply when the prices for production factors differ from equilibrium levels and reflect the effects of external forces. According to Scitovsky (1954) pecuniary external economies consist of 'interdependence among producers through the market mechanism" (p.146).[3] 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 exploration of knowledge pecuniary externalities makes it possible to qualify the characteristics of the specific context where and when external knowledge becomes available at costs that are lower than equilibrium levels. Such circumstances in fact do not hold everywhere and at all time, but only in highly idiosyncratic conditions (Antonelli, 2005).

The rest of the paper is organized as it follows. Section 2 provides an account of the role of external technological knowledge as a production factor for the generation of new knowledge. Section 3 elaborates a simple model that shows how pecuniary knowledge externalities have a direct effect in terms of total factor productivity growth. Section 4 elaborates some dynamic implications with special attention to the role of knowledge governance costs. 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

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[2] Following Scitovsky this is the case of technological external economies. They 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).

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

The characteristics of the knowledge, as an input, have important consequences on its generation process. Three different aspects of knowledge indivisibility play a key role: vertical indivisibility or cumulability, knowledge non-exhaustibility and horizontal indivisibility or complementarity. Because of cumulability knowledge is generated by means of pre-existing knowledge. The second aspect of knowledge indivisibility, that is knowledge non-exhaustibility, has important consequences in terms of a sharp difference between generation and reproduction costs. The costs of generating new knowledge are much higher than the costs of reproducing knowledge. Finally knowledge complementarity has an important role too. Knowledge is dispersed among agents and nobody has the full command of all available knowledge. In order to produce new knowledge however external knowledge, that is knowledge possessed by other parties, has a crucial role.

The knowledge external to the firm, at each point in time, is as 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.

In order to generate new knowledge, firms need to combine 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.

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 transaction and interaction costs (Arrow, 1969). Knowledge transaction costs include all the costs associated with the exploration activities in the markets for disembodied knowledge such as search, screening, processing, and contracting. Knowledge exploration strategies take into account knowledge transaction costs in the context of the choice between ‘make’ internal knowledge or ‘buy’ external one. 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. A close interaction takes place between knowledge transaction costs on the demand side and knowledge transaction costs on the supply side.

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.

External knowledge is acquired also by means of qualified interactions with other agents. Even in this case, however, knowledge does not spill freely and automatically in the atmosphere: 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, 1989 and 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 new knowledge. Imitation of competitors also provides access to external knowledge, as well as qualified interactions with the scientific community. Knowledge dissemination is better controlled 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).

The understanding of the costs of external knowledge has two important implications about the direction and the amount of technological knowledge being generated by the firm. Firms 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. Second, and most important, 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 transaction and networking 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.

The cumulability and non-exhaustibility of technological knowledge has a direct effect in terms of pecuniary knowledge externalities. In the markets for technological knowledge as a production factor, because of cumulability and non-exhaustibility, the supply curve exhibits the effects of increasing returns. Once generated, technological knowledge can be used again and again at diminishing incremental costs. Knowledge non-appropriability further contributes the negative slope of incremental costs: by means of imitation and re-engineering the new users can partly avoid royalties and fees.

The larger are the flows of technological knowledge that firms are able to generate in the system and the lower are the costs of external knowledge as a production factor.

The costs of external knowledge include knowledge governance costs. Knowledge transaction, absorption and communication costs have a role and increase the costs of external knowledge. 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 customers of external knowledge.

In a system characterized by high quality of knowledge governance mechanisms, the total costs of external knowledge for perspective customers are lower and decreasing. In a system characterized by low levels of knowledge governance, the total costs of external knowledge for perspective customers are higher, and can eventually increase, especially when the number of agents in the system increases. In specific circumstances governance costs can offset the working of knowledge non-exhaustibility and complementarity.

3. PECUNIARY KNOWLEDGE EXTERNALITIES AT WORK: A SIMPLE MODEL

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.

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.

The unit costs of internal knowledge consist in the market price for the resources that are necessary to hire 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 actual levels of u are below equilibrium levels u^*. The latter would hold if and when knowledge was a normal economic good.

The specification of the determinants of u is important here:

(3) $u = a (\Sigma \ T_N , KG_N)$ where $du/d \Sigma \ T_N<0$, and $du/dKG_N >0$

Where N is the number of the agent in the system. The stock of knowledge generated by the agents in the system has a negative effect on the market price for external knowledge. Moreover the latter increases with the number (N) of agents. Knowledge governance costs exert a positive countervailing effect on the actual price of external knowledge The latter as well are influenced by the number of agents in the system. Provided that knowledge governance costs do not fully offset the pecuniary externalities yielding from the stock of knowledge, then and only then $u<u^*$.

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.

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.

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

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

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.

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. Hence:

(6) $dY/Y= A$

where A measures total factor productivity growth stemming from pecuniary knowledge externalities.

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.

Formally the chain of arguments can be synthesized with the following string of equations:

(7) $A = dY/Y^* = f\ (s/s^*) = g\ (u/u^*)$

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.

4. DYNAMIC IMPLICATIONS

The perfectly divisibility and exhaustibility of goods and production factors is necessary for equilibrium conditions to apply at the aggregate level. Within the market place, the spontaneous coordination of agents is supposed to be able to identify equilibrium prices for divisible and exhaustible inputs in efficient markets for production factors. The derived demand for such factors crosses the supply curve when the marginal productivity of the additional quantity of the production factor equals its cost. The system converges towards a single attractor.

Because of the effects of knowledge non-exhaustibility, complementarity and cumulability, however, economies of density apply. The larger is the stock of technological knowledge dispersed in the economic system and the lower are the costs of external knowledge. The slope of knowledge incremental costs is negative and hence the supply curve of external knowledge exhibits a negative slope. Knowledge governance costs however may offset the dynamics.

The understanding of the dynamics of the system, in fact, requires the careful assessment of knowledge governance costs. The actual slope and position of the supply schedule of external is influenced by knowledge governance costs. Increasing knowledge governance costs in fact can hamper the system dynamics. The negative effects of increasing knowledge governance costs can offset the positive effects at the system level of the negative slope of the long terms supply curve for external knowledge.

Here the dynamic specification of equation (3) acquires a key role:

(8) $u(t) = a\,(\Sigma\ T_N\,(t), KG_N\,(t))$,
where $du\,(t)/d\,\Sigma\ T_N(t) < 0$, $du\,(t)/dKG_N(t) > 0$,

The dynamics of the total differential shows that two conditions can be identified with respect to a given level of u_t

(9) $u_t + (dKG_N\ du\,(t)/dGK_N(t) + d\,\Sigma\ T_N\,(t)\ du\,(t)/d\,\Sigma\ T_N(t)) < u^*$
(10) $u_t + (dKG_N\ du\,(t)/dGK_N(t) + d\,\Sigma\ T_N\,(t)\ du\,(t)/d\,\Sigma\ T_N(t)) > u^*$

As long as (9) applies, positive feedbacks are clearly at work. The system is likely to shift along a path shaped by the negative slope of the supply of external knowledge reinforcing the positive effects at the system level that stem from the characteristics of technological knowledge as an output and yet at the same time both an input in the production of other goods and an input for the production of further knowledge. External knowledge becomes cheaper and cheaper with the increase of the stock of technological knowledge available in the system under the form of external knowledge, firms rely more and more upon the sources of external knowledge and can generate increasing amounts of inputs, larger than expected in equilibrium conditions; hence total factory productivity keeps increasing with positive effects on the demand levels and hence further increase in the derived demand for production factors including external knowledge. A path dependent dynamics is at work: at each point in time the past dependent effects of knowledge cumulability, complementarity and non-exhaustibility in terms of economies of density can be reshaped and affected by the contingent effects of knowledge governance mechanisms. The path of the dynamics diverges from the past dependent trajectory.

As soon as (10) applies, in fact, knowledge governance costs stop the dynamics of the system. As soon the costs of knowledge governance push the costs of external knowledge above the levels of u*, pecuniary knowledge externalities no longer apply[4]. In Figure 3 the system dynamics is blocked in Z at time t_Z, for N_z.

INSERT FIGURE 3 ABOUT HERE

Figure 3 provides a simple graphic exposition of the path dependent dynamics of pecuniary knowledge externalities. The straight line shows the case where knowledge governance costs are not able to offset the effects of the stock of knowledge. The dotted line instead shows how and where the costs of knowledge governance offset the positive effects of knowledge non-exhaustibility. Knowledge is not exhausted but the knowledge governance blurs its positive effects. The positive effects of the knowledge spilling from the increasing number of agents is offset by the negative effects of knowledge governance costs driven by the increasing number of agents in the system.

[4] It is worth noting that when equation (8) acquires a quadratic form, because of the specific form of interplay between the positive effects of knowledge economics of density and the negative effects of knowledge governance costs, the dynamics of the process will follow a S-shaped path. It is easy to derive the formal conditions for an entry process of new agents in the system, fed by the opportunity for total factor productivity growth, where:

(11) $dN(t) = n\ (N(t) – (N^2(t))$

where (11) admits the standard logistic equation as a solution.

The implementation of effective mechanisms for knowledge governance becomes a central issue for the system dynamics that we have identified, to keep momentum.

The understanding of the key role of knowledge governance costs articulated in knowledge transaction, communication and interaction costs makes it possible to understand why the effects of technological knowledge are larger in some historic, geographic, sectoral and institutional circumstances, than in others. This marks an important progress with respect the new growth theory. Clearly the rate of growth of total factor productivity and of the output of an economic system with low levels of knowledge transaction, communication and interaction costs will be larger than those of an economic system with higher levels of knowledge transaction, communication and imitation costs.

This leads to grasping the key role of knowledge governance mechanisms in assessing the rate of growth of a system for given levels of resources invested in knowledge generating activities. A system with good knowledge governance mechanisms in place can get higher rates of total factor productivity even with lower levels of resources invested in knowledge generating activities. Actually high levels of knowledge governance can even substitute for the levels of knowledge generating activities.

The dynamics of the system is clearly affected by the changing quality of knowledge governance mechanisms. Institutional changes that increase the quality of knowledge governance mechanisms can prevent the loss of momentum. Some sectoral, institutional, geographic and regional contexts may exhibit higher knowledge governance mechanisms than others and can diffuse within the system. Public policy can help improving the effectiveness of knowledge governance mechanisms.

5. CONCLUSIONS AND POLICY IMPLICATIONS

The analytical framework provided by Kenneth Arrow with his analysis of the characteristics of technological knowledge as an economic good proves to be especially fertile to grasp the system dynamics of growth.

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.

Because of knowledge non-divisibility, pecuniary knowledge externalities apply and provide the basic ingredient for the implementation of a simple model of system dynamics. The growing stock of dispersed technological knowledge feeds the supply of external knowledge for the production of new knowledge at decreasing costs, below equilibrium prices, with increasing levels of production of knowledge and an increase of the general efficiency of the system.

Only knowledge governance costs can impede the long-term sustainability of such a process of self-propelling growth. The quality of knowledge governance mechanisms is crucial to assess the actual productivity of the resources invested in knowledge generating activities.

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.

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FIGURE 1.THE NELSON KNOWLEDGE PRODUCTION FUNCTION

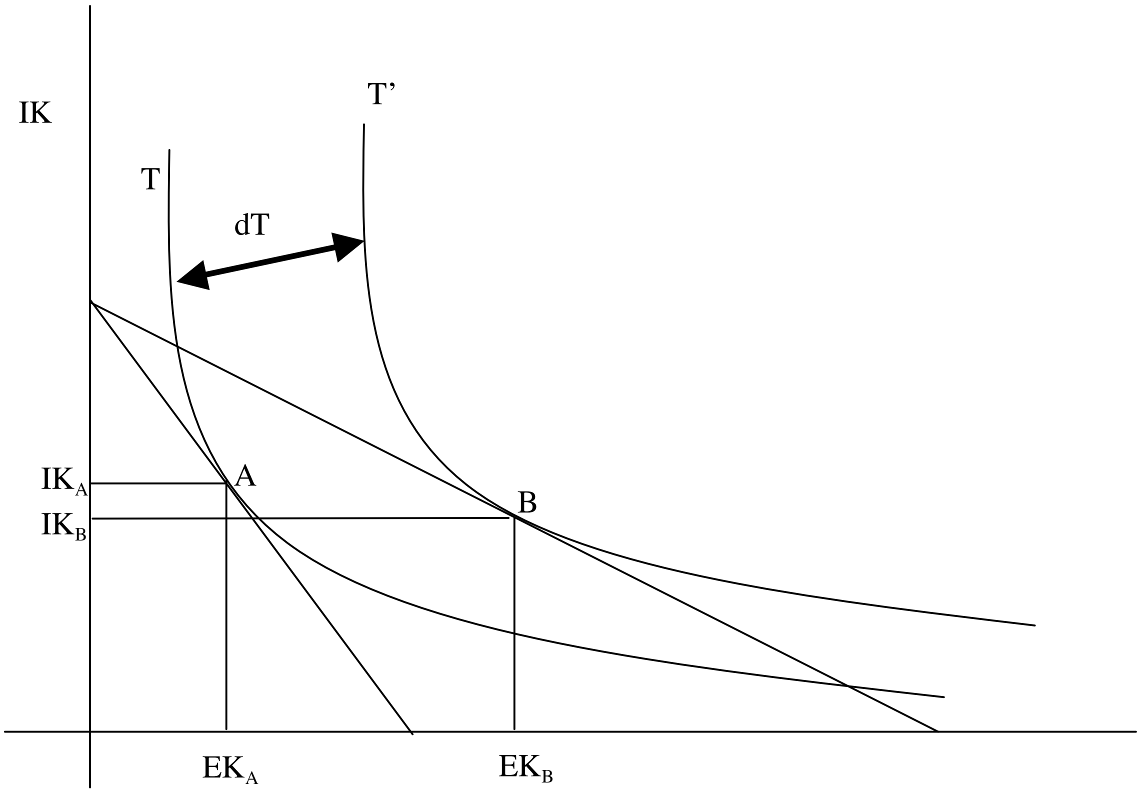

FIGURE 2. THE GRILICHES PRODUCTION FUNCTION

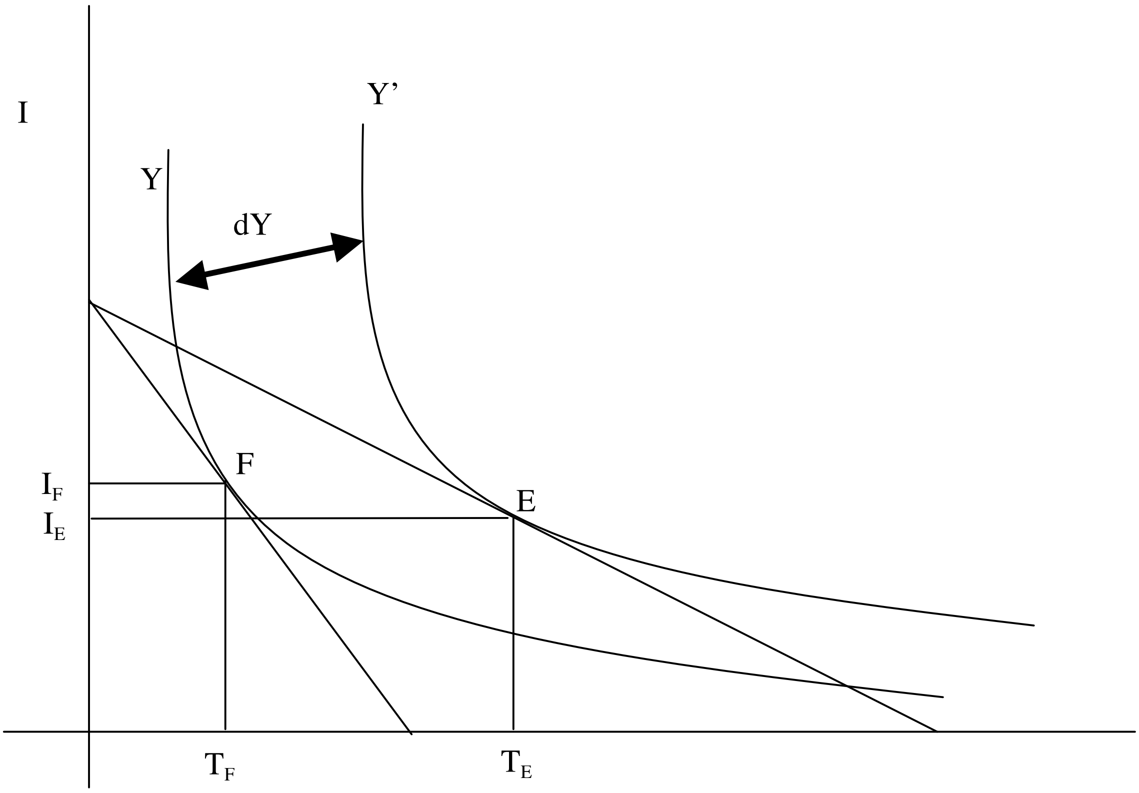

FIGURE 3. THE DYNAMICS OF PECUNIARY KNOWLEDGE EXTERNALITIES