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KNOWLEDGE GOVERNANCE PECUNIARY KNOWLEDGE EXTERNALITIES AND TOTAL FACTOR PRODUCTIVITY GROWTH[1]

CRISTIANO ANTONELLI

DIPARTIMENTO DI ECONOMIA
UNIVERSITA' DI TORINO
&
COLLEGIO CARLO ALBERTO

ABSTRACT

Building upon both the Schumpeterian and the Marshallian legacies, this paper elaborates a model of endogenous growth based upon localized technological change cum pecuniary knowledge externalities. It provides a systemic explanation for the levels and the rates of total factor productivity growth and its crucial heterogeneity through time, regional space and across agents. The generation of technological knowledge consists in the recombination of existing bits of heterogeneous technological knowledge that are necessarily possessed by a myriad of agents. As such much technological knowledge used in the generation of further knowledge is external to each agent, and yet an essential input into the recombinant generation of new technological knowledge. In this context knowledge governance mechanisms play a key role in the identification, recollection and provision of the specific item of technological knowledge, external to each agent, at each point in time. Consequently, effective knowledge governance mechanisms engender pecuniary knowledge externalities. The latter take place, mainly at the regional level,

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when and where existing units of external knowledge can be identified, accessed, unbundled and used –again- at costs that are below equilibrium ones for the recombinant generation of new technological knowledge so as to account for the levels and the rates of growth of total factor productivity.

KEY WORDS: TECHNOLOGICAL KNOWLEDGE; KNOWLEDGE EXTERNALITIES; KNOWLEDGE GOVERNANCE; TOTAL FACTOR PRODUCTIVITY.

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1.INTRODUCTION

This paper contributes the endogenous technological change approach arguing that innovation is an emerging property of the system into which the firm is embedded. It elaborates the view that innovation is the final result of the reaction to out-of-equilibrium conditions, both in factor and product markets, that can take place and become creative so as to lead to the generation of new technological knowledge and to the introduction of technological innovations only in localized circumstances that qualify the system into which the firm is embedded. The innovation process is affected by the costs and availability of internal and external knowledge. The latter, in turn, reflect the structural conditions of the system in terms of connectivity and knowledge governance. In so doing it contests the view that innovation is a homogeneous, inexorable process that depends only on the supply of knowledge and not its cost or process of production, as in the traditional growth theory.

The integration of the Schumpeterian and Marshallian legacies along the lines of the localized technological change approach provides a unifying methodology able to account for the origins of the levels and the dynamics of the residual. In this context, total factor productivity can be explained by the joint appreciation of the characteristics of the system, in terms of knowledge connectivity, and of the capability of individual firms to try and react to unexpected events by means of the introduction of technological innovations.

In the localized technological change approach, myopic firms are rooted in a limited portion of the technical, regional and knowledge space by substantial irreversibility. For that reason, they are exposed to unexpected events in their product and factor markets to which they cannot fully cope with traditional substitution. Nevertheless they can change intentionally their technology, provided a number of circumstances take place (Schumpeter, 1947).

Firms caught in out-of-equilibrium conditions by un-expected changes in both factor and product markets, localized by the irreversibility of tangible and intangible inputs and by their idiosyncratic tacit competence accumulated by means of learning process, try and generate new technological knowledge so as to introduce technological innovations. The generation of new technological knowledge may lead to the actual introduction of innovations that increase total factor productivity only if and when their economic system is characterized by high levels of knowledge governance. The latter enables the effective identification, access and use to external knowledge as a key input into the recombinant generation of new technological knowledge at costs that are below equilibrium.

Innovation is made possible by the structural characteristics of the system that provide reacting firms with external knowledge at costs that, in specific locations, are below general equilibrium levels and hence can account for localized total factor productivity: innovation is as an emerging property of an economic system. If external knowledge cannot be accessed and used at costs that are below equilibrium levels, firms' reaction is adaptive, rather than creative, and cannot lead to the introduction of productivity enhancing innovations (Antonelli, 2008b and 2011).

In this approach the systemic conditions that qualify the access and use of external knowledge spilling from 'inventors' to generate new technological knowledge and support the introduction of innovations are crucial to understand the actual introduction of productivity enhancing innovations (Arthur, Durlauf, Lane, 1997; Lane, 2009).

This approach combines the Schumpeterian emphasis on the role of the reaction of firms in inducing the attempt to introduce technological change in with the Marshallian analysis of externalities. The combination of the Schumpeterian reaction with the Marshallian externalities provides an integrated framework into which out-of-equilibrium growth and development can be understood by and partial equilibrium analysis. In so doing it enables to combine a microeconomic analysis of short-term, instantaneous equilibrium with a long-term analysis of out-of-equilibrium growth and structural change at the system level (Marshall, 1890/1920; Schumpeter, 1928; Metcalfe, 2007 and 2009).

This approach makes it possible to appreciate the variety of the localized contexts into which the generation of technological knowledge takes place. Moreover it enables to account when, where, why and how the pace of technological change is more or less rapid. The new growth theory, on the opposite, is bound to postulate a homogeneous rate of introduction of technological change across space and time.

The rest of the paper provides in section 2 a synthesis of the evolution of the notion of knowledge externalities and introduces the notion of knowledge governance. Section 3 frames a simple model that shows how the costs of external knowledge can account for total factor productivity growth. Section 4 elaborates the implications of the approach.

2. THE ECONOMICS OF KNOWLEDGE AND PECUNIARY KNOWLEDGE EXTERNALITIES

Technological knowledge is an economic good with particular characteristics such as limited appropriability and non-excludability, indivisibility and hence complementarity and cumulativity, non-exhaustibility. For quite a long time the economic of knowledge has focused attention on the limits of knowledge as an economic good stemming from its limited appropriability, non-excludability and intrinsic information asymmetries. As a consequence the benefits stemming from its production and exchange in the market place are missing together with the incentives for the allocation of resources to generate it and the opportunity for specialization. These characteristics would account for substantial market failure and major risks of undersupply. Because markets are unable to allocate the correct amount of resources into the generation of technological knowledge, public intervention is necessary (Nelson, 1959; Arrow, 1962 and 1969).

This approach has been reconsidered when, instead of focusing upon the negative aspects –in terms of missing incentives- of knowledge non-appropriability, attention has been directed upon the positive effects of the uncontrolled spillover of knowledge from 'inventors' to third parties. Technological knowledge generated by each firm affects, as an 'unpaid external' production factor, the production function of all the other firms. Technological knowledge, spilling in the atmosphere, becomes an externality and hence a resource for perspective recipients (Griliches, 1979 and 1992; Adams, 1990; Link, Siegel, 2007).

The new growth theory has implemented the analysis of the positive effects of knowledge non-appropriability, non-excludability, non-divisibility and non-exhaustibility and elaborated models of endogenous growth based upon the role of knowledge externalities. In the first wave of new growth models the spilling of knowledge externalities is homogeneous and automatic and enables the free utilization of the flows of knowledge generated in a system by third parties (Romer, 1986). Its accumulation through historic time takes place everywhere and at all times at no cost, benefiting lucky recipients who are just happy to be there (Romer, 1990). This literature implements the analysis of a self-sustained process of economic growth based upon the benefits of knowledge indivisibility and non-exhaustibility that is endogenous and yet becomes available. like exogenous manna. at no cost to passive recipients that use it as an additional factor that increases their efficiency, but do not alter their choices nor their strategies (Romer, 1994; Lucas, 2008).

The powerful analytical frame elaborated by the first wave of the new growth theory has stirred a wealth of empirical and analytical investigations on the economic characteristics of knowledge and their implications for economics at large, highlighting the uneven occurrence of productivity growth. Much evidence shows that the rates of technological change are far from being evenly distributed across historic times, industries and regional spaces, as suggested by the new growth theory. On the opposite, the introduction of technological change concentrates in historic time within well identified gales that are located in defined portions of the industrial system and clusters in regional spaces that do keep changing across time (Abramovitz and David, 1996; Mokyr, 1990, 2002: Metcalfe, 1995).

The growing empirical evidence provided by the economics of knowledge has progressively made clear that the use of knowledge spillovers is far from being homogenous and free. It entails dedicated activities and well identified resources. Knowledge does not fall from heaven to passive recipients and does not spill, freely, in the atmosphere, neither. The perspective users of technological spillovers need to act intentionally in order to take advantage of them (Mansfield, Schwartz and Wagner, 1981; Cohen and Levinthal, 1989 and 1990).

The identification of the key role of tacit knowledge and the consequent understanding of the central role of user-producer interactions in the access of users to the knowledge generated by third parties make clear that both knowledge cumulability and complementarity require the active participation of perspective users to access external knowledge and to use it in the generation of new technological knowledge (David, 1993).

The new understanding of the mechanisms underlying the generation of technological knowledge substantiates the new approach. The generation of new technological knowledge by each firm consists in the recombination of existing modules of knowledge and impinges upon high levels of complementarity with the knowledge generating activities in place in other firms, and cumulability with the stock of existing knowledge. Technological knowledge is at the same time an output and an input of the recombinant generation of new technological knowledge and external knowledge is an essential –indispensable- input. Eventually knowledge enters the production function of all goods: as such it is twice an input: an input into the generation of new technological knowledge and an input into the generation of all the other goods. The firm is primarily a knowledge integrator able to bundle different sources of knowledge in order to generate new knowledge (Weitzman, 1996 and 1998; Saviotti, 2007).

At each point in time, the system is endowed with a given amount of technological knowledge characterized by high levels of heterogeneity and diversity both with respect to its epistemic content, and location. Moreover it is possessed by the myriad of agents that generated it and are generating it. As such the stock of existing technological knowledge is not only heterogeneous but also dispersed and fragmented: much technological knowledge is external to each agent (Metcalfe, 1997, 2002).

External knowledge is strictly necessary to generate new technological knowledge and its use entails dedicated interactions between the recipients and the possessors. More specifically, external knowledge that can be accessed either via market transactions or spilling from their possessors can used by third parties only after dedicated interactions have been implemented and structured. Even knowledge spilling from the original possessor, because of limited appropriability, cannot be used freely by third parties. The appreciation of the notion of knowledge governance costs is crucial.

Dedicated interactions are necessary for its use to become possible not only when transactions in knowledge markets are involved, but primarily and necessarily when spillovers are concerned. This is due to the fact that it is dispersed in a myriad of highly idiosyncratic local contexts of application with high levels of irreducible tacit content. Moreover it is codified in a variety of non-trivial codes and possessed by a myriad of heterogeneous agents with their own idiosyncratic characteristics and routines. This implies that existing external technological knowledge can be used in the recombinant generation of new technological knowledge only after dedicated resources have been invested to identify, retrieve, extract it from its original context, learn and adapt it to a specific context of application. Most importantly it becomes clear that the use of external knowledge requires, occasionally transactions, but always and mainly dedicated intentional interactions with the actual possessors (Cassiman, Veugelers, 2006).

The access conditions of external knowledge depend upon the quality of the knowledge governance of an economic system. The knowledge governance consists in the set of rules, procedures, modes and protocols that organize the use of knowledge in an economic system. It includes a variety of institutional factors that qualify the architecture of relations, ranging from the extremes of pure transactions to pure interactions, including hierarchical coordination within firms, and, most importantly transactions-cum-interactions. The quality of knowledge governance mechanisms at work, at each point in time, within each economic system, can be seen as the spontaneous result of a systemic process of polycentric governance (Ostrom, 2010; Antonelli and Ferrari, 2011).

A variety of localized paths to organizing and managing at the system level the use of the existing technological knowledge as an input into the recombinant generation of new technological knowledge and the consequent introduction of total factor productivity enhancing technological change can emerge and consolidate, according to the institutional setting of each system and its path dependent characteristics (Link, Metcalfe, 2008).

The notion of pecuniary knowledge externalities applies far better than the traditional notion of pure externalities. External knowledge is not free and yet strictly necessary. Active search, screening, identification and interpretation of existing knowledge are necessary in order to use knowledge again and again as an intermediary input into the production of new knowledge. At the same time is seems now clear that external knowledge is an indispensable and non-disposable production factor and considering that its cost do affect the choice context of users. Pecuniary externalities matter when the costs of production factors differ from equilibrium levels: recipients are active and act intentionally taking into account the external effects so as to achieve more efficient production mixes. When pure externalities apply, external conditions affect the efficiency of the production process but do not enter the production set and the production choices: recipients are passive (Scitovsky, 1954; Antonelli, 2008a).

Pecuniary knowledge externalities are found where and when the knowledge governance costs incurred to accessing and using external knowledge are lower than its marginal product. The costs of accessing external knowledge reflect the localized conditions of using the existing knowledge that spills because of limited appropriability and can be used again because of non-exhaustibility[2]. Knowledge governance costs are determined by the quality of the knowledge interactions that make it possible to actually use the stocks of knowledge possessed by each other agents as well as the flows of new knowledge generated by each other agent. They include the costs of searching, screening, assessing, decodifying, extracting from its original context, learning and finally understanding the knowledge that cannot be fully appropriated by those who generated it.

Even in the extreme case that appropriability levels are nihil and the possessors of technological knowledge can retain no control at all of the stream of rents associated with its use, so that the market price of technological knowledge is zero, and all technological knowledge spills in the atmosphere, the access to it and its use as external knowledge into the recombinant generation of new technological knowledge takes place at the positive

[2] The model by Romer (1990) assumes that the stock of knowledge, available to all agents, increases freely and automatically at a rate λ and does not investigates the costs of its accumulation and its possible variance. The notion of pecuniary knowledge externalities is meant to provide the analytical framework to investigate the determinants of λ.

levels of knowledge governance costs. When appropriability levels are higher and the possessor of technological knowledge enters the markets for knowledge, interaction activities are necessary to perform successfully the actual transaction and to assist perspective customers in the actual use of knowledge that has been purchased. In both cases external knowledge can be used but only at a cost. The cost of external knowledge can be lower than equilibrium levels when its governance costs are especially low. Hence pecuniary knowledge externalities are influenced by the structure of the system, the distribution of agents within it that affect and qualify the activities that are necessary to engender the collective pursuit of generating new technological knowledge. In specific and qualified circumstances, highly localized in regional space, historic time and knowledge space, the levels of knowledge governance costs may be such that the cost of external knowledge is lower than equilibrium levels (Antonelli, 2007 and 2008b).

The localized context of action emerges as a fundamental aspect of the innovation process. An understanding of the key role of the localized pools of existing technological knowledge that make possible the actual use of external knowledge in the generation of new technological knowledge opens up new prospects of enquiry regarding the effects that the costs of external knowledge have on the equilibrium growth of firms, industries and regions and the causes of pecuniary knowledge externalities (Porter, 2000; Antonelli and Barbiellini Amidei, 2011; Antonelli, 2011).

3. THE EFFECTS OF PECUNIARY KNOWLEDGE EXTERNALITIES ON TOTAL FACTOR PRODUCTIVITY

The new relevance of the role of external knowledge and of its governance costs call attention upon the role of knowledge not only in the knowledge generation function but also in the cost equation. This contrasts a long-standing tradition focusing just the production function. Ever since the arrovian notion of learning, the effort to explaining the determinants of total factor productivity have been concentrated to analyzing the contribution of technology into the production function. The new growth theory has framed a model where increasing returns at the system level were compatible with standard equilibrium based upon the hypothesis of knowledge cumulability and non-appropriability and related free and spontaneous spillovers among firms.

We articulate in this section an alternative approach that builds upon the explicit identification of a knowledge generation function with internal and external knowledge as indispensable inputs and the related cost equation so as to accommodate for the role of knowledge governance costs and the possible role of pecuniary knowledge externalities. Next we nest the knowledge generation function into a production function that includes technological knowledge as an input. In so doing we shall show how pecuniary knowledge externalities can explain both total factor productivity levels and rates of change.

In the localized technological change approach the generation of new technological knowledge is activated when firms try and cope with un-expected events that affect their product and factor markets in order to introduce technological innovations as a form of reaction. The irreversibility of substantial portions of their tangible and intangible inputs limits their possibility to cope with such changes by means of traditional substitution processes. The reaction will be 'creative' if, when and where the generation of new technological knowledge and the eventual introduction of new technologies are supported by the actual availability of 'cheap' external knowledge to be used as an essential and indispensable production factor (Antonelli, 2008b).

In the knowledge generation function, internal knowledge obtained by means of research and development activities and the valorization of learning processes is an essential input. Next to it, however, also external knowledge is indispensable for nobody can command all the knowledge available at any point in time. External knowledge has been generated in previous periods and/or is currently used by other firms. In the recombinant generation of new technological knowledge, internal and external knowledge are complementary inputs that have to be combined in order to produce new technological knowledge (Nelson, 1982 and Weitzman, 1996 and 1998).

In our case, the generation function and the cost equation of technological knowledge of each firm can be written as follows:

(1) $T = (IK^{\alpha}\ EK^{\beta})$ with $\alpha+\beta = 1$

(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 cost of internal knowledge consists in the market price of the resources –primarily skilled labor- that are necessary to perform research and development activities and to valorize and maintain the internal stock of tacit knowledge and competence accumulated by means of learning processes. The unit governance costs of external knowledge include the costs of knowledge communication as well as knowledge networking and consist in the resources that are necessary to screen, identify, understand, purchase, learn and use knowledge generated, possessed and used by other agents in the system.

Pecuniary knowledge externalities are found where and when the governance costs of external knowledge (u) are below general equilibrium levels (u*). The latter would hold if and when knowledge were a standard economic good such that its equilibrium cost is found where its marginal and average costs meet its marginal product. According to the localized equilibrium condition:

(3) $\alpha/\beta \; IK/EK = u/p$

If the governance cost of external knowledge u* is found where its marginal cost equals its marginal product, the optimal left hand side ratio between internal and external knowledge would be equal to IK/EK*. When the actual cost of external knowledge is $u<u^*$, then the r.h.s. of equation (3) would diminish and in order to attain an optimum allocation, also the l.h.s. of the equation has to be lower. This implies a relatively higher application of external knowledge. In other words, in the context of the opportunity cost described, pecuniary knowledge externalities apply and the firm maximizing in a

localized context will be using a mix characterized by more external than internal knowledge, i.e. IK/EK<IK/EK*. Moreover, and most importantly, the amount of knowledge generated T will be larger than the equilibrium level T*. The firm will produce more and cheaper technological knowledge than in a system where external knowledge would have higher –equilibrium- costs.

Following Griliches (1979), technological knowledge enters directly the standard Cobb-Douglas production function of all the other goods with constant returns to scale of each firm. Hence:

(4) $Y = A (I^{\gamma} \; T^{\delta})$ with $\gamma+\delta =1$

(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, s its cost and A measures the total factor productivity level. According the equilibrium condition:

(6) $\gamma/\delta \; I/T = s/c$

firms that can benefit of positive pecuniary knowledge externalities in the access to external knowledge and hence take advantage of the upstream localized generation of larger amounts of 'cheaper' technological knowledge with cost below equilibrium level: $s < s^*$, will use a technique characterized by higher level of T and, most importantly, will produce an output Y that is larger and cheaper than in general equilibrium conditions.

Following Abramovitz (1956) we know that the level of total factor productivity is measured by the ratio between the real historic levels of output Y, and the theoretical ones calculated as the equilibrium use of production factors:

(7) $A = Y / I^* T^*$

Where I^* and T^* are the general equilibrium quantities of production factors and A measures total factor productivity.

The case for total factor productivity takes place when the access to technological knowledge as an input into the generation of new technological knowledge is affected by localized out-of-equilibrium conditions and is cheaper than in general equilibrium conditions. Hence the output of all the other goods produced downstream in localized equilibrium conditions characterized by pecuniary knowledge externalities will be larger than in general equilibrium conditions.

The results can be summarized as it follows: firms produce more than expected and hence experience a 'un-explained' residual in the actual levels of output that are larger than the expected ones ($Y>Y^*$), if and when:

1) the localized governance costs of external knowledge in the upstream knowledge generation function are lower than in general equilibrium ($u < u^*$);

2) the localized output in terms of technological knowledge is larger than in general equilibrium conditions, i.e. the actual levels of T (T') are larger than the general equilibrium levels (T^*) ($T'>T^*$);

3) the costs for the localized technological knowledge that enters the Cobb-Douglas production function for all the other goods are also lower ($s < s^*$).

These elementary passages enable to support the basic proposition that total factor productivity levels (and its increase) depend upon the levels (and the rates of increase) of the discrepancy between the general equilibrium costs of external knowledge and the actual localized ones. Hence we can put forward the basic proposition that total factor productivity levels are stemming from pecuniary knowledge externalities:

(8) $A = f\,(T'/T^*)$

(9) $T'/T^* = g\,(u / u^*)$

(10) $A = h\,(g(u/u^*))$

Total factor productivity levels can be explained by the excess amount of output and technological knowledge determined by the localized governance costs of external knowledge that are below general equilibrium levels because of positive pecuniary knowledge externalities.

In such conditions, qualified by pecuniary knowledge externalities, each firm operates in localized (and transient) equilibrium conditions, but the aggregate output of the system is larger than expected in general equilibrium conditions. The working of pecuniary knowledge externalities is compatible with short-term, Marshallian instantaneous equilibrium conditions at the firm level, while at the aggregate level the system is far from equilibrium.

From a dynamic viewpoint, total factor productivity growth can take place through time, that is

(11) $dA/dt > 0$

if, where and when

(12) $d(u^*-u)/dt = 0$ or >0

The crucial distinction introduced by Schumpeter (1947) between passive adaptation and creative reaction plays a central role at this point of the analysis to grasp the dynamics of the system and its effects, according to its localized conditions. Firms facing changes in their product and factor markets try and react with the generation of new technological knowledge. Their reaction will be creative if pecuniary knowledge externalities qualify the access conditions to external knowledge. In this case firms will be able to generate new technological knowledge at costs that are below equilibrium levels. The generation of technological knowledge will take place in conditions that make it possible the introduction of productivity enhancing innovations. The introduction of innovations will affect further the out-of-equilibrium conditions of the system and induce new firms to try and react in turn. A sustained dynamics of out-of-equilibrium growth is put in place and it will continue as long as the system is able to provide its members with the access to external knowledge at costs that are below equilibrium levels.

As long as there are pecuniary knowledge externalities, and the local costs for external knowledge remain below general equilibrium levels, the typical complex system dynamics, stemming from the positive feedback generated by knowledge cumulability and knowledge complementarity, implemented by good knowledge governance mechanisms and the convergence of knowledge generation activities, are at work. This outcome meets the basic expectations of the Schumpeterian tradition: "surplus values may be impossible in perfect equilibrium, but can be ever present because that equilibrium is never allowed to establish itself" (Schumpeter, 1942, 1950:28)[3].

When the knowledge governance mechanisms are no longer suited to organize the access to the stock of technological knowledge available in the system, pecuniary knowledge externalities decline and with them the opportunities to sustain the introduction of technological innovations, the increase of total factor productivity and hence the scope for dynamic increasing returns.

When the generation of technological knowledge cannot benefit from the availability of pecuniary knowledge externalities, the reaction of firms will be 'adaptive', as opposed to 'creative'. In these conditions firms can just introduce technical change as distinct from technological change and will yield equilibrium levels of output. Firms will be able to move in the existing map of isoquants and the existing map of techniques and no increase in the levels of total factor productivity can be detected. The equilibrium conditions of the system are not perturbed.

[3] I owe this quote to one of the anonymous referees.

The essential argument elaborated so far is that productivity growth is a complex process that takes place in an environment that is heterogeneous. Technological innovation, which is the key to productivity growth, occurs as a result of a reaction to unexpected events that takes place with costs of innovation being lower at particular points in time and space than the equilibrium level of those costs. Technological innovation occurs as a result of taking external knowledge (through screening, identification, understanding, purchasing, and using) and recombining it with the use of internal knowledge. It is actually introduced by firms that caught in out-of-equilibrium conditions try and react to unexpected changes in their product and/or factor markets and can take advantage of pecuniary knowledge externalities that make it possible to access external knowledge at a cost that is below equilibrium levels ($u>u^*$).

4. IMPLICATIONS AND CONCLUSIONS

This paper takes issue with the idea, at the heart of the first generations of the new growth theory, that innovation is a homogeneous, inexorable process that depends only on the supply of knowledge and not its cost or process of production. It suggests that a new generation of endogenous growth theory can be elaborated building upon the view that innovation takes place as a form of creative reaction supported and actually made possible by the actual availability of internal and external knowledge, as determined by the knowledge governance mechanisms that cope with the structural conditions of the system.

In our approach firms are induced to try and generate new technological knowledge, so as to introduce innovations, when unexpected changes in both product and factor markets push them out-of-equilibrium. The recombinant generation of new technological knowledge is activated. Its outcome is crucially affected by the localized conditions of availability of external technological knowledge that has been already generated and used by third parties, and yet, because of knowledge limited appropriability can be accessed by third parties as external knowledge and because of indivisibility and non-exhaustibility, can be used again.

At each point in time the system is endowed with a heterogeneous stock of technological knowledge possessed by a myriad of agents and embodied in a great variety of applications and uses with varying levels of actual connectivity. The generation of technological knowledge consists in the recombination of the existing bits of the heterogeneous stock of technological knowledge. Because of its intrinsic diversity, fragmentation and dispersion, much necessary technological knowledge is external to each agent. External knowledge is an essential input into the recombinant generation of new technological knowledge. Knowledge governance mechanisms enable the recollection of existing technological knowledge and enable firms to use it again. The governance of localized technological knowledge helps strengthening the knowledge connectivity of the system.

When knowledge governance is effective and enables the identification and actual use of external knowledge, at costs that are below equilibrium levels, the output of the recombinant generation of technological knowledge and of the downstream production of other goods increases beyond equilibrium levels. The localized generation of technological knowledge can take place at costs that are below general equilibrium levels. In these circumstances firms are successful in their attempt to cope with unexpected changes in their product and factor markets by means of the introduction of productivity enhancing innovations. The localized access to external knowledge at out-of-equilibrium costs is the key to sustain the introduction of productivity enhancing technological innovations, as it can account for the empirical evidence of the increase of the general efficiency of the production level, beyond the levels of output expected in general equilibrium conditions. The introduction of new technologies perturbs the system, engenders new out-of-equilibrium conditions and pushes new firms to try and react by means of the generation of additional technological knowledge. If the system provides access to pecuniary knowledge externalities, the process can keep going sustained by the open-ended loop of positive feedbacks.

On the opposite the reaction of firms caught in out-of-equilibrium conditions that try and react by changing the characteristics of their production processes or of their product without the support of pecuniary knowledge externalities, will be merely adaptive enabling firms their mobility in the existing map of isoquants, feeding substitution processes and the introduction of novelties in product markets that, however, cannot increase their total factor productivity. In these circumstances firms can only adapt to the changing conditions of their product and factor markets by means of technical change – as opposed to technological change- with no increase in the levels of total factor productivity: general equilibrium conditions are restored.

Here the conditions of the systemic conditions of regions, in terms of knowledge governance mechanisms at work, affect the cost equation of the generation of new technological knowledge of each firm. Pecuniary knowledge externalities are found when and where external knowledge can be identified, retrieved and used at low costs. Only when pecuniary knowledge externalities are found, can firms actually introduce technological innovations that can actually improve the general efficiency of the production process. For the same token, high levels of total factor productivity signal the positive effects of pecuniary knowledge externalities and the increase in the levels of total factor productivity signals the increase of the levels of pecuniary knowledge externalities.

Conditions for the access to external knowledge, at costs that are below equilibrium levels, are not given or exogenous at the system level. They do vary across historic times, regions, industries and countries. The levels of knowledge connectivity and the quality of knowledge governance mechanisms are endogenous to the system and strongly characterized by path dependence, as they are the result of the stratification and accumulation of the actions of firms at each point in time, and their effects on both the composition of the knowledge structure of the system and the viability of the knowledge governance mechanisms.

Dynamic increasing returns can take place if and when the attempts of firms to try and generate new technological knowledge and introduce technological innovations, to cope with un-expected events, and made possible by pecuniary knowledge externalities, are able to sustain over time appropriate levels of knowledge connectivity at the system level in terms of composition of the knowledge structure and quality of knowledge governance mechanisms.

This approach provides new opportunities for empirical research on the relationship between innovation and economic growth at the regional level. The region seems the most relevant unit of analysis to investigate and identify the working of knowledge governance mechanism and their effects in terms of pecuniary knowledge externalities and total factor productivity growth.

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