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

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ABSTRACT

Building upon both the Schumpeterian and the Marshallian legacies, this paper elaborates a model of localized technological change cum pecuniary knowledge externalities to provide a systemic explanation for total factor productivity. 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. Nevertheless external knowledge is an essential input into the recombinant generation of new technological knowledge. In

[1] This paper is dedicated to professor Stan Metcalfe from whom I have learnt much. A preliminary version has been circulated in occasion of the Festschrift in Honor of professor Stan Metcalfe. The comments of many are acknowledged as well as the funding of the European Union D.G. Research with the Grant number 266959 to the research project 'Policy Incentives for the Creation of Knowledge: Methods and Evidence' (PICK-ME), within the context Cooperation Program / Theme 8 / Socio-economic Sciences and Humanities (SSH), and the support of the Collegio Carlo Alberto.

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 explain the levels and the growth of total factor productivity when existing units of external knowledge can be bundled and used –again- at costs that are below reproduction ones.

KEY WORDS: TECHNOLOGICAL KNOWLEDGE; KNOWLEDGE GOVERNANCE; TOTAL FACTOR PRODUCTIVITY.
JEL CODE: O30

1. INTRODUCTION

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 cannot cope with unexpected events in their product and factor markets with traditional substitution. Nevertheless they can change intentionally their technology, provided a number of circumstances take place (Schumpeter, 1947).

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. This approach combines the Schumpeterian emphasis on the role of technological change with the Marshallian analysis of externalities. 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; Metcalfe, 2007).

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.

2. THE ECONOMICS OF KNOWLEDGE AND PECUNIARY KNOWLEDGE EXTERNALITIES

Technological knowledge is an economic good with particular characteristics such as partial or even non-appropriability, indivisibility and cumulativity, non-exhaustibility. It is the result of a recombinant generation process where existing knowledge is an essential and indispensable input.

Hence it is at the same time an input and an output. Eventually knowledge enters the production function of all goods: as such it is twice an input: an input into the generation of knowledge and an input into the generation of the other goods (Nelson, 1959; Arrow, 1962 and 1968; David, 1993; Weitzman, 1996).

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. The characteristics of knowledge would explain why the incentives to the production of knowledge and the benefits stemming from exchange in the market place and consequent opportunity for specialization could be inadequate because of its limited appropriability. In this sense, technological knowledge is a clear case of market failure.

This approach has been reconsidered by the path-breaking work of Zvi Griliches that, instead of focusing upon the negative aspects –in terms of missing incentives- of knowledge non-appropriability, introduced the notion of knowledge externalities to highlight the positive effects of the uncontrolled spillover of knowledge from 'inventors' to third parties. Technological knowledge generated by each firm enters as a '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; Link, Siegel, 2007).

The new growth theory has implemented the analysis of the positive effects of knowledge spillover and knowledge non-exhaustibility and elaborated a model of endogenous growth based upon the spontaneous, automatic and free utilization of the stock and flows of knowledge generated in a system (Romer, 1986, 1990 and 1994, Lucas, 2008).

The new growth theory fails however to accommodate the heterogeneity in time and space of the actual rate of introduction of technological innovations. Much evidence shows that the rates of technological change are far from being evenly distributed across historic times, industries and regional spaces. On the opposite they concentrate in historic time within well identified gales that are located in defined portions of the industrial system and regional space that do keep changing (Abramovitz and David, 1996; Mokyr, 1990, 2002).

Numerouse alternative views have been elaborated in the recent years. Among others, Paul David has indicated a conceptual route based upon the analysis of the implications of knowledge indivisibility and has articulated the distinction between diachronic and synchronic cumulability. The first identifies the indivisibility between present and past knowledge. Synchronic indivisibility qualifies the indivisibility and cumulability among knowledge activities conducted at each point in time by agents active in the system. Both require the active participation of perspective users and matter in the generation of new technological knowledge (David, 1993).

The generation of new technological knowledge by each firm in fact 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. The firm is primarily a knowledge integrator able to bundle different sources of knowledge in order to generate new knowledge (Weitzman, 1996 and 1998).

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. The access to external knowledge, although diverse, despite its dispersion and fragmentation, is essential because of its crucial role in the recombinant generation of new technological knowledge. The wider is the scope of the recombination and the higher are the chances to generate new technological knowledge (Antonelli, 2007; 2008b).

From a market oriented view point, existing technological knowledge cannot be used freely. This is due to the fact that it is dispersed in a myriad of local contexts of application. Moreover it is codified in a variety of non- trivial codes and possessed by a myriad of agents. 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 or imitate it from and adapt it to a specific context of application. Also, to finally and efficiently access it, requires dedicated activities of clearing the use conditions with the actual possessors, either through market transactions or on the way of intentional interactions (Cohen and Levinthal, 1989 and 1990).

Given that active search, screening, identification and interpretation of existing knowledge are necessary in order to use it again as an intermediary input into the production of new knowledge, and considering its particular characteristics, the notion of pecuniary knowledge externalities applies far better than the traditional notion of technological externalities (Schitovsky, 1954; Antonelli, 2008a).

Pecuniary knowledge externalities are found where and when the costs to accessing and using external knowledge are lower than in general equilibrium conditions. While they work out their essential influence on the system as a whole, 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 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.

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

The new relevance on the role of external knowledge calls attention upon the role of knowledge costs on the cost equation side. This contrasts a long-standing tradition focusing the production function approach. Ever since the arrovian notion of learning, the effort to explaining the determinants of total factor productivity has been paid 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 non-appropriability and related spillovers among firms. We articulate in this section an alternative approach that builds upon the role of external knowledge and pecuniary knowledge externalities in the cost equation. Next we nest a knowledge generation function that accounts for pecuniary knowledge externalities into a production function that includes technological knowledge as an input, The focus shifts from the production function to the cost equation. In so doing 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 external knowledge to be used as an essential and indispensable production factor (Antonelli, 2008b).

To frame this analysis we can specify a knowledge generation function (Nelson, 1982 and Weitzman, 1996 and 1998). External knowledge is the qualifying input, together with internal knowledge obtained by means of research and development activities and the valorization of learning processes. External knowledge is a non-disposable input, for nobody can command all the knowledge available at any point in time. External knowledge has been generated in previous periods and it 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.

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 costs of external knowledge consist in the resources that are necessary to screen, identify, understand, purchase and use knowledge possessed and used by other agents in the system, including the costs of knowledge communication as well as knowledge networking.

Pecuniary knowledge externalities are found where and when the localized costs of external knowledge (u) are below general equilibrium –average-levels (u*). The latter would hold if and when knowledge were a standard economic good. According to the localized equilibrium condition:

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

If the cost of external knowledge were equal to a normal-good-equilibrium level, u*, then the optimal left hand side ratio between internal and external knowledge would be equal to IK/EK*. When the actual cost of 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 cost opportunity 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* and 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) $Y = (I^{\gamma}\ T^{\delta})$ 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 and s its cost. Firms, according the localized equilibrium condition:

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

with positive pecuniary knowledge externalities in the upstream generation of technological knowledge and hence cheap localized costs of technological knowledge, 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 Abrmovitz (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 supply of 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 will be larger than in general equilibrium conditions.

Technological knowledge that has been generated without the availability of pecuniary knowledge externalities and with standard levels of connectivity will yield equilibrium levels of output. In these conditions firms can introduce novelties, rather than innovations. Novelties consist in changes in production processes, higher levels of product differentiation with new characteristics of their products. Novelties differ from innovations. Only the latter yield total factor productivity enhancing effects.

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 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 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, instantaneous equilibrium conditions at the firm level while at the aggregate level the system is far from equilibrium.

From a dynamic view point, 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

This is turn can happen if three, non exclusive, conditions apply: A) the successful recombinant and localized generation of new technological knowledge realized with pecuniary knowledge externalities enables higher rates of historic accumulation of complementary units of knowledge and larger flows of knowledge generation activities so that at each point in time the local system will take advantage of the endowment of a larger amount of technological knowledge stock with high levels of connectivity; B) the agents in the system are able to implement the coherence of the knowledge stock by means of convergent research strategies than enhance the connectivity of the system; C) the agents in the local system are able to improve the levels of knowledge connectivity and hence pecuniary knowledge externalities by means of the better knowledge governance mechanisms.

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.

When the dynamics of knowledge generation and knowledge governance mechanisms are no longer suited to organize the knowledge connectivity of the local system, however, 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.

4. THE CAUSES OF PECUNIARY KNOWLEDGE EXTERNALITIES: KNOWLEDGE CONNECTIVITY AND KNOWLEDGE GOVERNANCE

Pecuniary knowledge externalities are by definition exogenous to each firm, but endogenous to the system into which firms are embedded. Their levels depend upon the structure and the organization of the stock of the existing heterogeneous knowledge. Let us analyze them in turn.

The structure of the stock of knowledge. The applications of the economics of complexity to the economics of technological knowledge enable to analyze the structure of the stock of existing knowledge as a complex rugged and heterogeneous system characterized by a variety of diverse components, possessed by a variety of agents and embodied in a variety of artefacts linked by different levels of epistemic interdependence and interrelatedness (Saviotti, 2007).

The relations among such components may be qualified in terms of fungibility, cumulability and compositeness according to the actual levels of complementarity and contribution that each body of knowledge is able to make in the recombinant generation of new technological. Hence systems may differ at each point in time and change across time in terms of structural knowledge connectivity (Antonelli, 2011).

The actual levels of knowledge connectivity are endogenous to the system: indeed they are the aggregate result of knowledge generation activities of the myriad of agents. More specifically the determinants of connectivity will be found in the direction of the recombinant generation of the new flows of knowledge that take place at each time within each firm. Depending on the local knowledge endowments, firms have clear incentives to identify and implement a specific typology of technological knowledge and direct towards convergence the resulting generation of technological knowledge. In a heterogeneous system, where local knowledge endowments differ, firms have a strong incentive to identify the kind of technological knowledge that is most appropriate to benefit from the specific conditions of the localized pools of technological knowledge. In this sense the generation of new technological knowledge is twice localized in that it is not only sensitive to specific conditions that are internal to each firm, as the resource-based theory of the firm argues, but also to the external context of action.

From this view point the structure of the stock of knowledge is the result of a dynamic path dependent process of accumulation and stratification. This process is clearly shaped by the initial conditions and yet highly sensitive to changes in direction and intensity that may take place at each point in tine: small events may change the characteristics of the dynamic process. The coherence of the knowledge structure of the system may increase or decline according to a variety of specific small events along the path. Also the changing ability of upstream knowledge providers and of downstream creative knowledge users to implement creatively externally generated knowledge in their internal generation of further knowledge do matter (Gehringer, 2011).

The organization of knowledge governance. At each point in time, for given characteristics of the structure of the knowledge embedded within a system, in terms of knowledge coherence, complementarity and cumulability, the actual levels of knowledge connectivity that affect the levels of pecuniary knowledge externalities are strongly influenced by the knowledge governance mechanisms that are at work among firms, households and institutions, within industries, regions and countries. A variety of institutional and economic factors shape the levels of knowledge connectivity: secrets and intellectual property right regimes limit the dissipation of new and old technological knowledge. Dispersion and fragmentation limit the access to used knowledge. Additionally, also institutional mechanisms may be inadequate in offering an efficiently working system of knowledge transmission. Knowledge governance plays a key role in the organization of the systemic interactions that make possible the access and use of existing knowledge within an economic system (Metcalfe, 2002).

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).

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 identification, retrieval, and access to existing knowledge items takes place by means of a variety of knowledge governance mechanisms (Zeitlin and Herrigel, 1999). Three such models can be basically identified.

A) The corporate model. Economic systems characterized by large corporations rely upon internal markets and hierarchical interactions in the generation of new technological knowledge. This is the well-known 'American' corporate model. Its strength lies in the capability to accumulate and valorize internally stocks of existing knowledge. Conditions for its secondary uses are made effective by central coordination and hierarchical implementation. Diversification provides at the same time the opportunities to increase the scope of application and also to increase the breadth and diversity of knowledge units that can enter the recombination process. Corporations can internalize the dynamics of pecuniary knowledge externalities and appropriate benefits of dynamic increasing returns. Limitations of the corporate model are found in the resistance and lack of interest with respect to the external sources of technological knowledge. The corporation is afflicted by the non-invented-here syndrome and the costs of absorption of external knowledge are high. When the accumulation of technological knowledge exhibits significant discontinuities and sudden change in directions, the corporate model can suffer dramatically (Chandler, 1962, 1977, 1990; Antonelli and Teubal, 2010).

B) The distributed model. This model has been successfully experienced in Italy in the years 1950-1990. Networks of firms characterized by high quality user-producer interactions rely upon vertical relationships in building their technological knowledge. Direct relations among users and producers of capital goods are at the heart of this model. Direct knowledge interactions were the result of a long-term process of market exchanges based upon tangible goods. Relations between users and producers of capital goods gradually evolved into knowledge interactions. A novel mode of transactions-cum-interactions came out as an important outcome. The transactions of capital goods gradually were enriched by systematic knowledge interactions where both users and producers could take advantage of tacit knowledge generated in learning by doing and by using. Regional proximity within industrial districts reduced transaction costs and the risks of opportunistic behavior, increasing reciprocal trust and long-term commitment in relations (Porter, 2000; Boschma, 2005; Antonelli and Barbiellini Amidei, 2011). Considerable limitations of the distributed model stem from the possible unbalance of either ring in the vertical chain of user-producer interactions and transactions along which pecuniary knowledge externalities are generated and channeled. The path-breaking analysis of the delay of the European economy to take advantage from the gale of innovations centered upon information and communication technology implemented by Martin Fransman shows how the weakness of upstream suppliers of digital products may engender negative feedbacks and compromise the dynamics of increasing returns (Fransman, 2007)

C) The open innovation model. The open innovation model has been consolidating in the US after the ICT revolution and seems to be especially viable for science based technologies. Countries and regions with a strong academic and scientific infrastructure have an advantage in the introduction of science-based technologies via the start-up-venture capitalism mechanism. Academic entrepreneurship supported by the screening assistance and financial participation of venture capitalism maximizes the capillarity of the search for relevant units of existing knowledge. Knowledge dispersed and fragmented in a myriad of possessor can be actively searched and accessed by a myriad of academic entrepreneurs endowed with the distinctive capability to screen and appreciate the scope of application and recombination of the existing knowledge. Knowledge intensive business services are a crucial complement of academic entrepreneurship. Knowledge intensive business services act as intermediaries and interfaces between actual possessors of existing units of technological knowledge and the perspective users. The growth of knowledge intensive business services can lead to the emergence of a knowledge industry. Such role can take place only if the holding of technological knowledge in the transition phase is fully recognized and enforced. This new knowledge governance mechanism can thrive in economic systems characterized by low transaction costs in intermediary markets. Intellectual property right regimes play a crucial role for the implementation of this model of knowledge governance. The clear definition of property rights is, in fact, necessary for the indirect exchange of the existing units of technological knowledge. (Audretsch, 2006; Chesbrough, 2003; Chesbrough, Vanhaverbeke,West, 2006).

These different knowledge governance mechanisms can be considered alternative institutional solutions designed and implemented to organize the complexity of knowledge interactions and the creation and exploitation of pecuniary knowledge externalities. Only economic system able to organize their complexity and implement knowledge governance mechanisms can sustain the growth of output by means of the systematic increase of total factor productivity. The continual recreation of pecuniary knowledge externalities is crucial for the process to keep momentum in its dynamic path.

Pecuniary knowledge externalities are not bound to increase steadily, on the opposite, their levels can decline and reduce the opportunities for the successful generation of new technological knowledge and the eventual introduction of productivity enhancing technological innovations.

Dynamic increasing returns stemming from sustained growth of total factor productivity can take place as long as the system is able to sustain appropriate levels of pecuniary knowledge externalities. Congestion and opportunistic behavior may easily increase. The dynamic maintenance of knowledge governance mechanisms is crucial for the sustainability of dynamic increasing returns (Metcalfe, 1995 and 1997).

5. CONCLUSIONS

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 will 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 connectivity. Knowledge connectivity depends upon the composition of the knowledge structure of the economic system and the levels of knowledge governance. The latter enables the effective identification and supply of external knowledge as a key input into the recombinant generation of new technological knowledge at costs that are below equilibrium.

In our approach firms are induced to try and generate new technological knowledge so as to introduce innovations only when unexpected events –

that cannot be coped with traditional substitution process- push them out-of-equilibrium. The recombinant generation of new technological knowledge is activated. Its outcome is crucially affected by the localized availability of external technological knowledge that has been already generated and used by third parties, and yet, because of knowledge 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 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 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. 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 technological innovations. The localized generation of technological knowledge can take place at costs that are below general equilibrium levels. 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

Here the conditions of the systemic conditions, in terms of knowledge connectivity and 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.

A major distinction between innovations and novelties can be introduced. Innovations consist in changes in processes and products that do have clear productivity enhancing effects. Novelties consist in changes in processes and products that account for an increase in product variety, but not in higher levels of efficiency.

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.

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