Chapter **20**

Restructuring and Innovation in Long-Term Regional Change

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Introduction

REGIONS are simultaneously a source of major hysteretic constraints and a source of innovation opportunity. Hysteretic constraints result from the duration and irreversibility of fixed and intangible capital. Locations may thus be characterized by long-term rigidity and irreversibility or may provide a context for technological communication, external knowledge, and learning opportunities. Location is thus an important factor in assessing the rate and direction of technological change and economic fortune.

All changes in relative prices and desired output levels oblige incumbents to change the existing combination of superfixed and variable factors. Irreversibility, however, makes technical substitution impossible and pushes firms to out-of-equilibrium conditions. Such conditions can become a powerful inducement factor to try and introduce localized technological changes. To avoid technical inefficiency, induced innovations are introduced along the endowment line defined in terms of the original amounts of superfixed production factors.

The access to collective knowledge and the opportunities for technological pooling provided by effective communication systems, within technological districts, favor the efficiency of innovation activities within firms and the eventual introduction of localized technological changes. In turn, enhanced efficiency of innovation activities of firms and faster rates of introduction of innovations increase the amount of collective knowledge available in the

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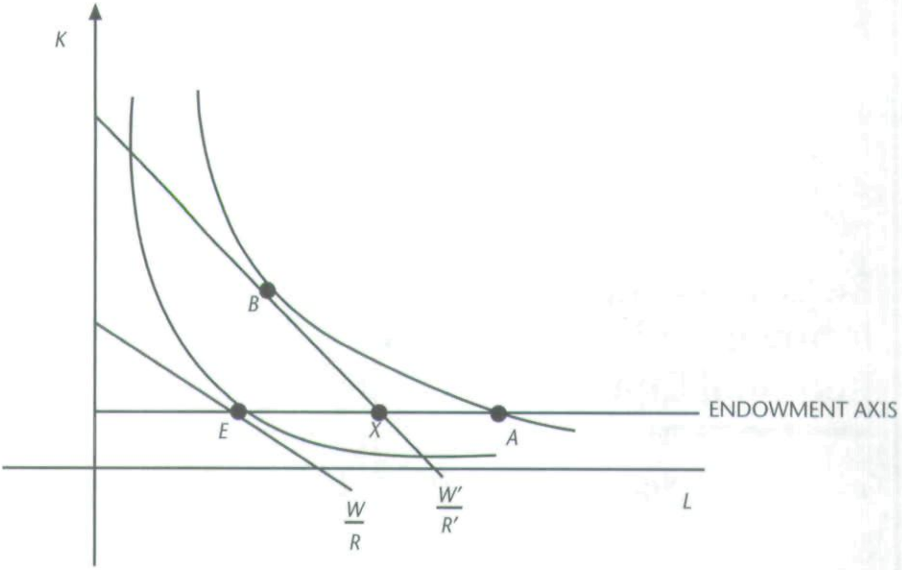

Fig. 20.1. Irreversibility, technical inefficiency, and the inducement to innovate

region. A spiraling interaction fueled by the localized positive feedback between firms and regions can take place with significant effects in terms of dynamic increasing returns both at the regional and the firm levels.

Regions are a major factor in making technological change hysteretic. Because of regional institutions and place-specific opportunities, innovations are introduced along technological paths that are defined in terms of factor intensity and technological continuity and based upon complementarity and interoperability and reflect different technological vintages. The interaction of the dynamics of localized technological changes and communication processes explains the clustering of innovations in well-defined technological districts as well as the rate and direction of introduction of technological changes.

This chapter elaborates an interpretative framework to understand the long-term interactions between location in regional space, irreversibility, and localized technological change. In the second section, a simple model shows how changes in demand and factor prices together with superfixed production factors induce the endogenous introduction of localized technological changes. In turn the interaction of endogenous technological change and communication processes, presented in the third section, explains the clustering of innovations in well-defined regional spaces, as well as the key role of knowledge-intensive business services and technological cooperation in assessing the innovative capability of regional innovation systems. The implications for economic analysis and the relevant policy issues are considered in the conclusions.

The Inducement of Localized Technological Change

An array of detailed empirical analyses, especially in industrial economics, has highlighted the key role of superfixed production factors (Antonelli 1999). Superfixed production factors are long-lasting, tangible, and intangible assets which once installed can be replaced only with huge costs and a long time span. Recent advances in the theory of investment are now dealing with such empirical evidence (Dixit 1992). The analysis of sunk costs has made important contributions to the theory of the firm and markets because it has provided a better understanding of the long-term effects of historic time in assessing the conduct of firms and the results of their strategic interaction in the market place (Sutton 1991).

Technical interrelatedness, which takes the form of major technical constraints among phases of the production process and between capital, intermediary goods and skills, subsystem bottlenecks and complementary assets, dedicated and idiosyncratic competence are all factors that keep the firm in a limited region of existing production frontiers or isoquants. Sunk costs are especially relevant when the discrepancy between purchasing costs of capital goods and resale prices in secondary markets is high: this is the case of most intangible assets. The idiosyncratic characteristics of the production process of each firm—such as reputation in both product and factor markets, type of managerial organization, standard operating procedures, capital structure and shareholder expectations, and last but not least traditions—add on to make evident the superfixed character of a significant portion of their production factors. Finally and most importantly, location in a well-defined regional space is a major factor of rigidity. Location roots firms in a variety of ways: plants and buildings are often difficult to change and expand; user–producer relations in intermediary markets have a strong regional aspect, as well as internal and external labor markets. Regions are a major factor of irreversibility also for the important role of infrastructures such as transportation, telecommunications networks, and research institutions.

When superfixed production factors are relevant, in that they constitute a major part of total production factors, all adjustments of firms to the changing conditions of the business environment are subject to significant constraints. Changes in the production mix and output size expose firms to relevant price and output 'Farrell' inefficiency, with the eventual emergence of 'quasi-losses'. In these circumstances, firms are pushed in out-of-equilibrium conditions that induce them to try and find a solution in the form of a new technology. In this case, they will incur innovation costs, that is, the costs of implementing their tacit knowledge and actually changing their technology.

In these circumstances, the implementation of tacit knowledge, the generation of localized technological knowledge, and the introduction of new technologies that make it possible to re-establish the efficiency conditions become a viable alternative to the quasi-losses.

On this basis, we can now turn to a brief formal exposition of the model.

Let us consider a firm in equilibrium with a given level of superfixed production factors and a ratio of wages W to capital rental costs R at point E. After a change in relative prices creating a new level of wages W' and rental costs R', the firm of the standard microeconomics textbook would choose the new technique B where the new marginal rate of substitution equals the slope of the new relative prices. A similar process takes place when the firm is exposed to increases in the level of demand. When demand increases, textbook firms should increase the levels of inputs, with a given technique, in order to expand output to the new desired level. Now that firm would reach the point B on the new isoquant placed further to the right on the same map. The combination of both changes makes the situation even more evident.

Such solutions however imply change in the levels of superfixed production factors: typically it is a very long-term solution that engenders relevant costs and may actually be impossible. It is now clear that our context of analysis is an extension of the time horizon of the traditional short-term cost and production analysis.

The firm with superfixed production factors cannot do any better than selecting the technique A, defined by the intersection between the isoquant and the endowment axis. This implies higher costs. Alternatively the incumbent can select the technique defined by the intersection between the new isocost and the endowment axis, but for a given map of isoquants and hence for a given technology, the new solution implies clear output inefficiency in terms of lower levels of output. In these conditions, it is clear that a firm exposed to significant changes either in the demand for its product or in the relative price of production factors is bound to experience either a decline in price efficiency or an emerging output efficiency (Farrell 1957). More directly, we can define the effects of such situations as quasi-losses.

We can write the quasi-loss function associated with both the changes in the relative prices of inputs and in the demand for incumbents characterized by relevant superfixed production factors, as follows:

$$QL = f(\mathrm{d}AX), \tag{1}$$

where QL are the quasi-losses measured in terms of the technical distance between A at the intersection between the endowment axis and the new isoquant and any new solution X on the endowment axis.

The introduction of a new localized technology can help the firm to restore equilibrium and even reduce costs. All new technologies that reshape the isoquant map along the endowment axis so as to make the solution X 'viable', enable the productive factors to be used rationally so as to restore the general price efficiency of the firm and can lead to an overall increase in efficiency and eventually in total factor productivity.

We can now turn our attention to the role of technological knowledge and technological change. In order to change their technology, firms must capitalize on the tacit knowledge acquired through the learning that has been going on in the techniques being used, and invest in formal R&D activities. Systematic search for available external knowledge is also necessary and relevant communication costs are associated with this. This research process can stop when the new technology is such that the firm reaches the equilibrium where the marginal rate of substitution again equals the slope of the new isocosts yet remaining on the endowment axis. Further movements along the endowment axis however are welcomed. They are actually likely to generate an increase in total factor productivity in monetary terms.

The costs of innovation activities necessary to move the isoquant along the endowment axis towards (and possibly beyond) the point X are a function of the leftward distance from:

$$CTI = g(\mathrm{d}XA), \tag{2}$$

where CTI represents the innovation costs borne in implementing learning procedures, acquiring external knowledge, and hence building technological communication channels with other firms and with other research institutions, operating R&D laboratories, and broadly of all the activities directed towards the introduction of the technological changes that are necessary to reshape the isoquant so as to move it along the endowment axis between the technique E towards and beyond the new point X.[1]

A firm that chooses to stay in technique A incurs a decline in general efficiency but avoids all innovation costs. Conversely, a firm that chooses the new technology X avoids the decline in efficiency, but incurs substantial innovation costs which are necessary to find the new technology that enables the firm to produce as much as it would have done on the old isoquant but next to and actually beyond the intersection between the new isocost and the endowment line.

We are now in a position to portray the decision process of the firm with the standard tools of profit maximization. The profit equation for the firm reads as follows:

$$P = R(\mathrm{d}AX) - CTI(\mathrm{d}XA) \tag{3}$$

where R stands for the gross revenue from adjusting to the new factor prices, measured in terms of the reductions in production costs, with respect to technique A, made possible by the introduction of technological changes that reduce price and output inefficiency. In other words, the revenue of changing the technology along the endowment axis consists of the reduction in the total

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[1] The 'necessary' assumption that $g > 0$ seems plausible.

costs in *A*. *CTI*(d*AX*) are the innovation costs and can be measured in terms of the distance on the endowment line between *A* and *X*.

Standard maximization of the profit equation enables the identification of the 'correct' amount of innovation costs a firm can bear, for a given technology production function '*g*', that is, for a given technological capability to create new technological knowledge and eventually introduce new technologies with a given amount of economic resources.

This geometric approach makes it possible to relate the amount of innovation selected directly to the technical inefficiency arising from superfixed production factors so as to establish a trade-off between technical inefficiency and technological innovation. Maximization here identifies the 'best' distance on the endowment axis a firm can travel by means of the introduction of localized technological changes, induced by the twin constraints of a production process characterized by heavy superfixed inputs and changes both in product and factor markets.

The introduction of localized technological changes along the endowment axis will make it possible for firms that cope with the increase in demand levels and changes in the relative prices of production factors to adjust the ratio of marginal productivities, actually changing the usage intensity of the superfixed production factor. The direction of technological change will be shaped by the endowment of superfixed production factors. Technological innovations introduced in this context will be strongly characterized by high levels of sequential cumulability, interoperability, complementarity, and technological continuity with respect to the existing and irreversible production factors. The rate of technological change in turn will be affected by the levels of turbulence of the business environment and the share of superfixed production factors of total costs. The larger are the former and the latter, the larger is the inducement to rely upon technological change in order to cope with the new factor and product market conditions.

The actual rate of technological change, for given levels of superfixed production factors and entropy in the product and factor markets, will be clearly determined by the effective capability of firms to generate new technological knowledge and hence technological innovations. With high innovation costs, incumbents will be unable to meet the quasi-losses with the introduction of innovation and will eventually decline. With medium innovation costs, incumbents are induced to make only incremental innovations so as to reduce the distance on the endowment axis between *A* and the intersection between the isocost and the endowment axis. In these circumstances, incumbents can only reduce quasi-losses and come closer to the best practice. With low innovation costs and large technological opportunities, incumbents can meet the emerging quasi-losses with the successful introduction of radical innovations that make possible a quantum leap on the endowment axis and actually go beyond the 'equilibrium' point with a substantial increase of total factor productivity.

It is now clear that location within regions plays a twin role. On the one hand, it is a major source of irreversibility: regions reduce the capability of firms to perform standard technical substitution on the existing map of isoquants, but on the other they can provide access to important sources of technological knowledge. Location within a region can increase the access to technological opportunities routed in a specific system of embedded relations and help increase the general efficiency of the technological production function '*g*' and hence can favor the introduction of technological innovation. Location within a region may introduce significant technological changes that enable the substantial increase of total factor productivity.

In this context, the access conditions to external knowledge and the levels of technological opportunities that stem from the interaction and technological communication among firms and between firms and local research institutions within a region play a major role.

The Role of Local Communication in the Dynamics of Localized Technological Change

The notion of localized technological knowledge emerges at the crossroads of the debates in the economics of knowledge about its codified or tacit character and its public or quasi-private nature as an economic good. The notion of localized knowledge stresses the process by means of which new knowledge is generated. In this approach, the production of technological knowledge is heavily dependent on the multiplicative relationship of: (1) internal learning processes which lead to the accumulation of tacit knowledge, (2) internal R&D activities which enable codified knowledge to be gathered, (3) the access to external tacit knowledge by means of the socialization of experience and competence among firms, and (4) the access to and eventual recombination of existing external codified knowledge. In such a complex mix, each element is complementary and indispensable (Antonelli forthcoming).

This approach has many implications. First, the localized character of technological knowledge increases its appropriability but reduces its spontaneous circulation in the economic system. Technological knowledge in fact is viewed as strongly embedded: it is industry-specific, region-specific, and firm-specific; and because of this it is costly to use elsewhere: respectively in other industries, other regions, and other firms. The transfer and adaptation of localized technological knowledge from one industry, region, and firm to another involves specific actions of firms and costs that need to be assessed. Secondly, localized knowledge is now viewed as a basic, indivisible, and single intermediary input into the production process of new knowledge. Hence knowledge has the typical codified characteristics of public goods, and yet it is dispersed and embedded in a variety of specific and localized contexts of application and partly appropriated by a myriad of users: as such its collective character is stressed.

Access to collective knowledge in turn depends on the extent to which effective communication among innovators takes place through the innovation system. In this context, the properties of economic systems, conceived as communication networks into which information flows, matter in explaining the capability of each agent to generate new technological knowledge. The conditions for technological communication become relevant and their assessment contributes significantly to the analysis of local innovation systems (Freeman 1991 and 1997; Nelson 1993; Antonelli 1999).

Localization within regional innovation systems characterized by effective communication channels can play a major role in this context. Agglomeration favors interaction and repeated exchanges; reduces opportunistic and free-riding behaviors. Agglomeration reduces transactions costs associated with the absorption of technological externalities (Lundvall 1985; Von Hippel 1988; Utterback 1994; Lamberton 1996 and 1997; Engelbrecht 1998; Antonelli forthcoming).

Technological communication differs from technological externalities. Too much emphasis has been put in the innovation systems literature on technological externalities as if external technological knowledge could be acquired freely in the 'atmosphere' without dedicated efforts. The notion of technological externalities is consistent with the Arrovian notion of technological information, a public good with low levels of appropriability and excludability. The notion of technological communication seems far more appropriate to the new theorizing about the quasi-private and hence collective nature of localized technological knowledge (Lamberton 1971, 1996, 1997; Cohen and Levinthal 1989; Lundvall 1985; Krugman 1996).

Recent progress in the analysis of communication processes suggests the application to communication processes of the methodology of spatial stochastic interactions. Within communication networks, we see in fact that at each point in time, the magnitude and the impact of the effective flow of information which is both emitted and received by each agent can be thought to be the outcome of the interaction between two classes of stochastic events: (1) the connectivity probability that the flows of effective communication and the exchange of information take place within information networks and (2) the receptivity probability that the results of the research and learning efforts of each firm in the system are effectively assimilated and eventually implemented by the amount of external information available in the technological environment. In turn the distribution of connectivity and receptivity probabilities is influenced by but not deterministically dependent upon the quality of connectivity links, their density, and the distance among firms and other research institutions and the distribution and intentional efforts of receptive agents. This methodology, moreover, makes it possible to reproduce analytically the dynamic laws of a process where the actual transfer of technological information can either take place or decay: stochastically, in fact, communication fails (David and Foray 1994; Krugman 1996; Antonelli 1999).

Location plays a major role in this context, not only as a factor of constraints in terms of rigidity and irreversibility, but also for its connectivity-enhancing effects. The quality of connectivity among agents can be probabilistically influenced by intentional connectivity-enhancing strategies such as active technological outsourcing, technological cooperation, and location in close vicinity to other innovators. Such communication strategies can in fact be better implemented by location in well-defined regional and local systems where the density of 'technological communicators' is high. Proximity and spatial density enhance technological connectivity on many counts: user–producer relations are easier as well as informal exchanges, labor market mobility, university–firms interactions (Allen 1983; Becattini 1987; Feldman 1994 and 1999; Von Hippel 1988; Castells 1989; Freeman 1991; Lundvall 1985; Utterback 1994).

Technological districts, that is regions which provide high levels of technological communication, are likely to be conducive to a virtuous cycle where irreversibilities and hence out-of-equilibrium conditions lead to fast rates of introduction of new technologies and hence fast increases of total factor productivity which in turn engender new turbulence in the product and factor market places. Regions with low levels of technological communication and high levels of irreversibility cannot resist markets' turbulence and are likely to experience a fast decline of efficiency and market shares. The different levels of effective communication among innovators, as measured by the mixed probability of the communication process, are likely to significantly affect the productivity of the total amount of resources devoted by each firm to research and learning activities and hence substantially reduce innovation costs (Nelson 1987).

This approach makes it possible to appreciate the characteristics of regions in terms of sectoral composition and technological strategies of firms. The variety of firms in terms of size and competence and hence sectoral distribution is an important factor of technological communication. Firms are less reluctant to share their knowledge with firms that are not direct competitors. Mobility of skilled and competent labor within local labor markets is an important factor of technological communication and increases the rates of accumulation of collective knowledge. The distribution and quality of knowledge-intensive business service industries also have important effects on the local economic systems in terms of communication and hence innovative capacity. The local supply of the services of consultants and advisers improves connectivity between agents, sharing learning experiences and creating learning opportunities, and thus advances receptivity. An active supply of knowledge-intensive business services, in terms of distribution, capillarity, competence, and access, can stimulate the technological outsourcing demand by small and medium-sized firms in particular, with in-house R&D. Advanced telecommunication networks, including high speed data communication and high-definition images, play an important role in favoring the local division of innovative labor among research units and learning firms. As growing evidence confirms, digital communication can complement rather than substitute for person-to-person communication. Technological districts with high-quality communication infrastructure can benefit from the spiraling interactions between digital and face-to-face communication. Finally, the quality of local academic infrastructure is an important factor in enhancing the capability of firms to absorb collective knowledge and make productive use of it because of increased opportunities to take advantage of technological externalities and benefit from interaction with the academic community. Agglomeration again can favor formal as well as informal university–enterprises interaction and hence successful technological communication (Mansfield 1991; Bania *et al.* 1993; Jaffe *et al.* 1993; Audretsch and Stephan 1996; Feldman and Audretsch 1999).

Agglomeration favors *de facto* technological cooperation among agents as well. Locally, technological cooperation takes place often within the context of outsourcing strategies with the active participation of suppliers and subcontractors in the identification of new processes and new products. Technological cooperation at the local level can play a major role in assessing the communication probability and hence the innovative capability for it enhances: (1) the circulation of tacit knowledge and its socialization; (2) the opportunity for external learning; (3) the opportunity for accelerated recombination of the bits of codified knowledge generated by each cooperating firm; (4) the scope for capitalizing on potential complementarities between the variety of firms and between the different R&D activities performed by each firm.

The characteristics of each technological district in terms of technological communication conditions should not be thought to be given and/or exogenous. On the contrary, communication conditions are themselves the—partly—intentional outcome of long-term routines, codes of conduct, and actual investments implemented by the strategic behavior of agents and governments to increase the innovation capabilities of economic systems. In fact, effective connections are the result of deliberate action and should be considered to be endogenous: an effort has to be made to establish each effective connection.

In sum, high levels of innovation activities, as induced by good technological communication conditions, are likely to increase the amount of collective knowledge available. This in turn affects positively the efficiency of research activities and further pushes firms along the endowment axis. All the characteristics of a self-reinforcing mechanism, based upon positive feedbacks, are now in place. Localization in a technological district increases the productivity of resources invested in innovation activities and the likelihood of the introduction of technological innovations that actually increase total factor productivity. Increased levels of innovation activities funded by each firm and augmented efforts in activating communication mechanisms increase respectively the amount of collective knowledge available in the districts and the communication probabilities. Fast rates of introduction of innovation push further the demand for the firms, which, for given levels of irreversibility, fuel the inducement to innovate. Higher levels of local technological opportunities, based upon the augmented stock of collective knowledge and the increased levels of open communication channels in place, further increase the efficiency of innovation activities.[2] This process is especially evident within technological districts such as Turin in Piedmont, Modena and Bologna in central Italy, Toulouse in western France, and the local innovation systems of Route 128 and Silicon Valley in the USA.

It is now clear that location in well-defined regions is a factor itself of long-term rigidity and irreversibility and hence potential losses in a turbulent environment and at the same time an opportunity for growth because it provides the context in which technological communication can take place and is hence a factor enhancing the rate of introduction of technological innovations along well-defined directions shaped by the intensity of superfixed production factors.

The stochastic nature of communication processes, however, makes such self-reinforcing feedback mechanisms random. Mixed communication probabilities are especially sensitive to all perturbations in both connectivity and receptivity probabilities. In such conditions, local innovation systems may eventually experience a sharp reduction in general communication efficiency, and reverse negative feedback may take place with major discontinuities in long-term growth patterns.

When technological communication fails, the generation of new knowledge and the related introduction of technological changes become more expensive; firms with a large endowment of superfixed production factors can face the increase in demand and the changes in the relative prices of variable production factors only with a substantial decline in technical efficiency and limited rates of introduction of technological innovations. The advantages of agglomerations decline and industrial districts decay. This is also the story of many traditional industrial districts in central England and northern France. The conditions for technological communication become a key issue of central relevance for a dedicated economic and innovation policy.

Conclusions

Standard microeconomics assumes the adaptive behavior of firms. Firms adapt quantities to prices and vice versa without any possibility of generating

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[2] Moreover, local communication probabilities at time t are likely to affect the behavior of agents not only with respect to the levels of their R&D expenditures, but also to the levels of deliberate action taken to build up connections and receptivity which can enhance the efficiency of the funds invested in R&D. Hence the local communication probability at time $t+1$ is influenced, but because of its stochastic nature, not determined by the conduct of the firms at time t.

endogenous changes in their technologies. Adaptive responses, however, are often made difficult by the irreversibility of production factors and relevant sunk costs. In these circumstances, firms can react. In so doing firms change their technology and modify their production conditions. Reactivity, as opposed to adaptivity, is the underlying theme of this chapter. Some limitations to adaptations have been explored and the conditions for reactivity have been assessed with reference to regional change. Economic analysis can make important progress when endogenous structural change, consisting in the intentional introduction of new production and utility functions, as induced and focused by economic factors, is fully acknowledged.

As a matter of fact, regions play a major role in both reducing the scope for adaptation and favoring the conditions for reactivity.

Superfixed production factors are a pervasive condition which economic theory is more and more taking into account. Technical interrelatedness, system bottlenecks, long-term obsolescence, limited span of application of intangible assets, location in well-defined regions are all factors that reduce the capability of firms to adjust, even in the long term, significant chunks of their stock of intangible and tangible capital.

In these conditions, all changes in relative prices and desired output levels are likely to induce a significant decline in both output and price efficiency: firms are unable to produce with the 'correct' combination of flexible and fixed production factors. Emergent technical inefficiency becomes all the more cogent in competitive markets with high levels of technical variety: firms with larger shares, in relation to total costs, of superfixed production factors are soon exposed not only to a decrease of technical efficiency but also to an actual decline of market shares and profits. Such an emergency can be accommodated by established firms with the endogenous generation of localized knowledge and the eventual introduction of localized technological changes that are compatible with superfixed production factors.

Regions and local innovation systems, characterized by high levels of superfixed production factors, business turbulence, and conducive conditions for technological communication are likely to experience fast rates of introduction of technological changes. Location within well-defined regions becomes at the same time a factor of irreversibility and inducement to introduce technological changes and a factor favoring the generation of technological knowledge in highly productive conditions. A local recursive hysteretic process is likely to take place in these circumstances. Much evidence, provided by industrial economics and economic history, about the increasing specialization of regions in the use of specific combinations of inputs, finds a consistent interpretative framework in the model so far elaborated. The stochastic nature of local communication processes and their key role in long-term growth can play a major role in explaining discontinuities in such self-reinforcing mechanisms with sudden declines of the local performances.

In this recursive context, the pervasive role of technological communication adds understanding to explain the dynamics of hysteretic and localized technological change. With high levels of mixed communication probabilities and hence innovation opportunities, firms' reactive responses to all changes in their business environment favor the introduction of localized technological change. The better are the access conditions to external technological knowledge, which flow within communication systems, the higher are the chances of introducing localized technological changes (Freeman 1991 and 1997; Nelson 1993).

Analysis of the interaction of the dynamics of localized technological changes and local communication processes provides important tools with which to understand the clustering of innovations in well-defined regional spaces as well as the emergence of technological systems characterized by the introduction of complementary innovations. In this context, the growing effect of new communication technologies, the diffusion of technological cooperation schemes, and the supply of knowledge-intensive business services play a key role in assessing the innovation capabilities of local innovation systems.

The approach so far elaborated seems useful in many ways. First, it provides a theory and an interpretative framework to understand why local economic systems exposed to similar shocks, in terms of changes of factor and product markets, can react with the introduction of compatible technological changes that increase total factor productivity or assist its eventual decline.

Secondly and most importantly, we now have a theory to understand the dynamics of agglomeration within regional clusters of innovative firms. The virtuous interaction between changes in the business environment and rates of introduction of localized technological changes, as shaped by the characteristics of local communication processes, is such that in regions with high levels of technological communication, the conditions for circulation and actual assimilation of technological information and the introduction of technological innovations reinforce each other with a self-propelling mechanism based upon the dynamics of positive feedback. The dynamics of localized technological change and communication processes can explain the emergence of regional clusters of innovative firms especially around centers of academic excellence.

Thirdly, we now have new elements to understand the role of regions in assessing the persistent dynamic variety of firms within industries. The dynamics of local feedback between regions and firms helps us to understand why firms, located in different regions, react with different strategies and achieve different performances. The regional context of embedment and action of firms needs to be fully taken into account, both in terms of irreversibility and technological environment, when assessing industrial dynamics.

In this context, the traditional outcomes of the analyses about the 'tragedy of commons' can be reversed (Stiglitz 1994). The positive effects of the renewable and ever-expanding commons of technological knowledge, embedded in well-defined regions, can be appreciated. The notion of collective knowledge, viewed as the result of a dynamic accumulation process characterized by the synchronic and diachronic complementarity between the research and learning activities of a myriad of co-localized agents, opens the way to new research into the economics of 'technological commons'. The study of technological commons can help us to understand the dynamics of increasing returns in the production of knowledge, the emergence of new technological systems, and the key role of technological opportunities stemming from the interdependent innovation capabilities of firms within local innovation systems.

Finally, receptivity-enhancing strategies can become the target of dedicated strategies at the company level. Receptivity and connectivity can be intentionally implemented by firms better aware of the role of technological communication to acquire and make use of external knowledge generated by other firms, reducing the communication lags and the not-invented-here syndrome.

The implications for industrial and innovation policies are far reaching. The appreciation of the factors governing the technological communication and the internalization of local technological externalities among firms which are involved in complementary innovation activities become a possible strategy for public intervention in that such activities will lead to an increase in the productivity of resources invested in innovation activities. More specifically, public subsidies to enhance technological communication in terms of better trade conditions for disembodied technological knowledge, local supply of knowledge-intensive business services, technological cooperation both among firms and between firms and universities, accelerated licensing of patents and know-how, can offer firms the opportunity to internalize the spillover of localized technological knowledge and take better advantage of available external knowledge with the active participation of both parties in the trade: vendors and customers. Enhanced rates of introduction of technological changes and faster rates of increase of total factor productivity may be obtained with the implementation of local communication processes.

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