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LOCALIZED TECHNOLOGICAL CHANGE

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LOCALIZED TECHNOLOGICAL CHANGE[1]

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1. Introduction

Technological change cannot be treated like the exogenous fall of manna from heaven. Technological change is endogenous to the economic process and it is the prime factor of continual change as it is the result of the pressure of economic forces both on the demand and the supply side. Technological change however cannot be treated like the customary result of routinely activities: total factor productivity growth measures confirm that technological change yields results that are far larger than any rational calculations based upon marginal productivity might consider.

The need to combine into a homogenous framework the endogenous understanding of the dynamics by means of which technological –and organizational- change is introduced in the economic system, with the elements of surprise and unknown that necessarily characterize it, has always proven challenging for economic analysis.

The localized technological progress approach provides an attempt to solve the puzzle by building upon different traditions of analysis: the bounded rationality and limited knowledge framework for understanding individual decision-making, the inducement approach, the economics of learning and the economic analysis of irreversibility. The key point is that firms are induced to change their routines and their technologies when a mismatch between plans and actual conditions emerge. Such an innovative reaction is made necessary and shaped by the burden of irreversibility. At the same time it is made possible, and yet constrained, by the dynamics of learning and the effects of limited knowledge and bounded rationality.

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The localized approach provides a framework to analyzing technological change as the endogenous and induced outcome of an out-of-equilibrium self-sustaining dynamics that takes place in a set of highly specific and contextual circumstances. To do this it integrates different strands of literature in order to overcome the criticisms and shortcomings of each of them. The rest of the paper is organized as follows. A simple exposition of the analytical mechanism is presented in section 2. The basic ingredients of the localized approach are identified in section 3. Section 4 presents the multidimensional analysis of the localized approach. The conclusions summarize the main results and put them in perspective.

2. Localized technological change: the mechanism at work

The introduction of technological innovations is the result of the creative reaction of firms, induced by changes in product and factor markets, firms are not able to cope with, by means of movements in the given technical space. The creative reaction is possible especially when it is favored by an appropriate environment, although it is constrained in a limited multidimensional space by the effects of irreversibility, limited information and learning processes that reduce their mobility.

In this approach, technological change is the outcome of the creative reaction, to the failure to meet the expected levels of aspiration and the mismatch between expectations and actual facts. It is made possible by the continual efforts of accumulation of competence and technological knowledge and the eventual introduction of innovations by existing agents rooted into a well defined set of scientific, technical, geographic, economic and commercial circumstances.

Firms are viewed as learning agents, which do not limit the scope of their action to adjusting prices to quantities and viceversa. They are also able to change intentionally and purposely their technology, as well as their strategies (Penrose, 1952). The introduction of innovation however is risky and agents are reluctant to innovate. Innovative behavior is solicited and induced by emerging discrepancies between plans and reality when performances fall below the expected levels of satisficing thresholds.

Sheer resilience in any given condition engenders actual losses or results below subjective expectations. The constraints imposed by irreversibility and limited knowledge about alternative techniques in the existing range of options, reduce the scope for traditional substitution and make it expensive and resource-consuming. The search for new routines and new technologies is now activated.

Technological change is primarily the result of the valorization and implementation of underlying learning processes, in doing as well as in using and in interacting, that are localized into the specific context of action of each economic agent.

Technological change moreover is also influenced by strategic decision making of agents which try and maximize their profits and do necessarily take into account the product and factor markets into which they are based. Finally and consistently, the rate and the direction of technological change are influenced by the specific set of circumstances, as they are perceived by decision-makers, at each point in time.

The efforts and the outcomes of the introduction of new routines and new technologies are confronted with the opportunity costs of resilience and the costs of switching, i.e. the costs of facing the constraints raised by irreversibility and limited knowledge. The firm will implement its adjustment by means of a mix of technical changes, consisting in movements in the existing space of techniques and products, and technological and organizational innovations, consisting in the actual modification of the space of techniques and products. The composition of the mix will depend upon the relative costs of technical changes with respect to technological (and organizational) ones.

Technological change in introduced by firms as a creative response to the mismatch between expectations and plain facts: hence technological change is generated in out-of-equilibrium conditions. The larger are the discrepancies between the expectations of each agent and their actual conditions and the faster are the rates of introduction of new technologies. The introduction of new technologies by each agent in turn however engenders new discrepancies between the expectations of any other agent and their actual market conditions. Hence technological change feeds technological change and out-of-equilibrium conditions further reproduce out-of-equilibrium outcomes.

Firms can react to the mismatch between expectations and actual conditions by means of the introduction of localized technological changes only if the specific context of action provides appropriate opportunities for the introduction of new technologies. The specific contextual conditions, internal to each firm, each region, each industry, each institutional context and each scientific and technological field are likely to play a major role in assessing the actual technological opportunities for each firm. The costs of innovative activities are highly contextual and contingent to the specific set of circumstances into which the action of firms is embedded.

Innovation is the possible result of the creative result of firm only when the surrounding environment is conducive to favoring the introduction of new technologies. The localization into technological districts where other firms carry on complementary innovation is a key factor in assessing the actual innovative capability of firms.

In less favorable contexts firms are obliged to face the discrepancy between expectations and actual conditions just by means of technical adjustments, bearing all the costs engendered by irreversibility and limited knowledge. Technological change is slower as well as smaller are the gaps between expectations and actual conditions: the system can converge towards more stable and static equilibria with lower opportunities for growth.

Proximity in geographical and knowledge space among learning agents able to react to the failure of their aspiration levels, by means of the introduction of complementary innovations, is an essential condition to activate the failure inducement mechanism of technological change, overcome the reluctance to change and convert the isolated reaction of dispersed agents to adverse market conditions into the collective introduction of systemic innovations.

Innovation is a highly contextual outcome, conditional to the occurrence of a large number of necessary conditions.

3. Localized technological change: the ingredients

The notion of localized technological change is the result of the selective merging of well distinct strands of literature: the notion of bounded rationality, the induced technological change approach, the economics of learning and the economics of knowledge, the economics of irreversibility.

The analysis of bounded rationality, the notion of satisficing behavior and the distinction between substantive and procedural rationality introduced by Herbert Simon provide the basic context for the analysis. The action of economic agents is characterized by relevant search and information costs: agents do not control all the information about all the techniques available at each point in time on the existing maps of isoquants. Quite obviously agents are myopic for they are unable to foresee all the possible consequences of their actions and cannot anticipate correctly all the possible technologies that any other agents is trying and introducing at each point in time. Agents however are able to organize rationally the sequence of actions when facing changes and alterations in their plans. Finally, agents behave on the basis of their own subjective perceptions of the environment and are especially sensitive to the subjective definition of internal satisfaction (Simon, 1982).

When the levels of aspirations are not realized, agents take into consideration the introduction of innovations. The introduction of innovation is the result of the deception and dissatisfaction of agents that can overcome their reluctance to innovate only in a specific context of complementary circumstances. The notion of failure-inducement elaborated in the behavioral approach complement and integrates the induced technological change approach (March and Simon, 1958; Antonelli, 1989 and 1990).

According to the induced technological change approach, the introduction of new technologies is induced by the conditions of the factors markets. Specifically a distinction has to be made between the models of induced technological change which focus the changes in factors prices and the models of induced technological change which stress the static conditions of factors markets. In the first approach, following Hicks and Marx, firms are induced to change their technology when the price of a production factor increase (Hicks, 1932). The change in factor prices acts as a powerful inducement mechanism, which explains both the rate and the direction of introduction of new technologies. The change in factors prices in fact induce firms to introduce new technologies, which are specifically directed to save on the factor which, has become more expensive. The introduction of new technologies complements the standard substitution process, i.e. the technical change consisting in the selection of new techniques, defined in terms of factors intensities, on the existing isoquants. This approach to the induced technological change differs from the static version, elaborated by Kennedy, von Weiszacker and Samuelson, according to which firms introduce new technologies in order to save on the production factors that are relatively more expensive. In this second approach the levels of factor price matter instead of the rates of change. Consistently only the direction of technological change can be induced, rather than the rate (Binswanger and Ruttan, 1978; Ruttan,1997 and 2001).

Both approaches, as it is well known, have been often criticized using the Salter's argument, according to which firms should be equally eager to introduce any kind of technological change, either labor or capital intensive, provided it makes it possible to reduce production costs and increase efficiency. Localized technological change builds upon the dynamic approach to the inducement mechanism and is able to neutralize the Salter argument, by integrating the economics of learning and the economics of irreversibility (Salter, 1960; Nordhaus, 1973).

The analysis of the inducement mechanism in fact is expanded so as to integrate the changes in the product markets. Not only do the changes in the factor markets induce the innovative reaction of firms, but also all the changes in the expected levels of the demand. Firms have made plans and built irreversible production capacities for expected levels of output. When the demand for the products of the firm changes, the firm, once again is exposed to switching and information costs. Elaborating on this argument both the demand pull analysis and schumpeterian rivalry become part of the inducement mechanism. Innovative reaction in fact is now induced by the macroeconomic pressure of aggregate demand as in the demand pull tradition of analysis (Schmookler, 1966) and by changes in the demand curve of each firm, determined by the rivalry among firms within each industry as in the schumpeterian tradition (Scherer, 1984 and 1992).

The economics of learning makes a major contribution to understanding the dynamics of localized technological change. Here the basic building block is provided by the arrovian analysis of learning as the key factor in the increase of efficiency. New technologies are, mainly, the result of learning processes that consist in the accumulation of experience and tacit knowledge and are strictly defined and circumscribed by the technical context of activity. Agents learn by doing well-defined product and by using well-defined machines. Learning is inherently localized in a narrow technical context (Arrow, 1962a).

Edith Penrose (1959) has considerably elaborated the arrovian notion of learning and has qualified the firm, its organization and its routines, as the privileged actor in the learning process. The bottom-up approach to understanding the dynamics of knowledge finds here the first input and in so doing it stresses the role of technological knowledge, acquired by means of localized learning processes, as the primary input in the generation of new knowledge at large, including scientific advances.

The analysis of learning has been subsequently stretched and sharpened by the insight of Anthony Atkinson and Joe Stiglitz (1969) who elaborated further upon the key role of learning in the generation of new technologies and introduced the strong hypothesis that technological change can take place only in a limited technical space, defined in terms of factor intensity. Technological change is localized because it has limited externalities and affects only a limited span of the techniques, contained by a given isoquant, that are identified by the actual context of learning. In other words technological change can only take place where firms have been able to learn: the localization here is strictly defined in terms of factor intensity and with respect to the techniques in place at each point in time.

In the analyses of Penrose and Atkinson-Stiglitz, technological change is localized and constrained by organizational routines, but it is the automatic result of learning without any intentional and explicit effort. The inducement context, characteristic of the localized technological change approach, makes it possible to overcome this major limitation. The analysis of the specific context into which learning provides opportunity for the eventual and intentional action of introduction of new technologies and innovation remains the element of strength.

The economics of learning contributes the economics of knowledge and paves the way to understanding the broader notion of localized technological knowledge. The notion of learning and localized technological knowledge in fact makes it possible to stress the role of knowledge as a joint-product of the economic and production activity. Agents learn how, when, where and what, also and mainly, out of their experience, accumulated in daily routines. The introduction of new technologies is heavily constrained by the amount of competence and experience accumulated by means of learning processes in specific technical and contextual procedures. Agents, in this approach, can generate new knowledge, only in limited domains and fields where they have accumulated sufficient levels of competence and experience. A strong complementarity must be assumed between learning, as a knowledge input, and other knowledge inputs such as R&D laboratories, within each firm (Arrow, 1962b and 1969; Lamberton, 1971; Loasby, 1999).

A second and most important complementarity takes place in the localized technological knowledge approach between internal and external knowledge. Firms can generate new knowledge and hence eventually introduce new technologies, only when and if they are able to take advantage of external knowledge. No firm can rely exclusively on its own internal knowledge, either tacit or codified, whether it is the result of learning processes or formal research and development activities. The notion of knowledge cumulability and complementarity between external and internal knowledge is central in the understanding of the localized technological knowledge (Antonelli, 1999, 2001, and 2003).

The relationship between external and internal knowledge becomes a key issue. Neither can firms generate new knowledge relying only on external or internal knowledge as input. With an appropriate ratio of internal to external knowledge instead internal knowledge and external knowledge inputs enter into a multiplicative production function. Both below and above the threshold of the appropriate combination of the complementary inputs the firm cannot innovate.

Technological change is induced by changes in factor prices and it is localized within the context of the learning activities. The analysis of Paul David on the effects of irreversibility of physical and human capital, as well as reputation and market relations, contributes the understanding of the factors of localization (David, 1975).

Agents are rooted by irreversibility, which limits their mobility and requires dedicated resources to be handled. Following Paul David, a distinction between weak and strong irreversibility can be made. Strong irreversibility takes place when no change can be made to a given context. The case of weak irreversibility emerges when a given constraint caused by the irreversible elements can be modified, albeit with some costs: the costs of switching.

The distinction between past-dependence and path-dependence is crucial in this context. Irreversibility is a source of past-dependence if no action may modify and integrate the effects of irreversibility. Irreversibility engenders path-dependence when and if specific and intentional actions may take place and modify the course of sequential events, albeit in a narrow and limited region. Irreversibility is the cause of technological change because switching costs limit the possibility for firms to react to changes in their markets by means of traditional substitution on existing isoquants. The introduction of innovation is necessary in order to adjust to the new market conditions and yet save on switching costs. Irreversibility is also at the origin of the localized introduction of innovations because it shapes the corridors of introduction of the new technologies and prevents the radical change of technical coefficients.

Localized technological change, as determined and shaped by irreversibility is inherently path-dependent. New technologies in fact must be introduced in order to cope with the discrepancy between plans and actual market conditions that irreversibility prevents to adjust to, by means of standard substitution. Yet they can change the course of actions, modifying the effects of irreversibility, although within a narrow and limited space of alternatives, defined by the effects of switching costs and learning.

Localized technological change combines the inducement mechanism with the economic implications of learning and irreversibility in a unique analytical system. Firms are characterized both by learning capabilities and bounded rationality and limited knowledge. Necessarily, firms make plans and consequently decide actions, which are partly irreversible. All discrepancy between expected market conditions, now including both factors and products markets, and planned decisions should be the cause of technical changes, that is changes in the existing space of techniques, consisting in either substitutions on a given isoquant or changes from one isoquant to another, or both. All changes in the existing space of techniques however engender specific costs due to the irreversibility of the production factors as well as to the information costs that are necessary in order to operate the new desired techniques. Switching costs prevent standard adjustments realized by means of substitution or sheer change in input levels. Localized learning provides the opportunity to introduce technological changes. Firms exposed to the discrepancy between plans and actual market conditions, limited in their mobility by limited knowledge and irreversibility, are induced to take advantage of the localized knowledge accumulated by means of learning processes and introduce technological innovations in a limited technical space.

Localized technological change is endless and fully endogenous. Firms cannot anticipate all the possible innovations introduced by any other firm in the economic system. And yet any discrepancy between plans and actual market conditions is likely to induce the localized introduction of new technologies, which in turn are the cause of new discrepancy between expectations and actual market conditions for other firms.

4. Localized technological change: the multidimensional scope

Localized technological change reflects the pervasive role of irreversibility, externalities, information asymmetries and bounded rationality and interdependence as well as the amount of creativity each agent is able to express as a way to solve specific and contextual problems arising in the daily management of its business. Hence technological change is necessarily localized in a multidimensional space, that is deeply rooted into the context of characteristics which define the activity of each agent.

Technological change is localized in historical time, in technical space, in the knowledge space, in technological systems, in the structural conditions of each economic system, in geographic space and in the space of product characteristics, technological change is localized in firms. The analysis has investigated the variety of processes by means of which technological change is localized in the historical, technical, technological, structural, institutional, regional, knowledge and organizational spaces highlighting how and why the introduction of innovation is conditional to the effects of proximity.

Localized technological change is primarily localized into historical time. Each technological innovation and each element of technological knowledge and competence can be understood only as a step in a historical sequence of the cumulative introduction of technological innovations and other bits of technological knowledge. Technological change is characterized by path dependence in that it can be analyzed effectively only when the effects of cumulability and irreversibility are put in context. Cumulability plays a key role in the production of knowledge and in the integration of the new production factors into the existing production process. Irreversibility is an essential characteristic of fixed capital, both tangible and intangible. The fixed and irreversible capital can be changed only at a cost and this affects the scope of any further innovative choice. The introduction of new technologies that are complemenetary to the existing ones becomes a clear constraint and incentive. (Antonelli, 1999a and 2001).

Technological change is localized into technical space, that is the space defined in terms of factor intensity, by the essential role of learning in building the competence and the technological knowledge that is necessary to introduce new technology and increase the efficiency of the production process (Atkinson and Stiglitz, 1969; David, 1975). Learning is essentially localized in a limited technical space and as such it cannot be applied easily elsewhere. Antonelli (1992 and 1995) has further developed this notion of localized technological change, emphasizing the role of irreversibilities in fixed and immaterial capital stocks and the related switching costs and coupling its effects with the local dimension of learning originally highlighted by Atkinson and Stiglitz (1969) and further stressed by Stiglitz (1987). As a result it seems clear that technological innovations are introduced within technical corridors identified by the original technical localization of innovating agents and defined by barriers to mobility originated by switching costs and learning opportunities.

Technological change is localized into the gales of technological systems activated by technological indivisibilities, complementarities and interdependencies among technologies. The efficiency of each technology is greatly enhanced by the availability of the other complementary and interdependent technologies. Firms induced to innovate are pushed to direct their innovative efforts towards the introduction of new technologies that are complementary to others so as to take advantage of typical network externalities in their dynamic form (David, 1987; David and Bunn, 1988 and Antonelli, 2001).

Technological change is localized into knowledge space. High levels of vertical and horizontal indivisibility characterize knowledge space. Each unit of knowledge has high levels of complementarity and cumulability with other units that are ordered vertically across historic time. Horizontal complementarity across different fields of origin is also relevant and can be defined in terms of complexity. Finally, each unit of technological knowledge can be applied and different fields of application: the notion of fungibility is important in this context. The production of knowledge relies on the continual recombination of existing bits of knowledge. The characteristics of such indivisibilities are most relevant and make it possible to identify the commons of knowledge. The borders of such commons of specific knowledge and competence become a powerful factor of specialization into well-defined technological fields. Good access conditions to the knowledge commons and good communication channels among learning agents make it easier for firms the introduction of innovations as a response to unexpected declines in performances (Weitzman, 1996; Antonelli, 2003b).

Technological change is localized into geographic space by the proximity between learning agents, because of the pervasive role of scientific communication and technological spillover. Proximity in geographic space interacts with proximity in knowledge space. Regional proximity favors the generation of new knowledge on three counts: i) it helps reducing knowledge transaction costs, ii) it facilitates the division of scientific and technological labor and hence increase the efficiency in the generation of new knowledge, and iii) it makes it possible to accelerate the circulation of knowledge and hence to capitalize on knowledge externalities.

Proximity in geographic space helps increasing trust among trade partners and reduces the scope for opportunistic behavior. Consequently proximity favors the emergence of local markets for technological knowledge, qualified systems of knowledge interactions, higher levels of specialization and division of labor in the generation of new knowledge, hence higher levels of general efficiency in the generation of new knowledge and in the introduction of technological innovations.

The localization into a technological district and the membership into professional communities makes easier the access to local knowledge commons, hence increases the effects of local knowledge externalities and increases the probability of introduction of successful innovations. The quality of the local scientific infrastructure and the connectivity of the communication channels in place between the academic and the business community add strong elements to understanding the key role of technological districts in localizing technological change from a geographical viewpoint. (Antonelli, 2001).

Technological change is localized in the economic structure of each economic system by local endowments, intermediary markets and hence factors costs. The structure of relative prices reflects the local endowments and the vertical organization of the economic system. It reflects in fact the vertical relations among industries along the 'filieres' within the input-output matrix. The characters and types of the market structures in each given layer have powerful effects downstream in terms of relative factor prices. The effects of technological innovations vary according to the interplay between the direction of technological change, defined in terms of the marginal efficiency of each production factor, and the local structure of relative factor prices. Composition effects, that is the consequences of relative factor prices for each possible direction of technological change, have powerful consequences in terms of total factor productivity growth. The endowments of each region and the structure of relative prices within each industrial system become a powerful factor in explaining the differentiated effects of the introduction of the same technology across economic systems. Composition effects may account for the delays in adoption of incremental and biased technologies. For the same token, composition effects however are a powerful inducement mechanism to selecting and focusing the factor intensity of the new technologies. Firms located in a labor abundant region have a clear incentive to introduce labor intensive technologies for they make it possible to make the most intensive use of the more abundant and hence cheaper local production factors (Antonelli, 2003a).

The analytical framework introduced by Lancaster (1971) proves to be especially fertile and productive, to accommodate the analysis of the innovation process in the space of product characteristics. The Lancastrian approach in fact can be easily used as a tool to stretch the localized technological change approach to analyze the role of proximity in the space of product characteristics and assess the choice between product and process innovations. It seems clear that product innovation is more localized the more specific and localized is the process of accumulation of competence and the more relevant is the latter in the generation of technological knowledge and the more dispersed the distribution of firms in the product space (Antonelli, 2003c).

Finally, it is clear that technological change is localized within firms. Firms differ in many relevant ways: the vintage of irreversible factors, the competitive context, the factors markets, the location and the communication channels in place with the external environment, the organization and the structure of decision-making, the learning procedures, the portfolio of products and the knowledge fields where competence is based, the composition of human capital. Each firm as a consequence follows its own path in reacting to the mismatches and introducing technological innovations. Elaborating on the legacy of Edith Penrose and Ronald Coase, it seems clear that not only the dynamics of accumulation of technological knowledge matters, but also the dynamics of competence in managing the governance mechanisms - including both transaction and coordination activities- as determined by the generation of organizational knowledge and the introduction of organizational innovations, plays an important role. Governance mechanisms are no longer viewed as the result of the static combination defined by given levels of coordination and transaction costs, but as the result of dedicated activities affected by the rates of accumulation of competence and organizational knowledge. Next to the production function a corporate function where alternative governance mechanisms are considered and assessed need to be used to analyze the firm. The interplay between technological and organizational innovations, based upon technological and organizational learning respectively, shapes the growth path of the firm and defines the sequence of technological innovations that each firm can generate and introduce successfully (Antonelli, 1999b, 2003d and 2001: 111-145).

The logic of localized technological change applies to understanding the diffusion and the selection of new technologies as well. Each new technology is localized and as such reflects the specific conditions of innovators as well as each firm is localized in its specific context of action. The factors of localization in fact help explaining why firms may delay the adoption of some technologies. Firms will select the new technologies that fit better with their own highly specific and idiosyncratic context of operation. New technologies may happen to be superior for some firms and in some circumstances and inferior for others (David, 1985).

5. Conclusion

Localized technological change integrates a variety of complementary approaches so as to provide a powerful analytical framework able to accommodate into a rational procedural explanation the introduction of the unknown and of the surprise.

Firms are reluctant to change their behavior and their routines: innovation is difficult and risky. Firms are induced to introduce new technologies when a number of conditions are met. When satisficing thresholds are not met, the levels of aspiration are not realized, because of a mismatch between plans and actual product and factor markets. When limited knowledge and irreversibility matter and limit the scope of substitution and technical change within the existing space of techniques. When learning and accumulated competence provide the opportunity to generate new technological knowledge, albeit in a limited technological space. When knowledge interactions and knowledge spillovers, within limited regional spaces, make external knowledge available and hence innovative activities possible and more productive. When technological complementarities with other parallel new technologies, increase the stream of benefits stemming from the introduction of a new technology within a technological system. When the distribution of rival products and customers preferences favors the introduction of product innovations, albeit in the proximity of existing product lines.

Technological innovations are introduced when a number of forces are at play and a highly qualified set of sequential conditions favor the positive outcome. As such technological change is the conditional and unpredictable result of a systemic context of opportunities and constraints.

Technological change is endogenous to the working of the economic system as it is induced by all changes in factors and products markets myopic firms are unable to foresee, and localized by the effects of irreversibility, limited knowledge and learning. Localized technological change is the result of out-of-equilibrium conditions and is the cause of out-of-equilibrium conditions. In such conditions no convergence towards a stable equilibrium point can take place. On the opposite an endless and path-dependent process of endogenous change is the result of the interplay between local mistakes and creativity, myopia and surprise.

6. References

Antonelli, C. (1989), A failure-inducement model of research and development expenditures: Italian evidence from the early 1980s, *Journal of Economic Behavior and Organization* 12, 159-180.

Antonelli, C. (1990), Induced adoption and externalities in the regional diffusion of new information technology, *Regional Studies* 24, 31-40.

Antonelli, C. (1991) and Gottardi, G. (1991), Localized technological change: The interaction between the generation and the diffusion of new technologies, *Economics of Innovation and New Technology* 1, 296-326.

Antonelli, C. (1994), Localized technological changes. A model incorporating switching costs and R&D expenses with endowment advantages, in Perlman, M. and Y. Shiononya (eds.), *Innovation in Technology Industries and Institutions: Comparative Perspectives. Studies in Schumpeterian Economics.* Ann Arbor, University of Michigan Press.

Antonelli, C. (1995), *The economics of localized technological change and industrial dynamics,* Boston, Kluwer.

Antonelli, C. (1999a), *The microdynamics of technological change*, London, Routledge.

Antonelli, C. (1999b), The organization of production, *Metroeconomica* 50, 234-259.

Antonelli, C. (2001), *The microeconomics of technological systems,* Oxford, Oxford University Press.

Antonelli, C. (2003a), *The economics of innovation, new technologies and structural change*, London, Routledge.

Antonelli, C. (2003b), Knowledge complementarity and fungeability: implications for regional strategy, *Regional Studies* 37, forthcoming

Antonelli, C. (2003c), Localized product innovation. the role of proximity in the lancastrian product space, TELL Working paper, Dipartimento di Economia, Università di Torino.

Antonelli, C. (2003d), The economics of governance: the role of localized knowledge in the interdependence among transaction, coordination and production, TELL Working paper, Dipartimento di Economia, Università di Torino.

Antonelli, C. (2004), Path dependence, localized technological change and the quest for dynamic efficiency, in Antonelli, C., Foray, D., Hall, B. and Steinmueller, E. (eds.), *Frontiers in the economics of innovation. Essays in honor of Paul David*, Cheltenham, Edward Elgar,

Arrow, K.J. (1962a), The economic implications of learning by doing, *Review of Economic Studies* 29, 155-173.

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

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

Atkinson, A.B. and Stiglitz, J.E. (1969), A new view of technological change, *Economic Journal* 79, 573-578.

Binswanger, Hans P. and Ruttan, Vernon W. (1978), *Induced innovation. Technology institutions and development*, Baltimore, The Johns Hopkins University Press.

David, P.A. (1975), *Technical choice innovation and economic growth*, Cambridge, Cambridge University Press, David, P. A. (1985), Clio and the economics of QWERTY, *American Economic Review* 75, 332-37.

David, P.A. (1987), Some new standards for the economics of standardization in the information age, in Dasgupta, P. and Stoneman, P. (eds.), *Economic policy and technological performance*, Cambridge, Cambridge University Press.

David, P.A. and Bunn, J. (1988), The economics of gateway technologies and network evolution: Lessons from electricity supply history, *Information Economics and Policy* 3, 165-202.

David, P.A. (1990), The dynamo and the computer: A historical perspective on the productivity paradox, *American Economic Review* (P&P) 80, 355-61.

David, P. A. (1992), Heroes herds and hysteresis in technological history, *Industrial and Corporate Change* 1, 129-179.

Hicks, John, R. (1932), *The theory of wages*, London, Macmillan.

Lamberton, D. (ed.) (1971), *Economics of information and knowledge*, Harmodsworth, Penguin.

Lancaster, K. (1971), *Consumer demand: A new approach*, New York, Columbia University Press.

Loasby, B.J. (1999), *Knowledge institutions and evolution in economics*, London, Routledge for Graz Schumpeter Lectures.

March, , J.C. and Simon, H. A. (1958), *Organizations*, New York, John Wiley and Sons.

McCain, R.A. (1974), Induced bias in technical innovation including product innovation in a model of economic growth, *Economic Journal* 84, 959-966.

Metcalfe, J.S. (1995), Technology systems and technology policy in historical perspective, *Cambridge Journal of Economics* 19, 25-47.

Nordhaus, William, D. (1973), Some skeptical thoughts on the theory of induced innovation, *Quarterly Journal of Economics* 87, 209-219.

Penrose, E.T. (1952), Biological analogies in the theory of the firm, *American Economic Review* 42, 804-819.

Penrose, E.T. (1959), *The theory of the growth of the firm*, 1st and 3rd editions, Oxford, Basil Blackwell (1959) and Oxford University Press (1995).

Ruttan, V.W. (1997), Induced innovation evolutionary theory and path dependence: Sources of technical change, *Economic Journal* 107, 1520-1529.

Ruttan, V.W. (2001), *Technology growth and development. An induced innovation perspective*, Oxford, Oxford University Press.

Salter, W.E.G. (1960), Productivity and technical change, Cambridge, Cambridge University Press.

Scherer, F. M. (1984), *Innovation and growth: Schumpeterian perspectives*, Cambridge, MIT Press.

Scherer, F.M. (1992), *International high-technology competition*, Cambridge, Harvard University Press.

Schmookler, Jacob (1966), *Invention and economic growth*, Cambridge, Harvard University Press.

Simon, H. A. (1982), *Models of bounded rationality: Behavioral economics and business organization*, Cambridge, The MIT Press.

Stiglitz, J.E. (1987), Learning to learn, localized learning and technological progress, in Dasgupta, P. and Stoneman, P. (eds.), *Economic policy and technological performance*, Cambridge, Cambridge University Press, pp. 125-153.

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