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THE DYNAMICS OF LOCALIZED TECHNOLOGICAL CHANGES. THE INTERACTION BETWEEN FACTOR COSTS INDUCEMENT, DEMAND PULL AND SCHUMPETERIAN RIVALRY[1]

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Localized technological change is the endogenous outcome of the interplay between substitution costs, switching costs and learning processes. New technologies are introduced when market pressures induce firms to change the levels of their inputs and their techniques. The dynamics of localized technological change is the result of the interaction between three processes: a) the Schumpeterian competition process as analyzed by the replicator dynamics and failure inducement mechanisms, b) factor substitution stemming from changes in factors markets, and c) post-keynesian demand pull pressures resulting from productivity growth. In such conditions out-of-equilibrium exchanges and localized technological changes drive a recursive process that is path-dependent in two senses, first it is highly sensitive to the initial conditions of the system, and second it is shaped by the interactions of agents.

KEY WORDS: Technological localized change, innovation, incentives and processes, market structure
J.E.L. Classification: D21, D43, O31, O33

1. INTRODUCTION

This paper presents an industry level analysis of localized technological change resulting from the interaction between three processes: a) the Schumpeterian competition process; b) factor substitution and c) changes

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in aggregate demand determined by productivity growth. The analysis attempts to integrate localized endogeneous technological change as an adjustment mechanism at the industry levels into the standard partial equilibrium analysis, while at the same time emphasising the out-of-equilibrium conditions of the dynamics.

The text-book description of supply and demand analysis assumes that firms at any time are fully able to change their size, production techniques, market conduct and location: no attrition reduces their ability to adjust almost instantaneously to the changing market conditions. The text-book theory assumes also that information on existing techniques is perfect and firms bear no costs to search on the shelf for the techniques built into the known technologies. Finally the text-book theory assumes that firms are not able to change their technology: technology is considered as an exogenous structural factor that shapes the economic systems but is not generated by the dynamics of the system itself.

When such restrictive hypotheses are relaxed, a much broader picture emerges, one where variety and dynamics play a major role (Arrow 1994; Stoneman 1983). More specifically when attrition forces, such as elastic barriers (David, 1975) and switching costs, as well as relevant information costs such as search and transaction costs and learning processes within and among firms that, combined with research and development expenditures, make it possible to build up competences and capabilities, are all taken into account, the notions of economic dynamics, structural change and localized technological change become pertinent.

Localized technological change is the endogenous outcome of the interplay between substitution costs and learning processes. In fact all changes in the levels of demand, input costs and relative competitivity for each firm engender substitution costs which are incurred due to switching both sizes and techniques (David 1975, Atkinson and Stiglitz 1969, Winter 1981, Stiglitz 1987, Antonelli 1995).

Changes in demand imply that firms are induced to make efforts to adjust to the in(de)creased levels of their output by in(de)creasing the levels of their inputs: such an action however is subject to dimensional switching costs. Dimensional switching costs consist in the resources that are necessary to modify the current levels of inputs by taking actions, such as firing and scrapping or adding on new vintages of capital and new employees to the existing mix of inputs. Dimensional switching costs force firms to mobilize all their learning capabilities so as to capitalize on the experience acquired and hence introduce innovations that make it possible to adjust output to the desired levels without changing their input levels when demand is in(de)creasing.

Changes in factor costs also would oblige firms to change their production techniques and that means that they will face switching costs especially arising from search, firing and scrapping. As a result firms may want to capitalize on their acquired competence by exploiting learning by doing and learning by using and this can be done by using appropriate R&D activities to increase the productivity of each factor as well as total factor productivity but their factor intensity remains unchanged.

According to this representation, localized technological change is generated by the interplay between different mechanisms of inducement. Localized technological change, portrayed as the outcome of a trade-off between substitution costs and learning, makes it possible to combine different strains of analysis:

i) the (neo)classic mechanism of generation of technological change induced by changes in the relative costs of production factors;
ii) the post-keynesian demand pull models of generation of technological change induced by the pressure of demand growth;
iii) the Schumpeterian models of generation of technological change induced by rivalry among firms.
Let us consider them separately.

a) The models of price-inducement

The literature on induced technological change explores at the aggregate level the determinants of the direction of technological change rather than the causes of the rates of introduction of technological innovations. It builds upon the hypothesis that firms are pushed to introduce factor-saving innovations by the factor intensity of their current production process (Kennedy 1964). As Binswanger (1978) puts it: "Suppose it is equally expensive to develop either a new technology that will reduce labor requirements by 10% or one that will reduce capital by 10%. If the capital share is equal to the labor share, entrepreneurs will be indifferent between the two course of action......If however the labor share is 60%, all entrepreneurs will choose the labor-reducing version. If the elasticity of substitution is less than one, this will go on until the labor and capital shares again become equal..." (p. 32).

b) The models of demand-pull

The literature on demand-pull, conversely, explores the determinants of the rates of introduction of technological changes. Here the basic assumption is that firms are pushed to introduce technological innovations by the pressure of demand (Rosenberg 1974). In fast growing markets the rates of return to innovation are so large that they trigger accrued innovative efforts of firms and independent inventors that eventually lead to the generation of faster rates of innovation (Schmookler 1966). Kaldor provides an aggregate framework for such dynamics when he spells out the hypothesis that there is a positive relationship between the growth of output and the growth of labor productivity due to the accelerated introduction of technological innovation triggered by the rates of growth of output (Kaldor 1957 and Kaldor-Mirrlees 1962).

c) The models of Schumpeterian rivalry

The Schumpeterian literature provides another set of explanations which can help us to understand the determinants of the rates of introduction of innovations. The Schumpeterian literature privileges the analysis at the firm level in out-of-equilibrium conditions where variety between firms is taken to be the leading characteristic of the market selection process. In the Schumpeterian literature the basic incentive to innovate is provided by market entropy, that is variety between firms in terms of efficiency, size, factor costs, age, organizational structure, technology, and innovative entry (Cantner and Westermann 1998). The larger the time variance in market shares, the larger the efforts of firms to introduce innovations. Fast growing firms that have increasing market shares, have larger mark-ups so that they can rely on larger cash-flows, retain larger shares of them to fund internally risky projects and hence invest larger amounts of resources in R&D activities. Competitive imitation eventually reduces the extraprofits of innovators. Radical innovations however are often associated with the entry of new firms that are able to take advantage of latent technological opportunities, incumbents are not ready to exploit (Scherer-Ross 1990).

In sum we have two classes of models at the aggregate level and one class of models at the micro level that offer different sets of interpretations which can be used to understand the rate and direction of technological change as an endogenous process where the rate and direction of introduction of new technologies is explicitly determined by the interplay of economic actions. Price-induced models provide the basic tool of analysis which can be used to understand the determinants of the direction of technological change. Demand-pull models provide the basic analysis for understanding the rates of introduction of technological change as triggered by the rates of growth of output. Price-inducement models and demand pull models are used to analyse the generation of technological change at the aggregate level and little effort is made to provide a microeconomic framework of analysis of the determinants of such technological changes. Conversely Schumpeterian models analyse, at the firm level, the changes in market conditions as the determinants of the rates of innovation and no hypotheses are elaborated about the direction of technological change; moreover little analysis is provided regarding the effects at the aggregate levels.

The dynamics of localized technological change, built upon the trade-off between switching costs and innovation efforts based upon learning opportunities, seem to be able to reconcile these different lines of analysis and to provide a consistent micro-macro analytical framework where the firm level and the aggregate level as well technological rivalry, price-inducement and demand pull interact in such a way as to determine a cumulative, path-dependent process of growth and technological change (David 1993a).

2. THE DYNAMICS OF TECHNOLOGICAL CHANGE: THE UNDERLYING ASSUMPTIONS

The theory of localized technological change builds upon three blocks: i) a theory of technological knowledge and information; ii) a theory of the firm and the context of the basic trade-off between switching and innovating and iii) a theory of the markets. Subsections 2.1 to 2.3 examine each of these blocks in turn.

2.1 The theory of technological knowledge and information.

The introduction of localized technological changes rests upon the availability of localized knowledge which consists of highly specific and tacit elements of technological competence featured by strong specific and idiosyncratic characteristics (David 1993a and 1993b).

Localized technological knowledge in turn emerges from daily routines and from the tacit experience acquired in using capital goods, in producing and manufacturing, in interacting with customers and with other manufacturers. Research and development expenses defined as the resources allocated in the specific activity of experimenting and developing new products and new processes are only one aspect of a more general process of learning and capitalizing on the experience acquired (Malerba 1992). Localized technological knowledge can also be viewed as the product of a systemic bottom-up process of induction from actual experience which contrasts sharply with the individualistic top-down process of deduction from general scientific principles on which the received theory of knowledge as a public good rested (Dosi 1988). Learning processes and formal research in fact is oriented towards the resolution of specific problems stemming from bottlenecks in production, fast-rising prices of specific inputs, market constraints which each act as focussing devices (Rosenberg 1976)

This approach to localized technological knowledge as a quasi-private good elaborates on recent theories regarding the origins and flows of the generation process of technological knowledge within organizations and in the relations among organizations:

(1) technological knowledge is embedded in the "circumstances" in

which the firm operates, hence technological change is localized in the techniques currently used by each firm, in the markets in which each firm operates, in the existing information channels among firms and customers, in the organizational structure of firms and in the informational space in which each firm operates (Cantwell and Barrera 1998).

(2) the traditional distinction between new technologies and existing technologies appears much less strong. In fact relevant search costs are incurred to acquire information and the command of techniques different from those currently being used, even though they are part of existing technology. Conversely the generation of new technologies can rely on the knowledge acquired by means of learning by doing and learning by using in the spectrum of techniques currently being used (Von Tunzelmann 1998).

(3) The generation of technological knowledge is the result of a joint process of production, learning and communication of which research and development activities should only be considered as part. Consequently research and development activities cannot and should not be considered the sole factors in the generation of new technological knowledge and should not be separated from the current flow of activities within the firm and in the relations between the firm and its environment (Cowan and Cowan 1998).

In such an approach the generation of new knowledge is mainly the outcome of the efforts of innovators who draw on learning processes which are highly localized and specific to the history and experience of each innovator.

2.2 The theory of the firm: local irreversibility and the basic trade-off between switching and innovating.

The firm is more than a production function. It is a learning agent that produces outputs combining inputs and knowledge, adjusts prices and quantities, selects its organization, acquires competence and capabilities and generates innovations (Chandler 1990 and 1992, Teece 1993, Cantwell and Barrera 1998).

The notions of sunk costs and local irreversibility play a major role in this theory of the firm. All existing capital stocks, both tangible, such as fixed assets, and intangible, such as reputation, experience and competence, have high levels of durability (Salter 1966; Sutton 1991). Hence it is costly to change both the amount of capital stock and the proportions in which it is used with other complementary inputs due to the changing market conditions. Durability of assets becomes a main factor of local irreversibility and sunk costs. Sunk costs in turn, together with learning processes, become a major focussing device in directing the endogenous generation and adoption of new technologies. Complementarity and interoperability between vintages of fixed capital and other intermediary inputs also in terms of skills of manpower add on as source of local irreversibility and hence cause major switching costs.

In this theory irreversibility acts as a source of costs as well as a source of opportunities: the experience and knowledge locally acquired about the existing techniques and the mix of production factors by firms through learning by doing and learning by using is in fact another source of local irreversibility which offers the opportunity to generate new technological innovations and hence to increase the levels of factor productivity and possibly the overall levels of total factor productivity.

Building upon their competence firms are able to change their technology. The introduction of technological changes is viewed as part of a more general process of institutional and economic change in which the behavior of firms is influenced by market structure and by the more general characteristics of the economic environment, but this action is not limited to price-output adjustments. It embraces a much wider scope of action which builds upon the notion of competence as the basic intangible asset that shapes the behavior and the performances of the firm.

Competence consists of the capability to generate technological innovations, organizational changes as well as new institutions. Hence the introduction of technological change can be viewed as part of a process of recursive structural change during which firms on the one hand adjust to a given set of structural features with traditional price output changes, and, on the other, react with a range of structural actions (Antonelli 1995).

It seems important here to stress the characteristic features of the theory of the firm that underlies the dynamics of localized technological change. In this approach firms do more than take prices as given and adjust output levels to prices. Firms are also able to learn from experience, to build competences and hence to change the structural parameters of the system and more specifically to change their technology, according to the specific conditions of their local environment. In this theory firms adjust quantities and competences, hence they are also able to change their technologies and to interact with their environment (Utterback and Afuah 1998).

When market conditions change and an economic action is necessary, firms face emerging switching costs. Switching in fact is not free: searching for the new techniques is expensive as is scrapping the existing tangible and intangible capital and reskilling the workforce so that it can cope with the new techniques. Hence firms, instead of switching techniques along the existing production function, consider the opportunity of introducing localized technological changes that make it possible to retain the existing techniques and factor intensity and yet increase the efficiency of each factor so as to cope with the new relative costs. Firms achieve this by taking advantage of their competence which is based upon locally acquired experience and knowledge gained through the use of the existing techniques and mix of production factors by means of leaning by doing and learning by using.

2.3 The theory of the markets.

The dynamics of localized technological change rests upon an evolutionary and post-Schumpeterian theory of the market. Variety and out-of-equilibrium behavior, in a context where competition is analyzed as a process characterized by replicator dynamics, are the key conditions to understanding how markets work (Metcalfe 1989, 1992 and 1994).

At any time a variety of firms of different size and age with different factor costs, different techniques defined in terms of factor intensities, different technologies, different competencies and different organizations operate in markets that retain both the Marshallian and Schumpeterian characteristics. Such markets in fact are characterized by a selection environment in which heterogeneous players, as in the post-Marshallian tradition, confront each other, but are also able to change their technology, as in the Schumpeterian tradition.[2]

Supply curves are shaped by the horizontal summation of the marginal cost curves of the different firms. With a given demand curve a market price is determined and exchanges in the market take place referring to this price: there is hence a variety of profit conditions. Some firms will have average costs well below the price, some firms will operate with average costs close to market prices, finally a number of firms will be incurring significant operating losses because their average costs are well above market prices.

It is then assumed that both exit from and entry into the competitive arena are slow because of significant barriers to entry and to exit. More specifically firms are reluctant to exit because of the high levels of sunk costs, determined not only by fixed capital, but also by the high levels of reputation and competence built into and acquired through strong learning opportunities, that were all closely associated with current production and techniques. Only firms with very high levels of losses will be forced to leave the market rapidly: firms which are able to recover variable costs will remain in the market for a longer time span. Firms are also reluctant to enter because of the risks associated to entry into highly unstable markets and the

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[2] In fact the dynamics of such a market, based on the combination of both Marshallian and Schumpeterian characters, reproduces the basic elements of classical competition as repeatedly analysed by Josef Steindl (See Steindl 1947 and 1952).

consequent danger of being locked into unknown markets by sudden changes driven either by shifts in industry demand curves or by the unanticipated entry and exit of other competitors.

The traditional Darwinian flavor of selection processes of the Schumpeterian tradition however, in this approach is complemented by a strong Lamarckian character. Selection takes place not only by means of the growth of the most efficient firms fed by investments and innovations. This is the distinctive Darwinian mechanism, translated into the formal modeling of replicator dynamics where the more efficient firms have greater chances to increase their size than their less competitive rivals. Selection is also the result of Lamarckian adaptation due to the internal effort of inefficient agents to take advantage of their competences and current opportunities so as to reduce their weakness, by means of the systematic introduction of technological changes (Antonelli 1989).

In this approach the working of the selection mechanism is only complemented by the pure "demographic" dynamics based upon entry and exit. This Lamarckian flavor makes it possible to stress the role of localized learning in the generation of new technologies and to appreciate the vigorous interaction between the dynamics of market entropy and the processes of technological rivalry and technological accumulation. In this approach there is a strong relationship between the evolution of the competitive position of each firm and its technological strategy. As Cantner and Westermann (1998) show, there is a direct relationship between the variety of firms in terms of efficiency and competitiveness and the localized advances of technology each firm is able to introduce in its own environment.

More specifically we assume that there is a quadratic relationship between the changes in market conditions, that is to say the combinations of profits, size and shares, and the efforts to introduce new technologies (See figure 1). Both negative changes and positive ones exert a strong inducement mechanism of technological change: most efficient firms, earning extraprofits, can fund more innovation activities in order to take advantage of the current favourable conditions. But also less efficient firms are forced to innovate in order to survive. If it is assumed that the rate of failure in generating innovations out of innovative efforts, is equal among efficient and less efficient firms, then there are important outcomes for the evolution of the industry.

The Schumpeterian inducement process complemented by the failure-inducement mechanism in fact should lead the industrial distribution of firms size towards greater concentration, with a limited number of efficient firms becoming more and more innovative, thus even more efficient and hence more profitable and as a consequence they grow in size.

Profits above the norm lead to higher market shares and higher rates of

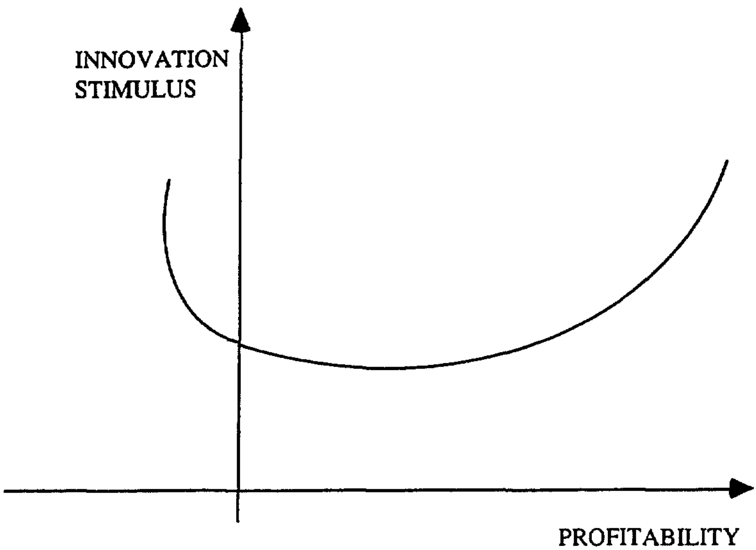

Figure 1. The Relationship between current profitability and innovation stimulus.

growth. Firms with average efficiency levels would have lower profits and thus weaker incentives to innovate and hence they would remain small in size. Finally the least efficient firms would be induced to innovate in order to survive. Failure induced innovators would eventually be able to re-establish some profitability levels. Profit levels for firms with below normal profits will eventually raise. Innovative survival can - up to a point - be substituted for exit. The findings of Mueller (1986) on the dynamics of the distribution of profits across firms in the long run provide strong empirical support to this interpretation.

With respect to the evolution of industrial structures, the empirical evidence confirms that, as industries mature, a skewed distribution in the size of firms emerges where there is only a few large companies - which are most likely to be the early innovators - and a large number of small and medium sized firms (Gibrat 1931, Simon-Bonini 1958, Nelson-Winter-Schuette 1976).

In the context of industrial economics, this approach leads to industrial dynamics being considered as the outcome of the interaction between industrial structures and firm strategies (Carlsson 1987). In fact, it is clear that the traditional "structuralist" chain of arrows that links the industrial structure, defined in terms of concentration, barriers to entry, exit and mobility and diversity of firms, to conduct, defined in terms of firms strategies, and eventually to performance, defined in terms of rates of growth and profitability levels, has now also a strong recursive character. Conducts, namely innovative and growth strategies, affect performances which eventually shape a new structure of the industry. Industrial structure can no longer be considered as an exogenous parameter, but on the opposite, it is clearly influenced by the conduct of firms and their outcome in terms of performances, in the previous historic times. Within industrial organization this methodology paves the way to building an approach that can be termed dynamic structuralism, which is both past-dependent, in that a firm's conduct is affected by the original features of the industrial system, and path-dependent because, over time, the features of the industrial structure are reshaped by the intentional strategies of the firms in the market place and by their interaction (Phillips 1970 and 1971, Caves-Porter 1977, Carlsson 1989, Eliasson 1989).

The Schumpeterian-failure inducement mechanism moreover is expected to play an important role also at the macroeconomic level. Market entropy should favor economic growth. With high levels of market entropy the dynamics of economic growth is enhanced by the effects of innovative efforts of both the most and the least efficient firms. Conversely the convergence of market performances across firms should exert a negative effect: when the levels of market entropy decline the rates of innovations are also likely to decline (Metcalfe 1995).

3. A SET OF STYLIZED RELATIONS

In this section we shall try to show how the dynamics of the different modes of introduction of localized technological changes can be portrayed as the outcome of a complex and cumulative path-dependent process of out-of-equilibrium growth where market entropy and aggregate changes interact on each other. Section 3.1 highlights the effects of Schumpeterian rivalry on the introduction of localized technological change. Section 3.2. shows the interactions between productivity growth, wage increases and demand pull induced localized technological change. Section 3.3. presents the full interplay of the forces involved and stresses the endless interactions between the systematic fluctuations in market prices and the generation of localized technological changes.

3.1 Market entropy and localized technological change

The concept of dimensional switching costs plays an important role here. For each firm the incentive to react to the demand pressure, generated by the selection process within the market, by increasing the levels of inputs is offset by the fast-rising cost of the additional inputs and by the cost of integrating them into the existing size of the plants and the firm. Instead of extensive growth based only on the increase in inputs, the firm will consider the opportunity of capitalizing on the experience acquired by means of learning by doing and by using, and so will develop it with appropriate funds invested in research and development activities.

In these conditions the replicator dynamics augmented by the localized character of technological change is likely to exert a major effect. Firms with average cost curves below the market price have a clear incentive to adjust their size to the market conditions: the exit of the least efficient firms, unable to innovate, leaves new room for their growth (See in figure 2 both the right and leftward shift of the supply curves).

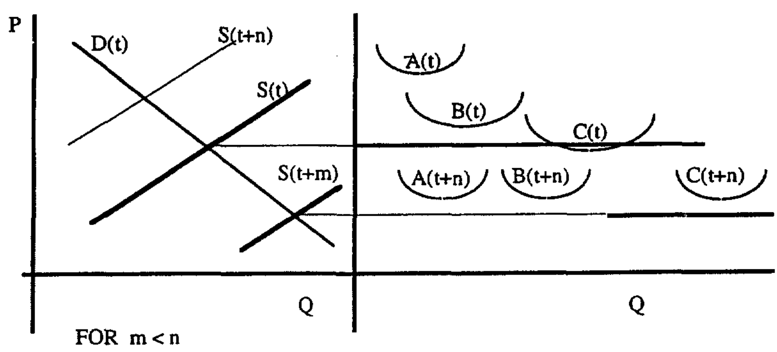

Figure 2. Market entropy and selection process.

Moreover it is clear that firms with average cost curve below the market price have high mark-ups and large cash-flows. Important shares of the extraprofits can be retained by the managers and used, after paying normal dividends to shareholders, to fund - internall - risky projects which it would be difficult to finance externally. Moreover it can be assumed that the larger the size of operation is and, even more important, the larger the market share, the better will be the appropriability conditions for innovation returns. Larger shares and sizes enable the average fixed costs of R&D activities to be reduced and still earn extraprofits on larger volumes of sales: appropriability is better enforced by larger market shares that delay entry and imitation (Scherer and Ross 1990).

The conditions of financial markets play a major role too. The more reluctant the financial markets are to fund R&D activities and the more risk-adverse the banks are, the more important will be the internal sources of funds to finance R&D projects and hence the more important will be the positive effects of large cash-flows on the rates of introduction of innovations and the stronger will be the links between quasi-rents and rates of introduction of localized technological changes.

The least efficient firms that have managed to survive in the short term realize quickly that they can avoid exit and consequent heavy losses of sunk costs only by means of systematic efforts to innovate and hence to reduce their costs. The profile of innovative efforts of the least efficient firms is also dictated by constraints in capital markets which specifically affect their R&D projects. The relationship between losses and innovative effort is probably as strong as the one between profits and innovative efforts. The failure-inducement mechanism here is very effective so that all the competences of the firm are mobilized to generate innovations which enable the firm to cope with adverse market conditions and survive in the market and avoid exit.

More specifically failure-induced technological changes are likely to consist mainly of incremental innovations based upon the adoption of process innovations which are designed to reduce the risks of research and development activities and to obtain quick results in terms of reduction of costs. Profit induced technological changes will probably be more radical in that they are the outcome of long-term R&D strategies and consist of product innovations.

The selection process in these Marshallian-Schumpeterian markets has now three important consequences:

i) the scrapping of the least efficient techniques and the exit of the least efficient firms, i.e. those which were unable to innovate;
ii) the rapid diffusion of incremental process innovations in the population of declining firms which are forced to adopt new technologies and to generate incremental innovations in order to survive;
iii) the accelerated generation of localized technological changes involving the introduction of more radical process and especially product innovations by the more efficient firms that face major dimensional switch-

ing costs but can take advantage of internally generated resources which are available to fund long term research and development activities that in turn can be used to mobilize the existing learning opportunities acquired in the course of past activities.

At the industry level the introduction of localized technological changes engenders a shift to the right of the supply curve and hence a decline in market prices that in turn causes the exit of a number of extramarginal firms, that are both less efficient and slower at generating localized technological changes. Their exit however will in turn engender a new leftward shift of the supply curve and hence a new jump in market prices which in turn leads to the increase of both market shares, output and profitability of intramarginal, technologically dynamic firms (Richardson 1962 and 1972) (See figure 2).

The interaction of the introduction of localized technological changes and the exit of extramarginal firms is likely to generate systematic fluctuations in market prices and market shares and output levels for the firms that are able to remain in the market place (Dixit 1994). The process of generation of localized technological changes within the augmented replicator dynamics is likely to be endless so that there is a continual increase in productivity at the aggregate level.

The rate of introduction of innovations will vary across industries according to the specific features of their market structure, which will depend on the variety of firms with respect to cost conditions, age, size, factor costs and on their innovative performances as determined by the levels of switching costs, of learning capacity and hence innovative capability (Pavitt 1984).

From the view point of the interindustrial flow of exchanges of intermediary inputs and capital goods it is now clear that the relative prices of different goods will keep changing over time for two important classes of factors:

i) the out-of-equilibrium conditions in which competition takes place in each industry; and
ii) the uneven rates of innovation between industries and hence the uneven reduction of best-practice costs.

Market entropy is likely to be the main engine propelling aggregate growth. The rates of introduction of technological change are clearly influenced by the degree of entropy within markets and among markets. To this extent disorder at the firms level is likely to be the underlying condition necessary if there is to be orderly processes of growth at the aggregate level.

3.2. Productivity growth, substitution and demand-pull localized technological change

Long term productivity growth, generated at the firm level by the interaction of localized technological change with the replicator dynamics, has important dynamic consequences at the aggregate level (Sylos Labini 1984). Productivity growth is in fact likely to engender two effects that in turn lead to the introduction of further localized technological change. Productivity growth resulting from market entropy in fact is likely to induce:

i) long term growth of derived demand for labor, a consequent increase in real wages across the economy (See figure 3b) and the reduction in

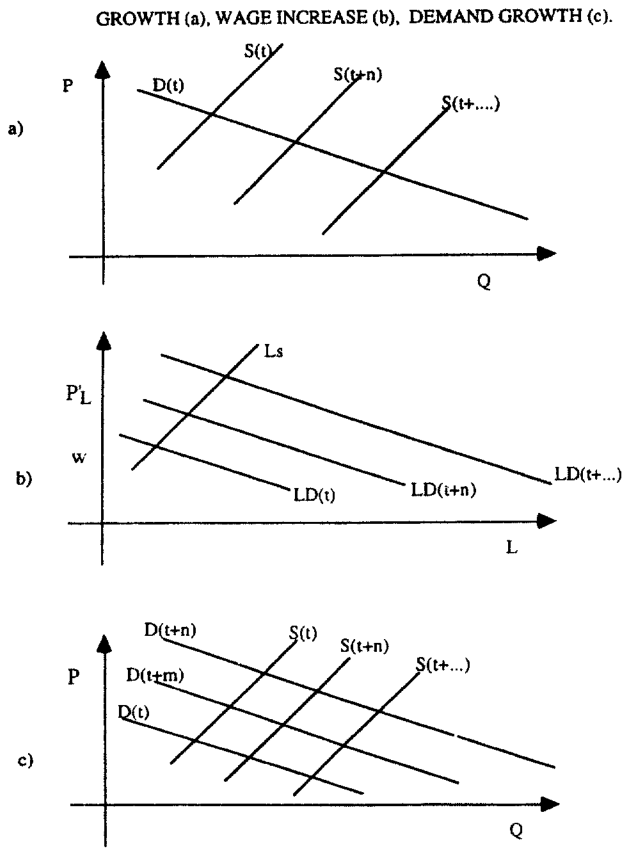

Figure 3. The relationship between productivity growth selection and output.

market prices of capital goods;[3] and hence
ii) a long term increase in the aggregate demand (See figure 3c).

Let us analyse the dynamic consequences of these two effects in terms of the introduction of localized technological changes in turn.

The increase in real wages and the reduction in market prices of capital goods, induced by the overall growth of total factor productivity, should force firms to substitute capital for labor and switch along the production function. Switching is expensive: sunk costs together with learning processes act as a major focussing device in directing the endogenous generation and adoption of new technologies that encourages localizing technological change in a very narrow range of techniques. Hence firms introduce localized technological changes that enable to retain the existing techniques and factor intensity while at the same time increase the efficiency of each factor so as to cope with the new relative costs (See figure 4).

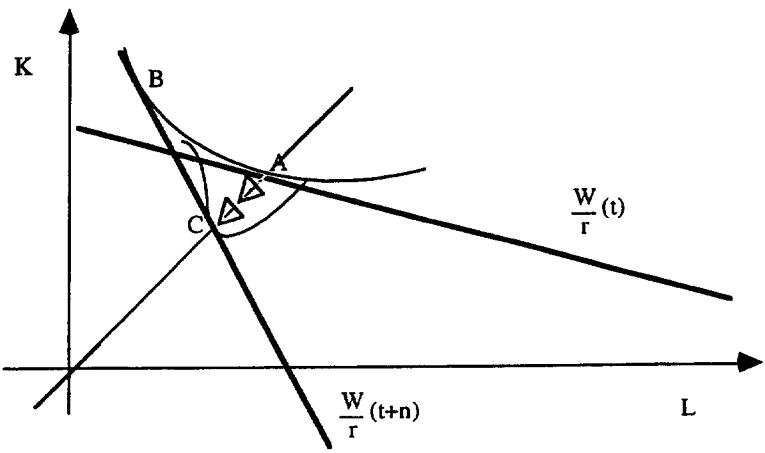

Figure 4. Localized technological changes induced by factor prices adjustments.

The increase in real wages and the reduction in market prices of capital goods, due to the overall growth of total factor productivity, which is gen-

[3] On the basis of well established empirical literature it is assumed here that the rates of introduction of innovations in the industries specializing in the production of capital goods are higher than the ones in the industries producing consumer goods (See Pavitt 1984).

erated by the localized technological changes and induced by the augmented replicator dynamics, associated with market entropy are together the origin of the introduction of further localized technological changes which are induced by changes in the conditions of factor markets and the modifications in the relative prices of production factors.

The direction of technological change is now influenced by the new conditions in the factor markets and more specifically by the rate of change of real wages and the reduction of rental costs of capital goods. Technological change will be more labor-saving in terms of output intensity, with respect to the previous technology, the larger is the increase of wages. It is interesting to note however that the more localized the new technology is, the more neutral it will be in terms of factor intensity.

The rate at which technological changes are introduced however is also influenced by the rates of changes in the mix of production factors, more specifically by the rate of increase in wages and the rate of reduction in market prices and hence rental costs of capital goods. The rate of the price-induced localized technological change in fact is influenced by the amount of the increase in wages: it is clear that the larger the wage increase and the larger the reduction in the rental costs of capital goods are, the larger will be the necessary switching, and hence the larger will be the innovative effort along the isocline that defines the factor intensity of the firm. This is necessary in order to retain factor intensity while coping with the new relative prices of production factors. It is clear that the amount of innovative effort as well as its direction is determined by the size of the increase in wages.

For given levels of heterogeneity in factor markets, the general increase in wage levels has one other important effect: i.e. the accelerated diffusion of previous waves of technological changes which had been already introduced, but were localized in techniques which were more capital intensive. These technologies in fact reduced the profitability of adoption for those firms, operating in labor abundant segments of the economy with low wages and hence in equilibrium in the labor-intensive portions of the spectrum of techniques. Such diffusion reinforces the positive effect of feedbacks from the increases in wages and of reductions in the market prices of capital goods on the further growth of total factor productivity levels.

The increase in wages and the reduction in the rental costs of capital goods however do not only have the effect of inducing the introduction and diffusion of localized technological changes aimed at reducing the amount of adjustment costs generated by switching along the original production function. The increase in wages and the reduction of market prices in the capital goods[4] also have important effects in terms of the level of aggregate

[4] When the demand for capital goods exhibits more than unitary price elasticities in the relevant portion of the curve.

demand. The income multiplier will cause the aggregate demand curve to shift to the right together with the increase in wages. Hence, back in our Marshallian-Schumpeterian industry it is now clear that not only does the supply curve shift to the right because of the dynamics of technological rivalry in the selection environment and in the competitive entropy, but the demand curve will also move to the right because of the changes in the aggregate conditions (See figure 3c). All firms now, irrespective of their profitability, will face an increase in market prices and demand.

The process of introduction of demand-pull localized technological changes is now likely to play a major role. Once again, firms facing pressure to adjust their size to the new levels of aggregate demand, will have to consider the trade-off between increasing their size by means of extensive growth based on an increase in the levels of input, or increasing their size by means of intensive growth based upon an increase in the levels of general efficiency of their production technology (See figure 5).

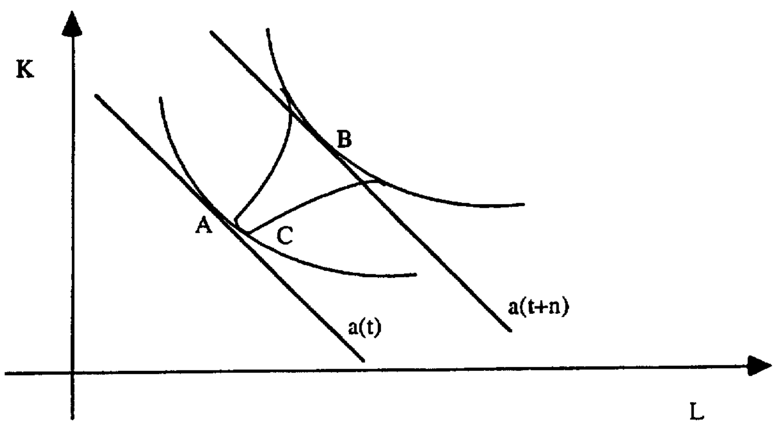

Figure 5. Localized technological changes induced by demand pull.

The rate of introduction of demand-pull localized technological changes will be directly related to the size of the increase in the demand levels, the levels of the dimensional switching costs, and the levels of opportunities to generate innovations based upon the experience and local knowledge acquired by means of learning by doing and learning by using and research and development activities.

The overall increase in demand levels, the rightward shift of the demand curves, has one further important effect on the diffusion of previous waves of technological innovations. Higher levels of investments, which are necessary to adjust output to the new desired levels of output, in fact make it possible for firms to adopt technological innovations that had been delayed because of the sunk costs of existing fixed capital. All additional investment can be used to purchase new capital equipment that embodies the new technologies. The diffusion of new capital goods embodying technological innovations reinforces the rates of growth of productivity of the system and stimulates further increases in real wages and raises the level of the demand curves.

3.3 The recursive interaction between the different forms of localized technological change

The interaction of the three forms of localized technological change described so far, and the additional momentum produced by the acceleration of diffusion processes will probably generate a recursive process of cumulative growth that is highly sensitive to both the initial conditions, a past-dependent process, and to the separate behaviors of the agents involved at each point in time, hence it will have the features of a strong path-dependent process (Young 1928, David 1975&1993a). At each point in time in fact the interaction of the different levels of localized technological changes and diffusion processes is acutely affected by a large variety of structural conditions and by their evolution over time and by the contingent behavior of a large variety of firms involved in the process (See figure 6).

At the firm level the distribution of market shares and more generally the dynamics of market conditions plays a major role together with the characteristics of the financial markets, the propensity of managers to fund risky undertakings, the willingness of shareholders to exert only a loose control on the destination of profits and the intensity of failure-induced reactions. The effects of irreversibility as expressed in the levels of switching costs and conversely the relative ease with which localized technological changes are introduced also play a central role. The latter underlines the importance of learning processes and the ability of firms to capitalize on them, which will in turn depend on factors such as built up specific competences, the relative weight of technological opportunities and more generally the possibility of introducing important innovations involving limited expenditure in research and development activities.

At the system level, the complex dynamics of localized technological change is strongly affected by the three-way interaction of productivity growth, i.e. the increase in wages and the reduction of market prices of capital goods and the consequent increase in aggregate demand. When and

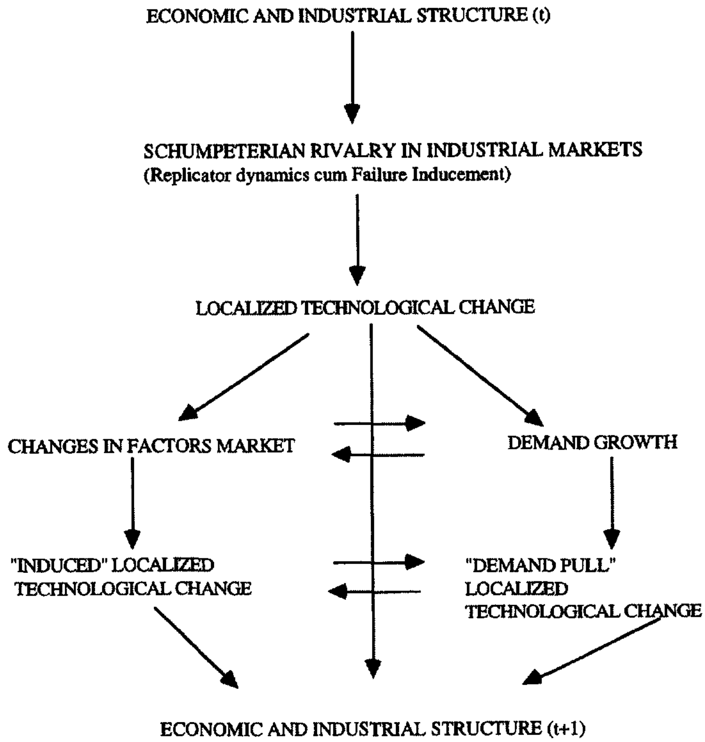

Figure 6. The path-dependent interations among the three modes of localized technological change.

where productivity growth leads to low increases in wages due to high levels of unemployment or flat labor-supply curves, and/or productivity growth leads to low levels of aggregate demand due to low increases in wages, low levels of income multipliers and low levels of new investment, the aggregate effects on localized technological changes are likely to be much weaker.

In this context the static and dynamic conditions of the institutional definition of the competitive arena in which firms interact play a special role. The wider is the variety of firms and hence the variance of their competences and performances, the larger will be the number of localized technological changes introduced by firms to face the process of technological rivalry and the shifting of demand curves. Hence all interventions that change the institutional borders of the competitive arena - such as the evolution of international economy, the process of economic integration and disintegration in global markets, the emergence of new limitations on competition - are likely to reduce/increase the degree of technological rivalry.

The same changes in fact are also likely to affect the extent of the feed-back effects of productivity growth, measured in terms of increases in wages and aggregate demand and hence the amount of induced productivity growth a system is able to generate. More specifically there is an important trade-off between the positive effects of all processes of integration and globalization in terms of increased variance and hence increased rates of introduction of technological change, and the negative effects generated by the loosening of the macro-micro feed-backs. In a global economy the effects of local technological rivalry on wages and aggregate demand, when measured in terms of productivity growth, are likely to be diluted in the global macroeconomic environment.

4. CONCLUSIONS

It is clear that the dynamics of localized technological change consists in a recursive cumulative process where the replicator dynamics augmented by the demand-pull introduction of Lamarckian localized technological changes acts as the microeconomic engine of the dynamics of the system. At the aggregate level, the productivity growth generated by the augmented replicator induces both an increase of wages and, in turn, an increase in demand levels.

Both activate the introduction of localized technological changes of different sorts: the price-induced localized technological change engendered by modifications in the factor markets and the demand pull localized technological change engendered by changes in the conditions of aggregate demand. Moreover, both processes also affect the rate of diffusion of innovations: all changes in factor market conditions encourage the adoption of capital-intensive technologies and changes in the aggregate demand levels favor new waves of investment and hence the adoption of new capital goods embodying technological changes.

These processes interact at the macro level as well as at the micro level. On the market side, the introduction of new localized technologies together with the well-known limitations to their instantaneous adoption by all firms leads, once more, to exchanges out of equilibrium, which are situated off the contract curve and away from tangent positions on the frontier of production possibility. Exchanges out of equilibrium-cum-localized technological changes lead to selection processes that are highly sensitive to the situations found to prevail in the system at that time, as well as to the effects of the interactions of agents at any point in time and hence to high levels of path-dependent irreversibility (David 1993a, David-Foray and Dalle 1998).

When the results of our analysis are brought together it would seem important to stress that entropy, competence and switching costs are at the origin of both disorder and waste, which should be taken into account, and productivity growth. Hence a system characterized by high levels of heterogeneity and variety within markets that are modeled along both Marshallian and Schumpeterian lines, will probably experience both high levels of variance in total factor productivity growth and high levels of "gross" productivity growth. The latter is because of the continuous efforts firms make in reacting to the selective environment in which they operate by introducing technological innovations. The former is a result of the high levels of disruption and switching costs that reduce the levels of general efficiency of the system and especially those of the less effective firms not to mention those firms which are forced to exit. In sum the high levels of "gross" productivity growth should be discounted by the cost of the trial and error processes that make them possible.

It seems increasingly clear, therefore, that when switching costs, learning, competence and information costs, and hence endogenous technological changes are properly considered, an analytical framework should be elaborated which takes into account the effects of high levels of irreversibility. More generally when dynamic and endogenous processes of change are taken into account it is clear that both local and global irreversibility as well as path-dependence play a major role in the analysis of the firm, the technology and the system. In such conditions economic systems in fact are likely to develop along a cumulative path that is highly sensitive both to the conditions, that happened to prevail at that time and to the behavior of agents at each point in time as well as to the effects of their interactions on the features of the system, both with respect to the organization of industries and the structures of the economy, with the result that multiple dynamic equilibria and multiple regimes of growth can be found.

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