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LOCALIZED TECHNOLOGICAL CHANGE AND FACTOR MARKETS: CONSTRAINTS AND INDUCEMENTS TO INNOVATION

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LOCALIZED TECHNOLOGICAL CHANGE AND FACTOR MARKETS: CONSTRAINTS AND INDUCEMENTS TO INNOVATION[1]

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ABSTRACT

The recent advances in the economics of innovation and the analysis of how composition effects influence the introduction of technological change in a global economy, characterized by the variety of production functions in use and different local factor markets, provide new strength to the induced innovation approach. Developing the localized technological change approach, it is argued that because there are irreversibilities, limited knowledge and local learning, the introduction of new technologies is induced by the disequilibrium conditions brought about in each system by all changes in relative factor prices. The direction of technological change in terms of its specific form of bias and how it is introduced and adopted, however, reflects the specific conditions of local factor markets. Well-defined long-term technological paths emerge in each region and they depend on the selection process in product markets. The more rigid and idiosyncratic, the endowment of production factors and the system of relative prices are, the more specific the technological path of each region is likely to be. The divide between the microeconomic and the macroreconomic models of induced technological change is reconciled.

KEY-WORDS: INDUCED INNOVATION -BIASED TECHNOLOGICAL CHANGE-COMPOSITION EFFECTS- LOCALIZED TECHNOLOGICAL CHANGE

JEL O31; O40.

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1. Introduction

The induced innovation point of view is a fertile line of approach to understanding what determines the rate and the direction of technological change. Recent advances in the economics of innovation have been grafted onto the induced technological change approach and provide new insights and basic guidance in understanding what determines the rate and direction of technological change. Many important dynamic implications are to be drawn from such an analysis of the interaction between composition effects and technological change and the notions of general and contingent technological change.

The divide between the microeconomic model, stemming from the observations of Sir John Hicks (1932) and macroeconomic theory developed by Kennedy (1964) and Samuelson (1965), can be reconciled within the context of the economics of localized technological change. This paper provides a systematic analysis of the role played by irreversibility, limited knowledge and localized learning in the inducement mechanism which together lead firms to introduce new technologies, in a context where the interaction between the rate and the direction of technological change and the specific context of their application are considered.

Section 2 reviews the basic results of the induced technological change approaches. Section 3 summarizes the notion of composition effects. Section 4 presents the distinction between general and contingent technological change. While section 5 is the core of the paper. Section 5.1 reviews the localized technological change approach and explores what determines the inducement mechanisms, which lead firms to introduce resulting in either general, or contingent technological changes. Section 5.2 goes on to present a formal model of localized inducement that combines both inducement caused by changes in factor prices and the inducement stimulated by the levels of factor prices resulting in the direction of technological change. Section 5.3 explores the implications of the model and applies it to understand the dynamics of technological change in a comparative and global setting. The conclusions put the results of the model in a broader perspective and list the main findings.

2. The induced technological change approach

According to the induced technological change approach, new technologies are introduced in response to conditions in the factor markets. First, a distinction has to be made between the models of induced technological change which focus attention on changes in factor prices and the models of induced technological change which stress the static conditions of factor markets. In the former approach, following Hicks and Marx, firms are induced to change their technology when the price of a factor of production increases (Hicks, 1932)[2]. According to the generalization of the basic hypothesis put forward by Binswanger and Ruttan (1978) and recently updated by Ruttan (1997 and 2001), firms introduce new technologies, which reduce the use of the factor whose costs have increased. A change in factor prices acts as an inducement, and explains both the rate and the direction of introduction of new technologies. The introduction of new technologies complements and actually increases the standard substitution process, i.e. the technical change involving the selection of new techniques, defined in terms of factor intensities, on the existing isoquants. Inducement concerns both direction and intensity. The stronger, the increase of wages (or any other factor) is; the larger, the effects will be, both in terms of labor saving intensity and in terms of the amount of innovation being introduced.

This approach to induced technological change differs from the macroeconomic version, developed by Kennedy (1964) and Samuelson (1965), in that, firms introduce new technologies in order to reduce the use of the factors of production that are relatively more expensive. In this second approach the level of factor price is important, and not the rates of change. As Ruttan (2001:103) points out, however, the macroeconomic approach is not able to explain why and how firms introduce new technologies. For these reasons, the fact that it does not have a microeconomic base, the macroeconomic model has been criticised to a point of being neglected.

The macroeconomic model, however, points out one important thing: i.e. there is a clear incentive to introduce a technology which makes the most intensive use of the resources that are locally most abundant. The recent and fruitful debate on skill biased technological change is centred on an analysis of the causal relationship between the abundant supply of skilled labor and the eventual generation and introduction of skill intensive new technologies (Acemoglou, 1998). As a matter of fact, there is a contradiction here between the macroeconomic model and the microeconomic one.

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2 Hicks (1976) provides a clear definition of the inducement hypothesis: "An induced invention is a change in technique that is made as a consequence of a change in prices (or, in general, scarcities); if the change in prices had not occurred, the change in technique would not have been made. I now like to think of a major technical change (one that we may agree to regard as autonomous, since, for anything that we are concerned with, it comes from outside) as setting up what I call an Impulse. If the autonomous change is an invention which widens the range of technical possibilities, it must begin by raising profitability and inducing expansion; but the expansion encounters scarcities, which act as a brake. Some of the scarcities may be just temporary bottle-necks which in time can be removed; some, however, may be irremovable. Yet it is possible to adjust to either kind of scarcity by further changes in technical methods; it is these that are the true *induced inventions*. The whole story, when it is looked at in this way, is in *time*, and can be in history…"(Hicks, 1976/1982: 295 and 296) (italics is the original text).

In the microeconomic model, firms are induced to introduce new labor saving technologies by an increase of wages. In a labor abundant region, however, there is a strong incentive to introduce labor intensive technologies, rather than labour saving ones, even after an increase in wages.

The induced approach and its contradictions, can be improved by considering the role of composition effects in the global economy and by taking into account what determines and what limits the localized introduction of innovation when there are effects of irreversibility, limited knowledge and learning.

3. Composition effects: The interaction between relative prices and the direction of technological change

Analyzing technological change in a global economy, characterized by heterogeneity in factor markets, different production functions in use in different countries and rivalry in interdependent international product markets, facilitates the inclusion of the combined effects of relative factor costs and non-neutral technological changes.

When a general purpose technology which can be introduced and applied widely becomes available, and the global economy is heterogeneous, with respect to the characteristics of the production functions in use and of the factor markets, the technology cannot be neutral everywhere (Bresnahan and Traitenberg, 1995, Helpman, 1998). When technological change is biased, the context in which it is introduced is fundamental in assessing its effects in terms of total factor productivity growth. When a new technology is biased, in that it favors the more intensive use of one of the factors of production, its effects measured in terms of productivity growth are stronger, the more abundant, and hence less expensive, the most effective factor is. Such dynamics have major effects, in terms of emerging asymmetries in the global economy, on firms operating in heterogeneous factor markets, while competing in homogeneous and global product markets.

Composition effects define what effect relative factor prices will have on total costs and total factor productivity levels. Differences in factor costs are relevant both when technology is given and when technological change is important. In the former case, it is seen that when, with a given biased technology, relative factor prices, as distinct from the levels of absolute factor costs, change, average costs also change. Specifically, whenever the relative cost of the most productive factor falls there will be a reduction in production costs. Such changes in production costs, even if they cannot accounted for by overall factor productivity measures, have a powerful effect on the competitive advantage of rival firms based in heterogeneous factor markets. In the latter case, it is seen that when a new superior technology is introduced in two countries -characterized by different endowments and hence different factor markets with different factor costs- it will have a much bigger effect in terms of raising overall factor productivity in the country where the most productive factor is cheaper. Composition effects are all the stronger when there are changes in both technology and factor costs.

Composition effects play an important role in the analysis of technological change in different industries and countries because of the strong effects relative prices have on the actual 'measured' overall growth of factor productivity in each country. The static and dynamic interaction between different kinds of change in technology and the levels and changes in relative prices can in fact take different forms. Let us consider some general cases.

Let us first consider an industry with a capital intensive production function in a region, where a neutral technological change has been introduced and the general efficiency of the production process has increased. Simultaneously, however, capital rental costs have also increased and wages declined. These two changes tend to have opposite effects. The increase in the overall efficiency should lead to an increase in output, for given levels of inputs. The increase in relative capital rental costs, however, leads to a reduction in the actual use of capital and hence in output. This reduction can perfectly offset the increase in the general efficiency.

Similar asymmetric relations take place when relative wages increase and a new neutral –capital-intensive - technology is introduced. The general efficiency of the production function is now raised by the increase in the wage to rent ratio and hence by reducing the use of the less productive labor and increasing the use of more productive capital. Again the more capital intensive, the production function is the stronger, the effects of the increase in the wage levels are.

The model becomes even more complicated when non-neutral technological change is introduced. Assuming that a smooth incremental technological change with labor-intensive and hence capital-saving features is introduced in an industry based in a region where wages are low and capital rental costs are very high. The composition effects in terms of the increase in overall efficiency are very important. The effect can be much stronger than a radical and biased technological change, which is characterized by a major shift in the general efficiency parameter, and also by a significant increase in the output elasticity of capital and a reduction in the output elasticity of labor. The latter technology will be less efficient than the former, although overall it should be regarded as better. It is clear therefore that the performance of technology depends very much on its bias and the relative costs of the factors of production.

Such an analysis immediately applies in a synchronic context where there is a variety of factor markets across industries and regions. A new and radical capital saving technology will have stronger positive effects in a labor abundant region with low wages than in a high wage country and this explains why such technology will be adopted more quickly in such regions. The incremental labor saving technology will have stronger positive effects and will be adopted more quickly in capital abundant regions with low relative capital rental costs.

Only technological change, which is characterized by a bias that is appropriate to the structure of local endowments, can strengthen technological variety in international markets where the relative prices of inputs differ because of differences in local factor markets. The global introduction of a new general purpose technology instead reduces technological variety with negative effects on the structure of comparative advantage and hence on the distribution of the gains from global trade.

The introduction of a global and hence necessarily biased technological change, has strong effects in terms of new asymmetries among potential adopters. When a new technology is biased, the increase in efficiency takes place in only a limited area of the map of techniques. In such conditions the new and the old technologies are likely to intersect. Before the intersection, the new technology is superior to the old technology in absolute terms and vice versa after the intersection.

4. General and contingent technological change

An analysis of composition effects provides a clear framework within which the distinction between radical and incremental technological change can be analysed. Macro- and micro-inventions, frequently developed in the literature on qualitative basis can also be considered (Freeman, 1994; Mokyr, 1990)[3].

[3] In so doing the early distinctions, in technical progress literature, based on factor intensity can be applied in a new context (Robinson,1937; Asimakopulos and Weldon, 1963; Blaug, 1963; Amendola, 1976; Besomi, 1999)

When a new technology is introduced in a heterogeneous economic system with a variety of local factor markets, the effects in terms of the growth of overall factor productivity are influenced by the local structure of relative factor prices. The ranking of different technology depends on the relative prices of the factors of production.

The distinction between general and contingent technological change can now be introduced. A new technology is general when it can be defined as a new production function where the shift parameter increases to such an extent that it is superior to any previous technology, even when the output elasticity of each production factor is affected. Contingent technological change instead affects only the composition and the ranking of production factors in terms of their output elasticities. The effects on total factor productivity are generated by the substitution of more productive inputs for less productive ones, with no (general) shift in the production function[4].

The notion of contingent technological change differs from previous specifications of technological change. Technological change is neutral, when it consists of a shift effect which leads to a traditional increase in overall factor productivity levels with no effects regarding the composition of the marginal productivity of the factors of production. Contingent technological change, instead, affects only the composition and the ranking of the factors of production in terms of their output elasticities. The effects on overall factor productivity are generated by the substitution of more productive inputs for less productive ones, with no shift in the production function.

The accepted tradition of productivity accounting, based upon the pathbreaking contributions of Abramovitz (1956) and Solow (1956) makes it possible to calculate a synthetic index of the changes in overall factor productivity levels. Following Salter (1960) and Brown (1966), simple calculations make it possible to split up the overall factor productivity level into two well defined components: the effects of introducing general technology and hence the shift effect, and the composition effects brought about by the introduction of new biased technologies which change the relative output elasticity of inputs.

The procedure is very simple and consists in first calculating the standard residual, based, as is well-known, on the calculation of a virtual output at time t1. This is based on the new observed levels of

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[4] The notion of general purpose technology contributes to our understanding of the distinction between general and contingent technological changes. General technological change is in fact a general-purpose technology with a wide range of applications both in terms of products and regions. Contingent technological changes on the contrary apply to a limited range of techniques and have a limited range of application (Bresnahan and Trajtenberg, 1995; Helpman, 1998).

inputs and the old output elasticities. Then it is compared with the actual values and the difference is attributed to the introduction of new technology.

The complementary methodology, aimed at splitting the bias and the shift effects, consists in calculating a new virtual output. The new virtual output is simply the product of the production function at time t1, with the new input levels and the new factor shares. The difference between the second virtual output and the actual one measures the shift effect. In turn the difference between the first virtual output and the second measures the composition effect.

Let us consider, with two simple production functions at time t1 and t2, respectively. A new technology is introduced with both shift and bias effects during the given time interval. The output elasticity of capital at time t1 is $\alpha = 0.25$ and it is a= 0.75 at time t2.

(1) $Y_{\mathbf{t1}} = K^{\alpha} L^{\beta}$ for $\alpha = 0.25$

(2) $Y_{\mathbf{t2}} = K^{a} L^{b}$ for $a = 0.75$

The standard total factor productivity index (A_T) is calculated as follows:

(3) $A_T = Y_{\mathbf{t2}} / K_{t2}^{\alpha} L_{t2}^{\beta}$

The shift component of the total factor productivity index can now be calculated as the ratio between actual output and estimated output expected, the levels of inputs at time t2 and the new output elasticities. Formally the calculation is as follows:

(4) $A_S = Y_{\mathbf{t2}} / (K_{t2}^{a} L_{t2}^{b})$

The difference between A_T and A_S can be termed A_B: which provides a measure of the joint effects of the changes in the relative prices (if any), the bias in the output elasticities and measures in a synthetic way the effects of the changes in the composition and relative efficiency of the factors of production:

(5) $A_B = A_T - A_S$

It is important to note that A_B may be negative as well as positive. A negative A_B occurs when a new general technology with a strong shift effect is introduced in a country although the factor intensities are not really appropriate for the local conditions in the factor markets. When A_B is negative an important opportunity for the eventual introduction of dedicated contingent technologies emerges. The generation of new biased technologies that build around the new shift technology and use the locally abundant inputs more intensively and hence reduce the use of some locally scarce and costly inputs, may be very advantageous.

The introduction of general technologies exerts powerful asymmetric effects in a global economy. Such technologies in fact are characterized by such an important shift effect that they are (almost) always and everywhere more efficient than previous technologies. Nevertheless, they will actually be more productive in some systems than in others depending on the relative costs of the most productive factors. The introduction of general technology with high levels of capital intensity in a capital abundant country yields a larger increase in total factory productivity levels than in a labor abundant country. It may still be adopted even in a labor abundant country, but it will register lower levels of overall factor productivity. The bias in technology engenders a strong and long-lasting asymmetric effect. The asymmetry will be stronger, the stronger the bias and the shift are, and hence, the relative profitability of adoption even in less favourable conditions.

The direction of technological change and the context in which it is applied are more important than is generally thought, especially in a global economy, where agents based in heterogeneous factor markets compete in quasi-homogeneous and, in any event, interdependent product markets.

The generation of either contingent or general technological change clearly is not an exogenous event, which takes place without any economic inducements or incentives. Instead, the introduction of either contingent and general technological change can be considered as the induced outcome of very specific incentives and constraints exerted and shaped by the structure of the economic system. The necessary tools are provided by traditional analysis being incorporated into the economics of innovation.

5. The inducement of general and contingent localized technological change

5.1. The economics of localized technological change

The economics of localized technological change help us to understand the inducement mechanisms that lead to the generation, introduction and adoption of innovations characterized by their respective bias (Atkinson and Stiglitz, 1969; David, 1975; Antonelli, 1995, 1999, 2001).

Developing the notions of bounded rationality, local search and localized technological knowledge, innovation is viewed as the result of a local search induced by the difference between expectations and reality. Firms are myopic agents affected by bounded rationality and as such they are unable to correctly anticipate all the possible conditions in the world. Myopic firms are not able to rationally calculate all the costs and benefits to be derived from the introduction of innovation, moreover they resist the introduction of all changes which would increase the burdens and the costly limitations of bounded rationality. Myopic agents however may be induced to innovate and introduce technological change when current conditions seem inappropriate and unexpected events occur[5]. Even myopic firms are aware of the costs of not-changing their productive and commercial set-up. The costs of not-changing are then compared with the costs of introducing new technology.

Innovation, the introduction of new technology is the result of reactive and sequential decision making set off by disequilibrium in both product and factor markets. Changes in the relative and absolute prices of the factors of production (as well as changes in demand conditions for their products) force firms to venture away from expected equilibrium conditions. There is a mismatch between the existing production pattern which is the result of previous irreversible decisions regarding both fixed capital and labour. Such decisions were based on necessary but myopic expectations – and the new situation created by unexpected changes in the product and factor markets. However, firms can adjust by changing their technology and they can no longer be considered to react only by adjusting output or prices.

The introduction of technological changes however is not free, and to a large extent, it is the result of intentional acts. The introduction of new technology requires the investment of dedicated resources to carry out research and development activities, to acquire external knowledge and to take advantage of new technological opportunities, to accumulate and articulate the benefits of experience and to use the tacit knowledge acquired in repeated processes of learning by doing, learning by using, learning by interacting with consumers, learning by purchasing. Each firm moreover cannot be analyzed separately when the generation of new technological knowledge and

[5] The reference to the behavioral theory of the firm, described by March and Simon (1958) and Cyert and March (1963) is clear.

the introduction of new technologies are being considered. The characteristics of the collective networks of innovators and the structure of interactive learning into which each firm is embedded play a major role here.

In such a context firms act on all changes in market demand and in the relative price of the factors of production only after some dedicated resources have been used to search for a new and more convenient procedure. Consequently, firms make sequential, yet myopic choices reacting to a sequence of 'unexpected changes' in their business environment, brought about by other agents introducing innovation in both product and factor markets.

When irreversibility is important, all changes in current business involve some adjustment costs that have to be accounted for. In such an approach, firms are portrayed as agents whose behavior is constrained by the irreversible and static character of most of their material and human capital needs. Moreover the management of firms is affected by bounded rationality which implies strong limits to their capability to search and elaborate information about markets, techniques and technology. As a matter of fact competence represents the basic irreversible factor of production. In turn competence is embodied both in the organization of the firm and in its stock of fixed capital (Antonelli, 2003).

The introduction of technological change is the result of the innovative behaviour of agents limited by relevant irreversibility and switching costs, which keep them within a limited technical area and prevent significant changes being made to the input mix. Technological change is introduced locally by firms which are able to learn about the specific techniques in use and hence to improve them. Myopic firms are induced to deal with the dynamics of demand and factor prices by introducing technological innovations and making adjustments in response to market fluctuations while retaining, the previous input levels as much as possible, and hence they change the technology locally, determined by the relative costs of introducing innovation[6].

The identification of two well distinct classes of technological change with respect to their effects leads us to develop the analysis concentrating on generation. Two well distinct rationales can be

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[6] Bounded rationality limits the capability of agents to elaborate correct expectations about all the possible outcomes of their decisions. Firms need to make irreversible decisions and yet they are not able to anticipate correctly all the possible consequences of their decisions in the long term. Bounded rationality leads to a myopic behaviour, but does not prevent the capability of agents to choose among alternatives, even though not all the possible consequences are immediately clear at the outset.

developed by drawing on traditional analysis of the economics of innovation, to understand the generation of contingent and general technological changes respectively.

From the point of view of the incentives it seems clear that the introduction of general technology is likely to yield a much larger benefit than the introduction of contingent technologies. Important differences in terms of costs and constraints to their introduction need to be considered.

Four groups of conditions are important here, the first draws on the distinction between top-down scientific opportunities and bottom-up technological opportunities. Technological opportunities are mainly based upon learning processes, while scientific opportunities draw on new scientific advances. The second condition concerns where the sources of new knowledge are, whether they are part of the economic system in which the firm is embedded or mainly external, in other regions or even other countries. In this context, the regime of intellectual property rights and the levels of international protection, as distinct from those of domestic protection, play an important role, in that, they determine the actual conditions of access to external technological knowledge. The third relevant group is the distinction between leaning processes whether it is a question more of learning by doing or learning by using capital and intermediary goods purchased from other industries often located abroad. The levels of switching costs are the fourth relevant group of variables which affect a firm's innovative behaviour. They include the costs associated with all changes in the existing stocks of tangible and intangible capital and techniques, including the expertise of the workers as well as the brand and reputation of firm.

For a given set of incentives, technological change will be either general or contingent depending on the specific values of the parameters for these factors. When top-down scientific opportunities emerge and the frontier of scientific knowledge is brought forward by relevant scientific advances, when internal knowledge is more relevant than external knowledge, when learning by doing is more relevant than learning by using and both irreversibility and switching costs are low, firms are more likely to introduce general technological changes. Instead, when technological opportunities are more important than scientific ones, when the major sources of technological knowledge are abroad, when learning by using is more fertile than learning by doing, and the irreversibility of both tangible and intangible factors of production is high, firms are more likely, for given innovation budgets, to introduce contingent technological changes rather than general ones.

General technological changes involve a radical shift of the map of isoquants, such that all techniques are now more efficient. They can be thought of as the typical result of scientific breakthroughs and research activities in technological domains where agents are able to improve the productivity of a large array of techniques. A major and radical breakthrough leads to new general-purpose technologies. Significant shift effects and hence high levels of increases in overall factor productivity characterize general technological change. The shift effects are such that the new technology is superior to most, if not all, technologies in use in terms of levels of overall factor productivity, whatever their bias and whatever the local factor costs. General-purpose technologies however are likely to reflect the specific and idiosyncratic factor endowment of the innovators: they are only locally neutral. Hence the factors that are most abundant in the innovating country, are likely also to be most productive. The introduction of general-purpose technology can be thought of as the outcome of the localized efforts of innovators aware of new scientific opportunities and so a general shift in the map of isoquants is induced.

When a new technology is locally neutral, its adoption elsewhere, engenders a significant diffusion and hence the growth of overall factor productivity across firms based in countries and regions that are characterized by heterogeneous endowments. Such positive effects, however, are asymmetric, in that they are stronger where most productive factors are cheaper. Contingent technological change is the result of the incremental introduction of a myriad of small changes after the main shift effect has been generated. Contingent technology is introduced by firms, facing unexpected changes in both product and factor markets, when the constraints of quasi-irreversibility of fixed capital stocks are low and hence less important than the switching costs associated with all changes in factor intensities. Markets for inputs are more flexible, capital intensity is lower and therefore the role of inertia engendered by sunk costs. Firms can change their factor-mix with relative ease. Further and most important, contingent technology can be considered to be the result of incremental innovations mainly based on learning by using procedures. Firms learn how to use new general technology, especially when it is embodied in capital goods and intermediary inputs, and eventually they are able to capitalize on the new tacit knowledge. The access to external knowledge through user-producer interaction with advanced, but remote sellers, sellers of new capital goods and intermediary inputs, can help adopting firms to invent and improve the factor intensity of the new general technology, so as to make it appropriate to the local structure of endowments.

The generation of contingent technology can be considered to be the result of a viable innovation strategy for firms which have limited resources to fund research budgets. Such firms rely more upon external and tacit knowledge, associated with processes of learning by using new inputs, they operate in flexible factor markets and are able to improve and eventually adopt new technologies, mainly invented elsewhere.

Specifically, a sequence between general and contingent technological change will now be described. A sequence which begins with the introduction of new general-purpose, but locally neutral technology in a leading country with idiosyncratic factor markets, and diffusion occurs very quickly across regions and industries because of the big increase in overall factor productivity levels, which result from the adoption of the new technology. However, as the new general-purpose technology is adopted in countries and regions where relative factor prices differ sharply from prices in the country where the technology originated, new adopters and other followers will use the new technology and increase its benefits, by introducing contingent technological changes that fit in better with the local endowment of production factors. The benefits stemming from the introduction of contingent technological changes are clearly much lower than the benefits derived from the introduction of general technological changes; their costs are also much lower.

The analysis in this paper makes it possible to consider the range of localized choice. At the firm level, the range of technological innovations can vary between the two extremes of a new general and hence locally neutral technology which only consists in a shift effect and a new contingent technology which only consists in a bias.

5.2. A model of localized technological change

The choice between introducing general and contingent technology, for a firm, constrained by weak irreversibility and bounded rationality, but induced to innovate by the new and unexpected conditions in its product and factor markets can be neatly encapsulated in the analytical framework of a nested frontier of possible adjustments that combines the choice between substitution and innovation and also between introducing either general or contingent innovations.

Firms are induced to change the pattern of their production process when there is a mismatch between the expected conditions in the factor and product markets and the conditions which actually exist. However, the firms have made irreversible decisions regarding both fixed and human capital and all changes in the level of inputs, with respect to their plans, are expensive. Adjustments are necessary: the disequilibrium conditions generated by the mismatch between expected and actual conditions in the market place generates losses and opportunity costs which cannot be sustained in the long run.

In this model all changes in the production pattern and hence all movements in the existing map of isoquants, either on a given isoquant or from one isoquant to another -but still in the same map-, engender switching costs[7]. Formally the following definition is given:

(6) SW = Z (dK/K, dL/L),

where dK/K and dL/L are defined as the changes in the levels of irreversible inputs, which are necessary in order to satisfy the new unexpected levels of demand and factor prices and SW, stands for switching costs[8].

The firm can either adjust to the new factor markets conditions, by changing its position within the existing area of techniques, defined by existing technology, or react, in a creative way, by introducing an innovation which makes it possible to change the technology and hence the area of techniques[9]. The firm is now set to consider the fundamental trade-off between the costs of switching occurred by technical change in the existing technical area and the costs of introducing technological changes, which reshape the technical area.

In diagram 1 it can be seen that the firm, originally in equilibrium at E_1, should move to E_2, because of the increase in wages and the reduction of capital rental costs[10]. The switching movement from E_1 towards E_2 is the standard substitution process and involves the introduction of technical change. The irreversibility of existing production factors and imperfect knowledge regarding remote techniques albeit on the existing isoquant, make the switching mobility of the firm expensive and resource consuming. Technological change, however, provides a viable alternative. The introduction of technological change in fact makes it possible to restore equilibrium conditions at E_3 or at any

7 In other models of this kind only changes in fixed capital were assumed to yield switching costs. See Antonelli (2001).

8 Appropriate tuning of the parameters of equation (6) can express a range of conditions including the case in which switching costs depend almost exclusively upon the required changes in fixed capital, or in human capital, or in both.

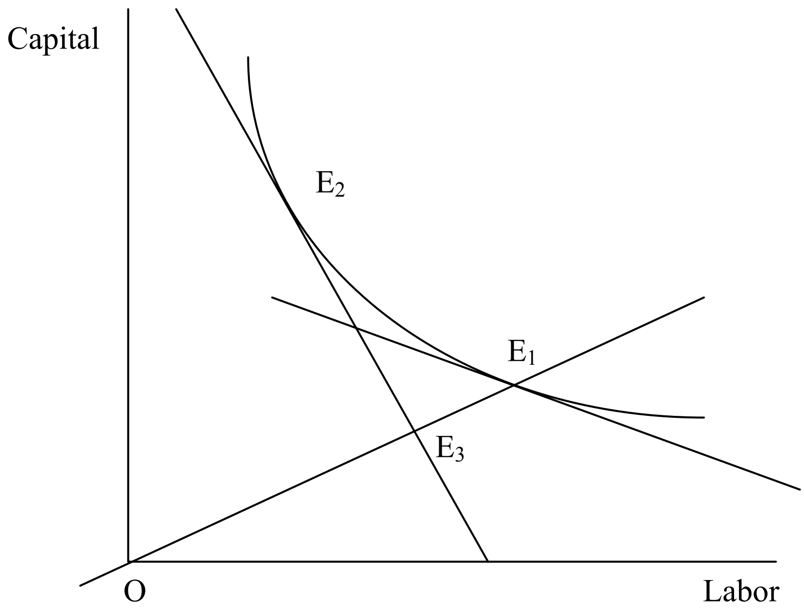
9 In this model the firm considers the possibility of introducing new technology in all possible technical directions. The direction of the innovation activity is not bound by the techniques in use. Localized learning takes place in the technique, defined in terms of input intensity, in use at each point in time, but it makes it possible to move in all directions so as to reshape the map of isoquants.

10 For the sake of clarity the rest of the analysis considers only the case where there is a change in equilibrium condition determined by a change in factor costs. The model however can be used to analyze the consequences of a change in the levels of the demand for the products of the firm and hence in a parallel shift of the isocosts, with proper changes.

other point that is part of the new isocost. It is actually better at any point beyond the new isocost. If the firm is able to go beyond the new isocost, technological change leads to an increase in overall factor productivity levels not only with respect to the old equilibrium conditions but also with respect to the production conditions at E_2.

INSERT DIAGRAM 1 ABOUT HERE

DIAGRAM 1: THE TRADE-OFF BETWEEN TECHNICAL CHANGE AND TECHNOLOGICAL CHANGE



The introduction of new technology is the result of research and learning activities. The resources available, to cope with unexpected changes in the product and factor markets, can be used to generate either general or contingent technology. The investment of the resources available leads in turn to research, learning and communication activities which translate into varying levels of generation of either general or contingent technology depending on how easy it is to introduce either kind of new technology.

The firm in other words faces two nested frontiers of possible changes when there is a mismatch between expected and actual market conditions. The first frontier of possible changes is the frontier of possible adjustments, which make it possible to compare the results of resources invested in either technical or technological change. The second frontier compares the different kinds of technological change, whether it is contingent or general. The first isorevenue is defined by the absolute level of the revenue generated by all the adjustment activities. This covers both the amount of losses that are avoided by the introduction of new techniques and the increase in output resulting from the introduction of the new technologies respectively. The second isorevenue compares the revenue generated either by general or by contingent technological changes.

Standard optimization procedures make it possible to jointly identify both the correct amount of technological change with respect to the levels of technical change switching and the ratio of biased technological change with respect to a shift in technological change. Specifically it is a case of maximizing output with a given isorevenue level which is set by the amount of adjustment costs that are necessary to reduce the mismatch between expected and actual market conditions.

Formally the following relations are given:

(6) TC = a(research activities)

(7) tc = b(switching activities)

where TC measures the amount of technological innovation necessary to change the technical area and 'tc' measures the amount of technical change necessary to move within the existing technical area.

In economic textbooks the amount of switching activities that are necessary to move within the area of existing techniques is very low because firms are not limited by bounded rationality and limited knowledge. Their mobility within the technical area moreover is not limited by the effects of irreversibility. The same economic textbooks suggest that the amount of resources necessary to change technology is extremely high. Hence a' is small and b' is high. In our analysis, instead, irreversibility and bounded rationality are relevant as well as a firm's technological creativity. Hence a' is large and b' small.

The choice between technical and technological change is affected by the specific content of technological change, i.e. whether it is general or contingent. Thus the analysis pursued in section 5.1 leads to the following relations:

(8)GSC = c(general innovation activities)
(9)CBC = d(contingent innovation activities)

where GSC measures the amount of shift that can be generated with a given amount of innovation activity necessary to introduce general technological changes. CBC measures the amount of bias that can be generated with a given amount of resources dedicated to innovation in order to introduce contingent technological change [11].

Assuming that it is possible to consider a frontier of possible adjustments, such that, for a given amount of resources necessary to correct a mismatch, firms can generate either technical (tc) of technological change (TC). Integral to the frontier of possible adjustments there is a frontier of possible innovations that can be obtained through the introduction of either general technologies (GSC) or new contingent technologies (CBC).

Formally this means that:

(10) tc = e(TC)

(11) GSC = f (CBC)

So as to make standard optimization procedures operational, two isorevenue functions need to be set. The first is defined as the revenue derived from adjustments (RA) and compares the revenue that adjustments involving switching within the technical area yield (SW), with the revenue of innovation (RI). The second isorevenue compares the revenue generated by the introduction of general technological change with the revenues generated by the introduction of contingent technological change. Formally, they are presented as:

(12) RA = s SW + t RI

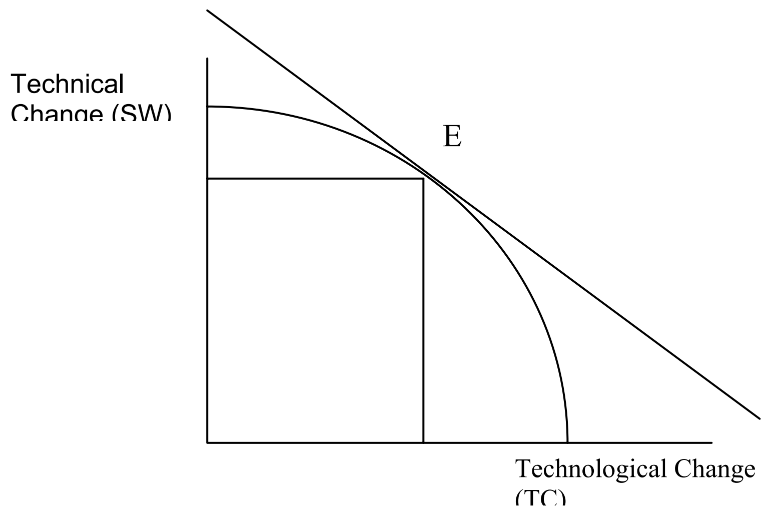
(13) RI = r GSC + z CBC

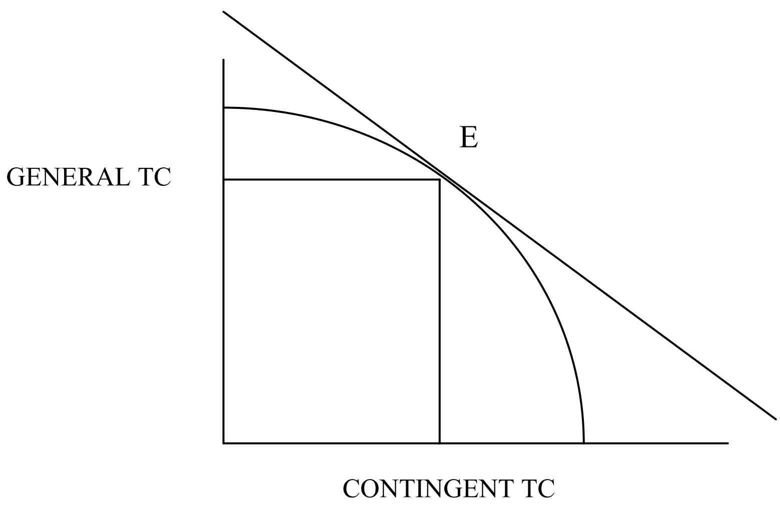
[11] The metrics of technological change is defined in terms of rates of overall factor productivity, while the metrics of technical change is provided by equation (6).

where s and t measure the unit revenue derived from switching and the unit revenue derived from innovation; r and z measure respectively the unit revenue derived from the amount of general and contingent technological change generated by the given amount of resources available for innovation and induced by the new, unexpected conditions in the product and factor markets (See diagram 2).

INSERT DIAGRAM 2 ABOUT HERE

DIAGRAM 2: THE NESTED FRONTIERS OF POSSIBLE ADJUSTMENTS AND SHIFT/BIAS TECHNOLOGICAL CHANGE





According to the analysis carried out in section 5.1, the slope of the innovation isorevenue is steep: introducing general technology yields far larger benefits than introducing contingent technologies. The slope of the frontier of possible innovations on the other hand reflects the large differences in the costs of introducing general technology compared with the low costs of introducing contingent technological innovation.

The system of equations can be solved with the standard tangency solutions so as to define both the mix of contingent and general technological change which firms are advised to select and the amount of innovation involved in switching, a solution they may prefer to adopt. The system of equilibrium conditions in fact is:

$$
(14) \quad \begin{cases} e'(TC) = t/s \\ f'(CBC) = z/r \end{cases}
$$

subject to[12] $TC = GSC + CBC$

$RI = rGSC + zCBC$

The cases of either only technical change or only technological change and alternatively perfectly general technological change, based upon pure shift effects, or purely contingent technological change, based upon a pure bias, seem extreme solutions. Much of the real world can be found between such extremes: technological change includes both a shift and a bias effect. The direction of technological change is influenced by the relative profitability of introducing general technological change with respect to contingent technological innovation and the relative costs of introduction all play a key role.

The correct direction of the new technologies being introduced is the result of two different but complementary processes. From an ex-ante point of view, myopic, but creative firms, select technological change which involves both a shift and a bias, which if mixed properly are the most appropriate to the specific conditions found in the marketplace both in terms of the profitability of introducing innovation and the relative cost of introducing them. This includes the levels of

[12] When the case for output maximization or cost minimization applies respectively

switching costs. From an ex-post point of view, firms which happen to have introduced a technological change along the correct direction have a greater chance of surviving. Firms, which introduce innovations with the wrong bias, are likely to be eliminated by a Darwin selection mechanism activated in the product market place by the rivalry among firms.

5.3 Applications and implications

The approach developed so far clearly belongs to the class of models of induced technological change. The inducement hypothesis develops the assumption that firms generate new technologies when factor costs change. Firms can react to disequilibrium in factor markets not only by adjusting quantities to prices and viceversa, but also, and mainly, by means of the generation, introduction and adoption of new technologies. Hence the primary inducement to introduce innovation is the disequilibrium in market place. This is a Marxian legacy, much developed and enriched by the economics of localized technological change. The levels of relative prices and specifically composition effects however have a strong inducement effect on the direction of the new technologies being introduced. The changes in relative factor prices induce the rate of technological change, because of irreversibility and limited knowledge, while the levels of relative prices induce the direction of technological change because of composition effects[13].

In the approach developed in this paper, in fact, any increase in wages (as well as in rental costs) induces the generation of new technology, because of the disequilibrium effects of irreversibility of the factors of production and related switching costs. Standard technical adjustment is inhibited by the costs of switching in the existing area of techniques. The introduction of new technology becomes a viable alternative to loss-making resilience. Here the 'Hicksian' inducement to the rate is relevant. The inducement to the rate of introduction of technological innovation, however, is separated from the inducement regarding the direction of the technological change. An increase in

[13] Paul David long ago suggested that the de-coupling of the inducement to innovate from the inducement of the direction of technological change was a fertile area of investigation. Little work however has been done along these lines since then. See David: ‘As soon as one is ready to discard the neoclassical conception of technological progress which insists that innovation and factor substitution be viewed as logically distinct phenomena, there is no longer any great difficulty in taking an important step toward this proximate objective. Specifically it becomes possible to indicate how the realized factor-saving bias of ‘changes in the state of technical arts’ may come under the influence of factor-prices-directly, as well as indirectly through the medium of choice of technique decisions. In regard to the latter, we may for the present purposes eschew less orthodox ‘behavioral’ approaches to the decision making of firms; the prevailing structure of input prices will therefore continue to be cast in the governing role assigned to them by the traditional theory of rational, cost-minimizing firm’ (David, 1975:57-58; see Antonelli, 1989 and 1990 for an exploratory attempt to develop this point).

wages in a labor abundant country with a large supply of labor and hence low wages, in fact, should not induce the introduction of a labor saving technology, but rather of a labor intensive one, because of the powerful composition effects. The Kennedy-Samuelson inducement is relevant here. The inducement regarding the direction can be different from what is expected in traditional microeconomic inducement models.

The identification of two well distinct inducement mechanisms: the inducement to the introduction of technological innovation and the inducement regarding the direction of new technology is relevant on two counts. First it provides a more articulated explanation of the increased substitution effect engendered by the introduction of new biased technologies. Second, it corrects a basic inconsistency in the basic inducement hypothesis applied to factor markets where the prices of inputs differ sharply and the initial conditions of the production function are asymmetric. Let us analyze them in turn.

Distinguishing between the inducement mechanisms seems appropriate to provide a sensible answer to the well-known critique Salter (1960) raised to the inducement hypothesis developed along the lines set out by Hicks (1932). Salter (1960) noted that firms should be equally eager to reduce the use of capital and labor irrespective of a recent increase in the unit costs of either factor. The basic aim of the firm in fact is to reduce total costs. The approach developed here takes this argument into account. When relative prices change, firms are drawn into disequilibrium. Firms can either react by changing their technology or their technique. Irreversibility and switching costs however induce firms to change their technology, and composition effects induce the direction of the new technologies. In order to increase output levels and reduce average costs firms will introduce and adopt the new technology, which uses the relatively cheaper factor, more intensively. This direction-inducement mechanism is activated by the levels of relative prices rather than by their changes. All changes in relative prices induce firms to innovate.

The distinction between the inducement to innovate set off by changes in factor markets, and the inducement to select a factor intensity for the new technology, seems to be capable of bringing together the different strands of the inducement hypothesis and providing a broader and coherent context into which they are complementary rather than alternative (Ruttan, 1997 and 2001)[14].

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[14] Strong assumptions about the full rationality and foresight of firms are not necessary. Myopic, but reactive and creative, firms, can innovate in a variety of directions. Only the new technology, which makes the best use of locally abundant production factors, will be chosen in the product markets. Rivalry in product markets can be considered a

When composition effects are taken into account, the basic inducement hypothesis according to which an increase in the unit cost of a factor (wage) should induce a specific factor saving (labor saving) is no longer applicable. An increase in wages in a labor abundant country might induce the successful introduction of a labor saving technology only if there is also a strong shift effect. In such a country in fact even if wages have just increased it still seems sensible to introduce labor intensive technologies which take advantage of the low relative cost of labor. The basic hypothesis, as formulated by Hicks, can apply only in a symmetric and single system where both output elasticities and relative input costs are equal. The distinction between the inducement to innovate, due to all changes in relative factor costs, and the inducement to direct the bias of the new technology, as dictated by the composition effects, however provides the inducement hypothesis a broader and more articulated context of application.

The framework developed so far provides a microeconomic tool with which to understand the role of relative prices as determinants of the direction of technological change at the level of the system. The hypothesis that technology is not exogenous, but is the result of the specific market conditions in which agents operate and reflects the historic process in which the markets interact, has been repeatedly put forward to explain the direction of technological change at the level of the system.

Habakkuk (1962) developed the hypothesis that American technology was different from that in Britain because of the differences in the two countries' factor endowments. A substantial scarcity of unskilled labor and relatively abundant natural resources and skilled labor characterizes the American economy. Abundant unskilled labor and the institutional and geographic scarcity of land and natural resources instead characterizes the British economy. According to Habakkuk, this difference does not lead only to the obvious variety of factor intensities in the two countries, but also, and most importantly to diverse paths of technological change. American technology is intrinsically biased in a labor-saving direction, while in Britain it is directed more towards capital-saving. David (1975) has developed this line of analysis further suggesting that economic systems are better able to move along technological paths that lead them to enhance their technology by following and deepening the original bias.

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reliable selection mechanism -a Schumpeterian Darwinism-, which is able to choose ex-post the correct direction of technological change.

This argument, originally put forward by Habakkuk and David, has been questioned and has been subject to a systematic analysis assuming that each system is able to introduce new technologies, which are locally progressive and are restricted to a range of techniques, defined by factor intensities, which reflect the relative scarcity of the factors of production (Antonelli, 1995, 1999 and 2001).

This approach assumes technology to be endogenous and its direction is strongly path-dependent. According to this line of analysis technological efficiency is very much dependent on the specific context of the application. Each technology and the related bundle of techniques, defined in terms of factor intensity, is appropriate to a set of idiosyncratic market conditions. The model developed so far provides an interpretative framework which helps us to understand the dynamics of technological change on a comparative and historical basis.

According to Broadberry (1997:5) in his impressive reassessment of the long term British performance in manufacturing productivity in an international context "the fact that accumulation of physical capital and human capital takes place around specific techniques helps to ensure that initial differences in factor proportions are preserved through time" and with them differences among countries in terms of comparative productivity ratios. Countries which are able to introduce a general technological change characterized by a wide range of applications, which have such a major shift effect that no alternative technology can survive, can become leaders in the global economy. All the other countries will be forced to adopt the new technology but will have lower rates of overall factor productivity growth and hence higher production costs. Their shares of international markets will decline as well as the opportunities for profitability and growth. In such conditions late-comers can only try and rely upon creative adoption. The new general technology provides the opportunity to introduce an array of contingent technological changes, which are aimed at adapting the new technology to the local endowments and hence to the local factor prices[15].

Firms which are active in factor markets which are radically different from those where the new neutral technology was initially introduced can take advantage of contingent technological strategies

[15] See Broadberry (1997:89): "During the period of American technological leadership during much of the twentieth century, successful technical development in Britain and Germany required adapting American methods to local circumstances, making use of abundant skilled shopfloor labour and customising output to meet heterogeneous demands. British and German 'flexible production' technology thus developed in different ways to American 'mass production' technology, despite the fact that al countries had access to the same pool of knowledge. Since technical change is a path dependent process and success requires the development of distinctive capabilities, there are clearly problems when a 'macro invention' in one country undermines the viability of a technology in another country. Slavish copying is unlikely to be a viable response, given different local circumstances."

and direct funds, available for intentional learning and research activities, towards the introduction of new technologies which build upon the shift already introduced. Thus, they are mainly directed towards a change in the relative composition of the productive inputs.

At the other extreme there are the firms which operate in innovation systems characterized by a complex scientific infrastructure. This means there are headquarters of large corporations, which have a well-established academic tradition, guaranteeing high levels of research and development expenditure and organizational structures, which can select and direct the results of R&D activities. Further, the financial markets are effective and are able to give a value to intangible assets and direct financial resources towards new high-tech start-ups (Freeman, 1987). Such corporations already operate close to the technological frontier of production functions, which already make the best use of the local endowments and show high levels of output elasticity for locally abundant production factors. These firms can develop technological strategies that are aimed at introducing actual shifts in the map of isoquants. They lead to the introduction of new technologies that are locally neutral. If they are introduced in other countries there will be major asymmetric effects for the adopters while the innovations will provide additional benefits in terms of barriers to entry and to imitation. Such barriers will be based on big cost differences, and hence big mark-ups in protected demand niches

Firms based in intermediate countries have a real opportunity to choose between a more-contingent and a more-general technological change. It is clear that introducing a new general purpose technology which has the most convenient specific mix of output elasticities for the local endowments is more profitable than introducing contingent technology which improves the local efficiency of a new general purpose technology introduced elsewhere. The relative cost of introducing a radical shift-technology and not a bias-technology is a crucial factor which affects the choice firms in intermediate countries make.

Access to scientific knowledge, both codified and tacit, play a major role. When and if the academic and scientific infrastructure is in place and appropriate incentives are at work, technological communication between research centers and the business community is also effective. Further, if and when the general institutional conditions for the acquisition and use of new knowledge, especially in terms of intellectual property rights, and large scientific opportunities are available, firms may be better able to direct their research strategies towards the introduction of more general technology. Similarly, the availability of technological districts and local clusters of firms specializing in complementary research and innovation activities may help such choices.

Important technological opportunities offered by the spread of new general technology, which is biased, at least for local adopters, offers them important incentives to direct research strategies towards the introduction of more contingent technologies. The conditions of access to external knowledge possessed by the providers of the new technology are very important here. This is because interaction between user-producers means that tacit knowledge can be shared. Effective protection of intellectual property rights in the global economy can prevent new general technological knowledge from being adopted, and so delay the introduction of contingent technologies in other countries. All incentives which make the transfer of technological know-how faster, may reduce such risks, as long as intellectual property rights are sufficiently protected.

The characteristics of technological knowledge and of its generation process play a key role in this context. When high levels of fungibility characterize technological knowledge the introduction of contingent technological changes, focussing primarily bias effects, is favoured. The introduction of new biased technologies can draw on a wide range of technological applications and the intrinsic versatility of the new knowledge. Instead, when technological knowledge is cumulative, the generation of new knowledge and eventually the introduction of new technology is based primarily upon the accumulation of competence and experience gained in previous vintages of the same knowledge. It is more likely that the introduction of general technological change with no bias effects and which is strictly neutral, at least locally, will be favoured.

The third relevant parameter is provided by the specific conditions of the factor markets. In regions and industries where the difference in factor prices is so close that the ratio of relative prices is near to unity, resulting in the slope of the isocost and the former technology being represented as a symmetric production function. The incentive to introduce contingent technology clearly is very low. In such regions a firm's research strategy is of necessity directed towards introducing technology which does not change factor intensity and is mainly based on a neutral shift. In the opposite case, in regions where the supply of a specific input is abundant and its derived demand is very low, there is a unique set of opportunities to direct research strategies towards introducing contingent technology.

Similarly in regions where the market prices of the factors of production are very elastic to all increases in demand, firms are likely to direct their innovation strategies towards introducing neutral technology. This means that a research strategy directed mainly towards introducing and adopting contingent technology can be valid as long as firms are active in regions where the current factor intensity is significantly different from that in the countries where shift technologies have been introduced. The difference in relative prices between countries is a prime factor in determining what kind of innovation strategies is chosen.

The levels and duration of transient monopolistic extraprofits due to barriers to entry and imitation for potential adopters influence the choice and introduction of general technologies. It is clear that the larger, the diffusion lag is, and the larger, the cost differences among innovators and imitators are, then the higher, the incentive to introduce general technology is. The long-term shape of the supply schedule for production factors is also important in this context. The profitability of introducing contingent technological changes can be severely reduced by the rigid supply of the most productive factors and hence there is a sharp increase in relative costs because of the introduction of new technology. Barriers to entry and exit in upstream sectors may change the relative profitability of both introducing and adopting new contingent technology. In general it seems clear that industrial dynamics and market structures play a major role in determining how profitable it is to introduce either of the technologies[16].

The analysis of the effects of local factor markets on the actual productivity of new technologies and the ranking of the profitability of adoption in terms of the matching between the bias of the technology and the relative abundance of the most productive factor in each local factor market provides multinational corporations with a unique opportunity to take advantage of the localized fitness of innovations (Cantwell and Iammarino, 2003).

6. Conclusions

The economics of technological change have been developed in the context of a static and single factor market. The production function is the only tool to describe a standard analysis of technologies. In the traditional analysis of the economics of technical change, the introduction of

[16] The social construction of a technology does in fact take place but it is the lengthy result of the interplay between the rate and the direction of technological change shaped by such a process of selective innovation and diffusion (Bijker, 1987).

technological change is presented as an act of substituting an old technical area with a new one. A new map of isoquants is associated with a new technology. Introducing a new map of isoquants has two consequences: first it may, at given factor prices, set off a substitution process, including the factors of production; second it enables the levels of output for given levels of inputs to be increased.

The substitution of the old map of isoquants with the old one is analysed in a single and static context. A situation in which the heterogeneity of factor markets and production functions at work in a global economy are not taken into account and where there is no change in the relative prices of the factors of production. Moreover, possible overlapping between the old map and the new map is not considered. The analysis is concentrated on the narrow area of techniques defined in the maps of isoquants representing the previous equilibrium, as determined by the tangency between the isocost and the relevant isoquant.

The inducement approach has split analysis into two strands: the microeconomic model stresses the role changes in factor prices play as the basic inducement, which determines the rate of technological change. The macroeconomic model focuses attention on the levels of factor shares and hence on relative factor prices as the mechanism that induces the direction of technological change at the aggregate level. The economics of localized technological change helps to reconcile and integrate the two approaches.

Much of the current analysis of the effects and determinants of each new wave of technological change does not seem to provide a systematic understanding of the static and dynamic role of the structural characteristics of the economic system into which the new technologies are being introduced. More generally, too much attention has been paid to assessing what effects and what determines the rates of technological change. Instead, there has been too little analysis of what determines and effects the direction of technological change. Even less attention has been paid to the interaction between the rate and the direction of technological change in a dynamic and complex context, a situation in which factor costs are allowed to change in time and in area.

Composition effects, the actual levels of the measured overall factor productivity of each technology depend on the specific system of relative prices in each factor market. Composition effects determine the consequences of introducing technological change in each regional system, and are characterized by the specific system of relative factor prices in two ways.

The contribution of the economics of localized technological change is very important here. Irreversibility and limited knowledge engender switching costs that limit the mobility of firms within the area of existing techniques. All changes in input costs, in this context, set off a clear inducement to introduce technological innovation. Firms in each region, induced to innovate, will introduce the technology, which best fits in with the specific conditions of the factor markets. Relative factor prices become a selection mechanism, which makes it possible to choose technology. Over time firms based in one region will make consistent choices and select technologies shaped by similar factor bias. Hence, composition effects can be endogenized by potential innovators who direct their technological efforts towards introducing technology which is biased in such a way as to make the best and most productive use of the production factors which are most easily available. Thus, they have the lowest prices in each specific region. At a general level, there is technological variety across regions in both cases. This is because the bias in the adoption and the bias in the generation of new technology leads to choosing the mix which is the most appropriate to the specific factor markets in each region.

Such a bias in the direction of technological change can be thought of as being due to the intentional ex-ante decision of innovators who are well aware of the relative scarcity of inputs in their own region. Innovative firms, for a given cost of an innovation, will find it more profitable to introduce new technology which makes a more intensive use of the locally most abundant factor. The bias in the direction of technological change can also be determined ex-post by a selection process among innovators. Those firms, which happened to have introduced the technologies, which use the locally most abundant production factor most intensively, would emerge as the winners of the selection process. Replicator dynamics would force the 'wrong' innovators out of the market and would favor the 'correct' innovators who would rapidly increase their market share.

The direction of technological change in terms of the specific form of its bias sequentially introduced and adopted reflects the specific conditions of local factor markets. In the long term well-defined technological paths emerge in each region as the result of the selection process in the global product markets. The more rigid and idiosyncratic, the endowment and the system of relative prices are; the more specific, the technological path of each region is likely to be.

The direction of the technological path may change as each economic system is exposed to international competition. After a new radical and general technology has been introduced, in fact, the search, in each country, for appropriate technologies may lead to the introduction of new contingent technologies, that is to say, the production function is reshaped.

In any event, the introduction of new technology is clearly the result of an out-of-equilibrium situation, which forces the firm to innovate. In fact, firms will innovate if a number of key systemic conditions exist. Such a situation can provide a unique opportunity to bring together results of the economics of innovation which is more interested in assessing the rate at which innovation is introduced and analysing the characteristics of new products and new processes and merging them into an analytical framework which develops the role of factor intensities and output elasticities. The basic common thread and the unifying element in the above analysis is the out-of-equilibrium approach which is a distinctive element of the economics of innovation.

REFERENCES

Abramovitz, M. (1956), Resources and output trends in the US since 1870, *American Economic Review* 46, 5-23

Abramovitz, M. (1989), *Thinking about growth*. Cambridge, Cambridge University Press.

Acemoglu, D. (1998), Why do new technologies complement skills? Directed technical change and inequality, *Quarterly Journal of Economics* 113, 1055-1089.

Amendola, M. (1976), *Macchine produttività e progresso tecnico*, Milano, ISEDI.

Antonelli, C. (1989), A failure inducement model of research and development expenditure: Italian evidence from the early 1980's, *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. (1995), *The economics of localized technological change and industrial dynamics,* Boston, Kluwer.

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

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

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

Asimakopulos, A. and Weldon, J.C. (1963), The classification of technical progress in models of economic growth, *Economica* 30, 372-386.

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

Besomi, D. (1999), Harrod on the classification of technological progress. The origin of a wild-goose chase, *BNL Quarterly Review* 208, 95-118.

Binswanger, H.P. and Ruttan, V.W., (1978), *Induced innovation*: *Technology institutions and development*, Baltimore, Johns Hopkins University Press.

Bijker, W. E. et al. (eds.) (1987), *The social construction of technological systems,* Cambridge, The MIT Press.

Blaug, M. (1963), A survey of the theory of process-innovations, *Economica* 30, 13-32.

Bresnahan, T. F., Traitenberg, M. (1995), General purpose technologies: 'Engines of growth'? *Journal of Econometrics* 65, 83-108.

Broadberry, S. (1997),*The productivity race. British manufacturing in international perspective, 1850-1990*, Cambridge, Cambridge University Press.

Brown, M. (1966), *On the theory and measurement of technological change*, Cambridge, Cambridge University Press.

Cantwell, J. And Iammarino, S. (2003*, Multinational corporations and European regional systems of innovation*, London, Routledge.

Cyert, R. M. and March, J.C. (1963), *A behavioral theory of the firm*, Englewood Cliffs, Prentice-Hall.

David, P.A. (1975), *Technical choice innovation and economic growth*, Cambridge, Cambridge University Press,

Freeman, C. (1987), *Technology policy and economic performance*, London, Pinter Publishers.

Freeman, C. (1994), The economics of technical change, *Cambridge Journal of Economics* 18, 463-514.

Habakkuk, H.J. (1962), *American and British technology in the nineteenth century,* Cambridge, Cambridge University Press.

Helpman, E. (ed.)(1998), *General purpose technologies and economic growth,* Cambridge, The MIT Press.

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

Hicks, J.R. (1976), Time in Economics, in Tang, A.M., *Evolution welfare and time in economics*. Quotes are drawn from Hicks, J.R. *Collected essays on economic theory*, Volume II, Oxford, Basil Blackwell.

Mokyr, J. (1990), *The lever of riches. Technological creativity and economic progress,* Oxford, Oxford University Press.

Robinson, J. (1937), The classification of inventions, *Review of Economic Studies* 6: 139-142.

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.

Samuelson, P. (1965), A theory of induced innovation along Kennedy, Weiszacker lines, *Review of Economics and Statistics* 47, 343-56.

Solow, R. M. (1957), Technical change and the aggregate production function, *Review of Economics and Statistics* 39, 312-320.