THE ECONOMICS OF INNOVATION

NEW TECHNOLOGIES AND

STRUCTURAL CHANGE

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IV. COMPOSITION EFFECTS: THE DIRECTION OF TECHNOLOGICAL CHANGE AND ITS CONTEXT OF INTRODUCTION

Introduction

Much attention has been deserved in the economics of innovation to the rate of technological change. Much less analysis has been focused upon the direction of the new technologies being introduced and to the structural characteristics of the economic systems into which the new technologies are being introduced. As a matter of fact the direction and the rate of technological change interact in many ways with the context of introduction and its evolution and affect in depth the actual effects of technological change. Section 2 of this chapter elaborates the analysis of composition effects. Section 3 considers the effects of the direction of technological change in heterogeneous factors markets. Section 4 considers the effects of changes in relative factors prices on average production costs with a given technology. The conclusions summarize the results and pave the way to further analysis.

2. Composition effects

Composition effects have major implications for the analysis of technological change across different industries and countries because of the strong effects of relative factors prices on the actual 'measured' total factor productivity growth of each country. The static and dynamic interactions between types of changes in technology and levels and changes of the relative price of production factors are relevant. Let us consider some cases.

Let us first consider a capital intensive production function. A neutral technological change has been introduced and the general efficiency of the production process has increased. At the same time however capital rental costs also have increased and wages declined. These two changes have conflicting effects. The increase of the general efficiency should lead to an increase of the output, for given levels of inputs. The increase in relative capital rental costs leads however to a reduction in the actual capital efficiency and hence in output which can perfectly compensate the increase in the general efficiency.

Specifically we see that, for a given level of increase in the general efficiency, the larger is the productivity of capital in the production function and the stronger are the composition effects associated to a given generalized increase in relative capital rental costs, and the lower the total factor productivity effects, as perceived with the current methodologies. For two countries, using two technologies, exposed to the same increase in relative capital rental costs and in the general efficiency of the production function, the measured increase of total factor productivity, as estimated with the Abramovitz-Solow procedure, will be larger in the country with the lower levels of capital productivity.

Similar asymmetric events take place when relative wages increase. An increase in the general efficiency of the production function is now augmented by the increase in the wage to rental ratio and hence by the reduction of the use of less productive labor and the increase in the use of more productive capital. Again the more capital intensive is the production function and the stronger are the effects of the same increase in the wage levels.

The picture becomes even more complicated when non-neutral technological change is accounted for. Let us assume that a smooth incremental technological change with labor-saving and hence capital using features is introduced in a region where wages are low and capital rental costs very high. The composition effects in terms of the increase of the general efficiency are very important here. They can be much stronger than a radical and biased technological change which is characterized by a major shift in the general efficiency parameter, but 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 previous one, although in general terms it should be regarded as a more performing one. It is clear here that the performance of technologies is highly contingent upon their bias and the relative costs of production factors.

When technological change is biased, the context of introduction plays a key role 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 a production factor, the effects in terms of productivity growth will be stronger, the more abundant and hence less expensive the production factor. This dynamics has major effects, in terms of emerging asymmetries among firms in the global competitive arena.

When the scope of introduction of a new technology is global and the global economy is heterogeneous, it cannot be neutral everywhere. Only technological changes, characterized by a bias, consistent with the structure of local endowments, can reinforce technological variety in international markets where the relative prices of inputs differ because of local factor markets differences. The global introduction of a new radical and biased technology on the opposite can reduce technological variety with negative consequences on the structure of comparative advantages and hence on the distribution of the gains from trade in the global economy

The introduction of a global and hence necessarily biased technological change has powerful effects in terms of new asymmetries among potential adopters. When a new technology is biased, the increase in efficiency takes place only a limited space of the map of techniques. In these conditions the new and the old technology are likely to intersect. Before intersection, in absolute terms, the new technology is superior to the old technology and vice versa after intersection. According to their relative factors prices, some countries will be able to benefit more than others, from the introduction of the same technology. Actually some countries would not be able to benefit at all: the old technology is still better than the new one.

Such asymmetric effects are reinforced and amplified by the dynamics of relative prices. When, with a given biased technology, relative factors prices, as distinct from absolute factors costs levels, change, output per unit of output and hence average costs also change. Specifically all reductions in the costs of the most productive factor have direct effects in terms of a reduction of the production costs and an increase of output per unit of input. Such changes in production costs, have not effects on total factor productivity measures, but in any event, do have powerful consequences upon the competitive advantage on global markets of rival firms based in heterogeneous factors markets.

Specifically we see that with a capital intensive technology in place all reductions in the relative costs of capital, even if compensated by an increase in wages, increase output levels. Similarly when a labor intensive technology is place a reduction in the relative cost of labor engenders an increase in output per unit of input, even if purchasing power is held constant. On the opposite all increase in the relative costs of capital, with a capital intensive technology in place, lead to a reduction in output. This is also the case when an increase in the relative levels of wages takes place with a labor intensive technology in place.

The analysis of the dynamic and synchronic interactions between factor endowments, relative factors prices and the rate and the direction of technological change are complex enough to deserve two distinct approaches. In the following section the effects of the direction of technological change upon heterogeneous factors markets are considered. The following section analyses the effects of changes in relative prices, holding constant the technology.

3. Relative factors prices, the direction of technological change and productivity growth

The analysis of composition effects has a strong and direct relevance in a synchronic context where a variety of factor markets across countries and regions is accounted for. A new and radical capital saving technology will have stronger positive effects in a labor abundant region with low wages. This explains why this technology will diffuse faster in such regions. The incremental labor saving technology will have stronger positive effects and diffuse faster in a capital abundant region with low relative capital rental costs.

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

A brief formal analysis can help and make the point clearer[1]. Formally we can see two different standard Cobb-Douglas production functions i and j with constant returns to scale. The latter has a larger total factor productivity level but lower output elasticity of labor:

[1]The analysis will consider a simple two basic factors production function for the sake of clarity.

(1) $Y_i = A_1 f(K^a \ L^{1-a})$

(2) $Y_j = A_2 f(K^b \ L^{1-b})$

the assumptions are

(3) $Y_i = Y_j$

(4) $b > a$

(5) $A_2 > A_1$

When assumptions (3), (4) and (5) hold, it can be shown that the isoquants of the technologies i and j overlap, so that Y_i and Y_i
intersect for:

(6) $K / L = (A_1 / A_2)^{1/b-a}$

In fact:

(7) $Y_i / L = A_1 \ K^a \ L^{1-a} / L$

(8) $Y_j / L = A_2 \ K^b \ L^{1-b} / L$

(9) $Y_i / L = A_1 \ (K/L)^a$

(10) $Y_j / L = A_2 \ (K/L)^b$

(11) $A_2 / A_1 \ (K/L)^b / (K/L)^a = 1$

(12) $A_2 / A_1 \ (K/L)^{b-a} = 1$

When the two technologies i and j are in such a relation, it is clear that the bias-effect interacts with the shift-effect. A non-neutral technology superior in terms of shift effects can be inferior because of the bias effect. The context of introduction matters in terms of the local structure of endowments and hence relative prices.

Equation (12) suggests that the overlapping cannot take place only when technological change is Hicks-neutral. It clearly makes a major difference however whether the overlapping takes place in marginal regions of the new meta-map of isoquants or instead it affects the central regions. Central regions, with respect to map of isoquants, are clearly those where realistic values of the ratio of wages to capital rental costs are represented. In central regions actual relevant choices are made and hence relevant actual economic behaviors are likely to take place: when the conditions stated in equation (12) apply in central regions of the meta-map of isoquants, technological change can be defined as contingent and hence both locally regressive and locally progressive[2].

In such conditions the economic analysis of the effects of small differences in relative prices of production factors can yield important insights on the differentiated consequences of the introduction of the same technology across countries and regions. For the same token it is also true that the same small changes in relative prices can have major consequences in terms of production costs in two countries using two different technologies (see the following paragraph).

Equation (12) is important because it makes clear that the larger is the shift and the more peripheral are the overlapping regions. This confirms that the more relevant is the absolute increase of total factor productivity levels and the wider the scope of instantaneous adoption and hence the smaller the levels of technological variety. Only agents active in extreme factor markets could repeal the adoption of such technologies.

Equation (12) provides the basic discriminator to assess whether a new technology is general or contingent. A technology is contingent, the smaller is the extent of the neutral shift and the larger are the regions where the old technology deserves rational adoption. Hence the smaller is the neutral shift and the larger is the scope for technological variety, for given levels of variance in factors markets conditions across regions and industries.

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2 The distinction between contingent technological change and biased technological change becomes clear here. A technological change is contingent when it is biased and moreover it is characterized by a (small) shift such that it engenders a total factor productivity growth only within a limited range of possible relative prices of production factors. Conversely, a technological change is not contingent when either it is neutral, or it combines both a strong shift effect and a small bias. In any case a technological change is general when its application, in all possible regional factors markets, is likely to engender an actual increase in total factor productivity levels.

INSERT TABLES 1 AND 2 ABOUT HERE

Table 1 shows clearly that the relative distances AA' and BB' on the respective isoclines between the equivalent isoquants extracted from the two technologies are equal. Table 2 instead shows that the distance AA' is relatively larger than the distance BB': technological change is more effective in the upper region than in the lower one. It is important to stress here that the distance BB' is actually negative while the distance AA' is positive. This is the basic difference with respect to the traditional analysis about factor intensity developed in the economics of technical change. The traditional definition of factor intensity in fact has been elaborated with respect to a single system of relative prices, that is with respect to a given and single isocline. When the analysis takes into account the full metamap of new and old isoquants the coexistence of negative and positive distances emerge as a necessary condition. Actually in table 3 the two equivalent isoquants eventually intersect.

In this context the specific characteristics of local factors markets play a major role. Because the isoquants of the different technologies overlap, it is always possible to find a specific isocost which is tangent to equivalent isoquants which belong to two different technologies. Formally in fact we see that:

(13) $W^*/ R^*=dY_1/L^{1-a}/dY_1/dK^a = dY_2/L^{1-b}/dY_2/dK^b$

For all isocosts slopes that are smaller than W*/R* technology 1 will be superior to technology 2 and viceversa. A large set of techniques, which belong to both technologies and are comprised between the two extreme values, on the opposite will not be put in use.

It is now clear that a small change in relative factors prices can have major implications. Firms which rationally resisted the adoption of technology 2 will suddenly find it profitable with major consequences in terms of performances and demand for production factors. Technology 1 is actually more productive not only before the intersection with the equivalent isoquant of technology 1 but before the tangency with the dividing isocost W*/R*.

It seems now clear that a biased technological change can affect different industries within different regions with different effects. The larger is the variance in factors markets and the larger is the scope for technological variety. For a given new technology which makes an intensive use of a production factor, industries and firms within industries located in regions where the new most productive factor is abundant are likely to be better off than industries and firms located in regions where the new most productive factor is scarce. Their total factor productivity is now ranked according to the relationship between the output elasticity of the production factors and the ratio of the relative costs of production factors.

Composition effect shape total efficiency levels synchronically and also, -and worst from an analytical viewpoint- diachronically. Technology 1 can rank better than technology 2, in a given country and for a given system of relative prices. When the latter change however the technological ranking may be reverted and the inferior technology 2 actually becomes better and vice versa. A strong case for technological variety emerges.

In a static context it is clear that for any given technology there would be a 'best' system of relative prices and relative endowment of production factors. Specifically for a labor intensive technology, a labor abundant region would be the 'best' factor market. Conversely for a given endowment and system of relative prices, there is a 'best technology'. For a capital abundant region a capital intensive technology would clearly be the best one.

INSERT TABLE 3 ABOUT HERE

The analysis becomes much more complex when a dynamic context is taken into account: one where both technologies and relative prices change. A new understanding of the notion of technological change emerges from this line of enquiry. It is now important to distinguish between 'contingent technological changes' and 'general technological changes'. The former consist in the introduction of a bias in the use of production factors, that is in changes in the shape of the technology without any shift, i.e. without changes in potential total factor productivity levels.

The combination of both movements, in the shape and in the position or level of the isoquant, that is the composition of both a shift and a bias may lead to overlapping isoquants which belong respectively to new and old technologies. A metamap of isoquants where both (all) technologies are represented becomes necessary.

The reference to a Cobb-Douglas production function here is useful. A new and actually more productive technology can be introduced without any actual increase in the parameter A which customarily measures total factor productivity levels. The technological change in this case is such that without any increase in the levels of the shift parameter an actual increase total factor productivity levels, may take place because of the new biased composition of the production function with respect to more and respectively less productive inputs.

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 the traditional increase of total factor productivity levels with no effects in terms of the composition of the marginal productivity of the production factors. Contingent technological change instead affects only the composition and the ranking of production factors in terms of their output elasticity. The effects on total factor productivity are generated by the substitution of more productive inputs to less productive ones, with no shift in the production function.

A continuum can be identified between the two extremes of neutral/general and contingent technologies. At the one extreme we find neutral and radical new technologies that are consequently both general and global. Such technologies are characterized by such an important shift effects that they rank (almost) always and everywhere higher than previous technologies in terms of efficiency. Nevertheless they may be actually more productive in some systems than in others depending upon 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 exhibit lower levels of total factor productivity. The bias in the technology engenders a strong and long-lasting asymmetric effect.

A new general and neutral technology can be stylized as a production function where only the parameter A increases and the output elasticity of each production factor is not affected. With respect to the benchmark provided by equation (14) where the old technology is stylized, we see that with the new technology, stylized in equation (15) only A changes:

$$(14)\ Y_{\mathbf{t1}} = A_1 K^{\alpha} L^{1-\alpha}$$

$$(15)\ Y_{\mathbf{t2}} = A_2 K^{\alpha} L^{1-\alpha}$$

A general technological change consists of an actual increase of absolute total factor productivity levels. This increase is so strong and radical that even when and where the most productive factors are very expensive, actual total factor productivity levels increase with respect to (almost) any previous technique. In equilibrium models diffusion of these technologies should be instantaneous with no lags in adoption rates and no substantial variance in terms of penetration rates across agents in different regions and industries.

At the other extreme we find contingent technological changes. Contingent technological changes consist of innovations which can be stylized in a production function which fits better in each specific factor market. They consist of the single bias in the direction without any shift effect, i.e. without any change in the absolute total factor productivity levels. With respect to equation (14) now the contingent technology can be stylized so that the shift parameter A is not affected and only the output elasticity of production factors change:

$$(16)\ Y_{\mathbf{t2}} = A_1 K^{\beta} L^{1-\beta}$$

Contingent technologies rank higher than previous technologies only in regions with similar local endowments: they are only locally superior.

In between the two extremes we can identify technological changes that consist of both a bias in the direction and a shift. Both make it possible to increase actual total factor productivity levels. Still with reference to the benchmark equation (14) now the new technology exhibit both a change in the shift parameter A and in the output elasticity of the production factors:

$$(17)\ Y_{\mathbf{t2}} = A_2 K^{\beta} L^{1-\beta}$$

Such technologies rank higher than previous, older technologies, only in a limited range of relative factors prices and hence only in a few factors markets. With a given system of relative prices such technologies are progressive. In other factors markets however they actually rank inferior to previous technologies. They are likely to be adopted by rational firms only in some circumstances.

It seems now useful to emphasize again an important result of this analysis: the ranking of new technologies depends upon the relative prices of production factors. Rarely can a technology be absolutely superior to any previous one. Hence technological reswitching can take place when the relative prices of production factors change. Technological reswitching is different from the classical technical reswitching. Here the ranking of technologies can be reverted by a change in the relative price of production factors. In the case of technical reswitching, the focus was rather on the ordering of techniques defined in terms of factors intensities. The actual levels of output which can be produced with a technology are influenced by the relative costs of production factors. The case of technological reswitching seems most relevant for technologies that are both characterized by a shift and a bias effect.

In the complex economic system where a variety of technologies complement the heterogeneity of endowments and local factors markets, the changes in both the technologies and the relative prices of production factors can affect the ranking of technologies. A technology which is neutral in the country of introduction in fact may reveal a strong bias in other adopting countries. From this viewpoint the distinction between shift and bias effects is blurred. The issue of technological reswitching may become relevant. Especially in a global economy.

A distinction between potential and actual productivity growth can be introduced. Potential total factor productivity growth is obtained, for each given new technology, when the most productive input has the lowest cost. Actual total factor productivity growth is the one made possible in each region with the specific conditions of the local endowments. A full range of total factor productivity levels can be generated by the introduction of a single new technology in heterogeneous regions.

The actual ranking of technologies in terms of measured levels of total factor productivity depends upon the relative prices of production factors[3]. The effects of the introduction of a new technology, stylized by a new production function with a shift effects and different output elasticities for the two basic production factors, in two regions that differ in terms of factors costs, are larger, in terms of total factor productivity growth, the larger is the output elasticity of the cheaper production factor. Hence we must conclude that both A, the standard general efficiency parameter, the output elasticity of labor and capital and relative factors prices matter in assessing the actual effects of technological change. The direction of technological change and the context of introduction are necessary components in a general assessment of technological change.

The received 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 total factor productivity levels. With that methodology it is not possible to disentangle the composition effects, as determined by all changes in the relative prices of production factors and by the introduction of contingent technologies, from the shift effects.

Following Salter (1960) and Brown (1966) instead, simple calculations make it possible to decompose the standard residual and hence the total factor productivity level into two well defined components: the effects of the introduction of general technologies and hence the shift effect, and the composition effects brought about by both the introduction of new biased technologies which change the relative output elasticity of inputs.

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

[3] See Ruttan again: "An implication is that the gains from labor-saving technical change are less in a low wage than in a high-wage economy. What happens to index number bias when non neutral technical change is combined with changing relative prices? Suppose that the factor-saving and price effects both act in the same direction as when 'labor-saving' technical change is combined with increases in the price of labor relative to capital? In this case the rise in the price of labor induces substitution of capital for labor and the technical change induces labor saving by increasing the marginal productivity of capital relative to labort. In this case the index number bias and the neutrality effect tend to be cumulative… Suppose, however, that the factor saving effect and the price effect act in the opposite direction (technical change is autonomous). The rise in the price of labor causes substitution of capital for labor. But the technical change bias increases the marginal productivity of labor relative to capital. In this case, if the technical change is sufficiently nonneutral, the 'true' measure of technical change could fall outside of the index number 'brackets '. " (Ruttan, 2001: 57-58)

of inputs and the old output elasticities and, second, its comparison with the actual one. The difference is then attributed to the introduction of new technologies at large.

The complementary methodology, aimed at decomposing 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 factors 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 start again, with two simple production functions respectively at time t1 and t2. In the time interval a new technology has been introduced with both shift and bias effects, moreover, relative prices have changed. Specifically we that: the shift parameter has increased from $A_1= 1$ to $A_2=2$. The output elasticity of capital at time 1 was $\alpha = 0.25$ and it is at time t2 a= 0.75.

(18) $Y_{\mathbf{t1}} = A_1 K^{\alpha} L^{\beta}$ for $\alpha = 0.25$

(19) $Y_{\mathbf{t2}} = A_2 K^{a} L^{b}$ for $a = 0.75$

The Abramovitz (A) residual is calculated as follows:

(20) A-RESIDUAL = dY – (dY/dK) dK - (dY/dL) dL

The shift residual (S) can now be calculated as the difference between the actual output and the estimated output expected when using the levels of inputs and the new output elasticities. Formally the calculation is as follows:

(21) S-RESIDUAL = Y_{t2} - ($K^{0.75}$ $L^{0.25}$)

In equation (21) the second term cannot include the effects of the changes in the shift parameter which are unknown. The output elasticities instead, with standard assumption about equilibrium conditions, can be derived from the share of production factors on income. The new levels of capital and labor are also drawn from the actual evidence.

The S-residual measures all the substitution effects, that is both the effects of changes in the relative prices of production factors and the effects of the introduction of biased technological changes which modify the relative productivity of inputs.

The difference between the A-residual and the S-residual can be termed C-residual, i.e. the composition residual which provides an indicator of the joint effects of the changes in the relative prices and in the output elasticities and measures in a synthetic way the effects of the changes in the composition and relative efficiency of the production factors:

(22) C-RESIDUAL = A-RESIDUAL – S-RESIDUAL

It is important to note that the C-Residual may be negative as well as positive. A negative C-Residual takes place when a new general technology with a strong shift effect is introduced in a country although the factor intensities are at odds with the local conditions of factors markets. When the C-Residual 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 make a more intensive use of the locally abundant inputs and hence save some locally scarce and costly inputs, may be very productive.

4. Relative factors prices and average production costs

Relative factors prices have a direct effects on production costs and output levels. When the technology in place is biased, production costs do reflect the structure of relative prices. Comparative advantage among regions with heterogeneous factors costs and hence heterogeneous endowments are based upon the differences in production costs according to the differences in factors prices. In a dynamic context all changes in relative factors prices have direct effects on production costs. In a global open and competitive economy all reductions in relative factors costs, for the most productive input, have a direct effects on the levels of output and production costs. The extent of such effects is influenced by the bias of the technology in place. The stronger is the bias and the more effective the dynamic effects of the relative factors costs upon the production costs. In turn production costs in the global markets have a direct bearing on markets shares and hence opportunities for growth.

The formal analysis is here useful to clarify the point. Let us start with a simple Cobb-Douglas production function and the related cost equation:

(23) $X = K^{a} L^{b}$

(24) $C = wL + rK$

The dual transformation of the production function into a cost function, can be easily performed after taking into account respectively r and w, the unit costs of the two basic production factors, capital and labor. This leads to equation (25) where the long term dual average cost function has been derived from the production function:

(25) $C/X = w\,((r/w\ (b/1\text{-}b))^{1\text{-}b} + r\,(\,(w/r)\,(1\text{-}b/b))^{b}$

The differentiation of the dual cost function with respect to the ratio of the relative factor costs shows that output levels and hence average costs are sensitive to the ratio of factor costs. This effect is stronger the larger is the difference of the ratio of the output elasticities from unity. Formally we see that:

(26) $C/X = w(\,r/w\ b/1\text{-}b)\,(r/w\ b/1\text{-}b)^{-b} + r\,(r/w\ b/1\text{-}b)^{-b}$

(27) $C/X = (r/w\ b/1\text{-}b)^{-b}\,(\,r\ b/1\text{-}b + r) = (w/r\ 1\text{-}b/b)^{b}\,(\,r\ b/1\text{-}b + r)$

(28) $C/X = (w/r\ 1\text{-}b/b)^{b}\,(r/1\text{-}b)$

(29) $C/X = r\,(w/r)^{b}\ (1\text{-}b)^{b\text{-}1} / b^{b}$

(30) $d(C/X)/d(w/r) = b\ r(w/r)^{b\text{-}1}\,(1\text{-}b)^{b\text{-}1} / b^{b}$

From equation (30) it is clear that all changes in the ratio of the relative prices of production factors affect the average costs and that the effect is stronger the larger the difference from 1 of both the ratio of factors costs and the ratio of output elasticities. If wages equal capital rental costs there is no composition effect on average costs when, because of a biased new technology, the output elasticity of inputs changes. The same is true when the output elasticity of capital equals the output elasticity of labor. When the isoquant is perfectly symmetric and the slope of isocost equals unity, composition effects are nihil. Too often such an undergraduate textbook exposition is assumed as a legitimate generalization. As a matter of fact instead, and especially at the desegregate level of analysis, technologies exhibit a significant bias and the differences in factors costs are relevant.

A simple numerical exercise makes the point clear. If the change in the relative prices is perfectly compensated so that the product of r and w is kept constant, average costs (AC) do not vary only when a=0.5; AC vary instead in all the other cases. For a=0.3, r=0.1, w=10, AC= 0.73332 and fetch the value AC=1.76601 for r=0.9 and w=1.11. For a=0.5, r=0.1, w=10, AC= 2.0 and stay at this level for all relative factor costs including r=09 and w=1.11. For a=0.7, r=0.1, w=10, AC= 4.62695 and reach the value AC=1.92131 for r=09 and w=1.11 For a=0.9, r=0.1, w=10, AC = 8.73337 and fetch the value AC=1.50587 for r=0.9 and w=1.11.

INSERT TABLE 4 ABOUT HERE

The results of equation (30) are shown in table 4 where it is clear that for a labor intensive technology the compensated change of relative factors prices with the proportionate decline of wages and increase of capital rental costs makes it possible to reach a tangency solution on isoquant 2 from the previous isoquant 1 without any actual increase of the purchasing power.

In assessing the actual efficiency, defined in terms of average costs, equation (30) has two important analytical implications. First, relative factor costs interact with absolute factor costs in assessing production costs. Second, relative factors costs bear effects on the general efficiency of agents using a given technology, when this is measured in terms of average costs.

From equations (29) and (30) it is clear that average costs can be low even if absolute factor costs are high, respectively lower than those possible with higher absolute costs, provided that the combination of the technology and the characteristics of the local endowments of production factors are such that the most productive input is relatively cheap.

A numerical example helps grasping this relevant point. Let us assume the extreme case of a highly labor intensive technology, say software, with b=0.9. Average costs (AC) fetch the minimum 0.21952 for r=10 and w=0.1. With r=0.9 and w=0.2, that is far higher absolute costs, AC=0.3218. For r=010 and w=1, AC=1.742. With r=10 and w=5, AC= 7.4174. In this later case absolute costs are far above the benchmark and yet are still much lower that the extreme case of a factor market where r=01 and w=10, where AC=8.73.

Absolute factors costs are compensated by relative factors prices. Because relative prices compensate for the absolute level of factors costs they become a source of basic pecuniary externalities for firms. Competition among agents based in different factor markets is strongly affected by the relative prices.

The reduction of production costs engendered by the reduction of the relative prices, as distinct from the absolute levels of factors costs, is larger, the larger is the range of output elasticities. These effects in terms of production costs are important in a global contexts. Firms with lower production costs are more competitive and hence can acquire larger markets shares. This in turn provides opportunities for growth.

From a methodological viewpoint it clear that a case for total factor productivity growth cannot be made. An increase in total factor productivity cannot be statistically observed. Output per unit of input however increase, even if the technology has not been changed. Nevertheless, the firm, industry or region where the change in the relative prices has taken place is actually more efficient than before.

The growth of nations and regions depends, also, upon the changes in the relative prices, for any given technology.

5. Conclusions

The analysis of the interactions between technological change and the structural characteristics of the economic system has made it possible to introduce an important distinction between general technological change consisting in the general shift of all the possible techniques, defined in terms of factors intensities, and contingent technologies which consist in a localized change of the mix of relative efficiency of production factors. Contingent technological changes engender a partial shift, while the shift brought about by general technological change concerns all the range of possible techniques. This distinction can be better appreciated when the achievements of economics of innovation in understanding the determinants and the effects of the generation, introduction and diffusion of new technologies are considered in a single integrated analytical framework.

When a new biased technology is introduced in a heterogeneous economic systems with a variety of local factors markets, the effects in terms of total factor productivity growth are influenced by local the structure of relative prices. The ranking of technologies is conditional to the relative prices.

When relative prices change and the technology in place is such that the output elasticity of each production factor is not the same, production costs and output levels also change. The reduction in the relative price of the most abundant factor has effects that are stronger, the stronger is the difference in output elasticity, with respect to all the other inputs. In the global economy the actual changes in the general efficiency of agents, in terms of average production costs, depends on both the increase in total factor productivity, brought about by new technologies in terms of bias and shift effects, and upon the changes in production costs brought about by the changes in the structure of the relative prices.

In a dynamic and global context, one where both relative prices and technologies can change and factors markets are heterogeneous, the general efficiency of each firm is influenced both by the changes in the technology and by the changes in the relative prices. The latter in turn is stronger the more biased is and has been the technological change. We can terms these effects as composition effects.

The direction of technological change and the context of introduction matter more than it is currently appreciated, especially when in a global economy, where agents based in heterogeneous factors markets compete on quasi-homogeneous products markets.

Two important notions can now be retained. First, the distinction between potential and actual total factor productivity growth. Potential total factor productivity growth is obtained, in a non-neutral production function, when the most productive input is cheapest. Second, the distinction between general efficiency and total factor productivity growth. Production costs, for a given technology, are influenced by the levels of relative inputs costs. The general efficiency of the production can increase not only because of the introduction of a new technology, but also by means of a reduction of the relative price for the most productive input. The effects of given relative factors prices on the range between potential and actual total factor productivity levels and the consequences of the changes in the relative inputs prices on production costs, for a given technology, can be termed composition effects.

The generation of either contingent or general technological changes cannot any longer regarded as an exogenous event which takes place as the result of an autonomous process with no economic inducements and incentives. On the opposite, the introduction of both contingent and general technological changes can be considered as the outcome of well specific incentives and constraints exerted and shaped by the structure of the economic system. Here the tradition of analysis built into the economics of innovation plays a key role providing the necessary tools.

The identification of such structural incentives is a first step towards the full understanding and mapping of the path dependent characteristics of the evolution of the system. Path dependence in fact is the result of the dynamic interdependence between the effects of the structure and its changes upon the rate and direction of technological change and the effects of the rate and direction of technological change upon the structure of the economic system.

V. NEW TECHNOLOGIES AND STRUCTURAL CHANGE: CONSTRAINTS AND INDUCEMENTS TO INNOVATION

Introduction

The analysis of the interaction between composition effects and technological change and the notions of general and contingent technological change have many important dynamic implications both for the economics of innovation and the economics of structural change.

A divide consolidated in economics between the notion of technological change and the notion of innovation. The former is used to define the introduction of more productive techniques, with a given system of relative prices. The latter is frequently used to define all possible changes in the production and organization of the firm without any clear reference to their characterization in terms of factor intensity and the effects in terms of total factor productivity. As an important result of our analysis it seems now possible to reconcile these two strands of analysis. As a matter of fact, for a given system of relative prices, all changes to the spectrum of techniques in use have actual effects in terms of average costs and hence in the relationship between inputs and outputs. The distinction itself between techniques and technologies is blurred.

This chapter provides a systematic analysis of the inducement mechanisms that lead firms to introduce new technologies, in a context where both the rate and the direction of technological change are considered. Section 2 presents a broader definition of the innovative firm which takes into account the role of relative factors costs in assessing the actual performances of new technologies. Section 3 explores the determinants of the inducement mechanisms which lead firms to the introduction of either general or contingent technological changes. The conclusions summarize the main findings.

2. The localized generation of general and contingent technologies

Innovation consists in the introduction of techniques that make it possible to produce a given output with a new mix of production factors even outside the pre-existing isoquants so as to affect directly the performance of the firm, under the constraint of the absolute and relative price of production factors. Innovation consists in the capability to move in the space of techniques, beyond the specific shape of the boundaries of equivalence defined at each point in time by the maps of isoquants.

A firm is innovative and successful when and if it is able to appreciate the bijective relationship between the constraints of the technology in place and the constraints imposed by the local systems of relative prices. From a dynamic viewpoint the innovative firm is successful when it is able to master the coevolution of both the relative prices and the technology. The understanding of this relationship makes it possible to consider a broader range of innovations including both those generated by the application of new scientific discoveries and those consisting in the manipulation of the technology so as to make it better and more consistent with the structural characteristics of the economic system.

Technology and location interact in many ways. For each given technology and a variety of possible locations in different economic systems with different relative prices, there is always a best solution and consequently a ranking of locations. The best location clearly provides the most abundant supply of the most productive factor. Conversely it is also clear that for each location, and hence each system of relative prices, there is always a better technology. The ranking of technologies depends upon the output elasticity of the locally most abundant factor.

With respect to the theory of the firm this is most important because it stresses the central role of a variety of specific competencies. In order to achieve high levels of performance firms need to know not only how, but also where and when. The direction of innovation efforts is clearly influenced by the specific endowment of the economic system where each firm is embedded.

At the same time this approach stresses the limitations of the so called competence based theory of the firm. Too much emphasis is put on the entrepreneurial capability to innovate of single firms and to little attention is paid to the structural determinants of the successful introduction of innovations. A broader set of factors needs to be taken into account by the theory of the firm and specifically the role of relative factors prices and of location in economic space.

It is also important to note that a trade-off may consolidate between technological change and relocalization. Firms may always achieve higher levels of actual total factor productivity by changing the location of their production facilities in sites which provide a larger supply and hence lower relative prices of the most productive factor of a given technology. The choice of relocation may substitute for the introduction of new more productive technologies.

Globalization is both the result of institutional changes in the international political arena and of the increasing drive towards internationalization of companies via increased flows of export of their products, increased flows of imports of components and other intermediary inputs, and multinational growth, by means of foreign direct investments in regions which can make a better use of well selected technologies.

The growth of multinational companies can now be interpreted as the result of the search for competitive advantage by firms which try and master both the technology and the relative factors prices. Multinational companies in fact provide the best example of agents able to manage the co-evolution of both the structural characteristics of each economic system and the direction of technological change. The multinational global corporation in fact is a portfolio of technologies and countries where each location should provide the best match between the technology, in terms of relative productivity of each production factor, and the local relative prices.

The understanding of the range in total factor productivity levels engendered by the introduction of a single non-neutral technology in heterogeneous regions and of the effects of relative prices on average production costs, provides the economics of innovation a broader perspective. The actual performances of the innovations introduced by each firm are strongly influenced by the specific characteristics of the economic system into which each firm is embedded. Too much emphasis has been put by economics of innovation on the firm as the single relevant unit of analysis. More attention should be paid to the role of the economic structure with special attention to the markets for both basic inputs and intermediary production factors and hence to the industrial architecture of each system, to grasp the characteristics and the effects of the interplay of the dynamics of technological and economic change.

The main results of the economics of innovation to understand the localized inducement mechanisms that lead to the generation, introduction and adoption of innovation contribute the analysis of the generation of either general or contingent technological change.

Elaborating upon the notions of bounded rationality, local search and localized technological change innovation is viewed as the result of a local search induced by the divergence between expectations and facts. Firms are myopic agents affected by bounded rationality and as such unable to anticipate correctly all the possible states of the world. Myopic firms are not able to calculate rationally al the costs and benefits of the introduction of innovations, 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 changes when the current state of affairs seems inappropriate and unexpected events take place[4]. Here even myopic firms are aware of the costs of non changing their productive and commercial set-up. The costs of non-changing are then confronted with the costs of the introduction of new technologies.

The introduction of technological changes in fact is not free and it is the result of intentional conducts to a large extent. Each firm however cannot be analyzed in isolation, as far as the generation of new technological knowledge and the introduction of new technologies is considered. The characteristics of the collective networks of innovators and the structure of interactive learning into which each firm is embedded play here a major role[5].

Innovation and the introduction of new technologies is the result of reactive and sequential decision making activated by disequilibrium in both product and factor markets. Changes in the relative and absolute prices of production factors, as well as in the demand conditions for their products, push firms away from expected equilibrium conditions. In order to face the mismatch between the actual production set, as defined by previous irreversible decisions, concerning both fixed capital and

[4] The reference to the behavioral theory of the firm, laid down by March and Simon (1958) and Cyert and March (1963) here is clear.

[5] See the results of the analysis in the section 6 of Chapter 2.

labor, -based as they are upon necessary but myopic expectations, and the unexpected changes in products and factors markets, firms however can (also) change their technology and cannot be any longer regarded as just quantity or price adjuster.

The introduction of a new technology however requires the investment of dedicated resources to conduct research and development activities, to acquire external knowledge and take advantage of new technological opportunities, to accumulate and articulate the benefits of experience and to valorize the tacit knowledge acquired in repeated processes of learning by doing, learning by using, learning by interacting with consumers, learning by purchasing. In such a context all changes in market demand and in the relative price of production factors are coped by firms only after some dedicated resources have been applied to search for a new more convenient routine. Consequently in this approach firms make sequential and yet myopic choices reacting to a sequence of 'unexpected changes' in their business environment, brought about the introduction of innovation by other agents in both products and factors markets[6].

The introduction of technological changes is viewed as the result of the innovative behavior of agents constrained by relevant irreversibility and switching costs which keep them within a limited technical region and prevent significant changes in inputs composition. Technological change is introduced locally by firms able to learn about the specific techniques in place and hence to improve them.

When irreversibility matters all changes in current business require some adjustment costs that are to be accounted for. In our approach firms are portrayed as agents whose behavior is constrained by the irreversible and clay character of a substantial portion of their material and immaterial capital and by their employment levels. Moreover the conduct of firms is affected by bounded rationality which implies strong limits in their capability to search and elaborate information about markets,

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[6] 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

techniques and technology. As a matter of fact competence constitutes the basic irreversible production factor. In turn competence is embodied both in the organization of the firm, in the stock of fixed capital, in the levels of human capital embodied in the existing employment relations, in the relations with suppliers and customers and in the communication channels in place with the markets and within the company itself (Antonelli, 1999 and 2001).

Myopic firms are induced to cope with the dynamics of demand and factor prices by introducing technological innovations and make the adjustments to market fluctuations yet retaining, as much as possible, the previous levels of inputs and hence change locally the technology, according to the relative costs of introducing innovations.

The identification of two well distinct classes of technological changes with respect to their effects pushes to articulate the analysis on the generation side. Two well distinct rationales can be articulated, drawing from the economics of innovation tradition of analysis, to understand the generation respectively of contingent and general technological changes.

Four baskets of factors matter here, the first draws from the distinction between top-down scientific opportunities and bottom-up technological opportunities. Technological opportunities are mainly based upon the learning processes which draw from new scientific discoveries while scientific opportunities draw from new scientific advances. The second concerns the location of the sources of new knowledge whether they are internal to the economic system into which the firm is embedded or mainly external, in other regions and 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 shape the actual conditions of access to external technological knowledge. The third relevant axis is the distinction between leaning processes whether it consists more of learning by doing or learning by using capital and intermediary goods purchased from other industries often located abroad. The role of switching costs provides the fourth relevant basket of variables affecting the innovative conduct of the firms, with respect to the costs associated with all changes of the existing stocks of tangible and intangible capital and techniques, including the expertise of workers and the brand and reputation of firm.

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that are the true *induced inventions*. The whole story, when it is looked at in this way, is in *time*, and can be in

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

General technological changes consist of a radical shift of the map of isoquants, such that all techniques are now more efficient. They can be thought to be 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. General technological change is characterized by a significant shift effect and hence high levels of total factor productivity. The shift effects are such that the new technology is superior to most (all) technologies in place in terms of rates of growth of total factor productivity. General purpose technologies however are likely to reflect the specific and idiosyncratic factor endowment of innovators: they are only locally neutral. Hence locally abundant factors are likely also to be most productive. The introduction of general purpose technologies can be thought to be the outcome of the localized efforts of innovators aware of new scientific opportunities and able to induce a general shift in the map of isoquants. Nevertheless the new technology is likely to be locally neutral, that is to reflect their own original technical choices and hence factor intensity. Even general purpose technologies can engender significant spreads in terms of total factor productivity growth across countries and regions that are characterized by heterogeneous endowments.

Contingent technological change can be conceived of as the result of the incremental introduction of a myriad of small changes after the main shift effect has been generated. Contingent technologies are introduced by firms, facing unexpected changes in both products and factors markets, when the

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history…"(Hicks, 1976/1982: 295 and 296) (italics is the original text).

constraints of quasi-irreversibilities of fixed capital stocks are lower and hence are less important the switching costs associated with all changes in factor intensities. Markets for inputs are here more flexible, the capital intensity is lower and as such the role of inertia engendered by sunk costs: firms can change their combinations with some ease[7]. Next and most important, contingent technologies can be considered the result of incremental innovations mainly built upon learning by using procedures. Firms learn how to use new general technologies, especially when the latter are embodied in capital goods and intermediary inputs, and eventually are able to capitalize upon the new tacit knowledge. The access to external knowledge by means of user-producers interactions with advanced, but remote sellers, sellers of new capital goods and intermediary inputs can help adopting firms to invent around and improve the factor intensity of the new general technology.

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

Specifically here a sequence between general and contingent technological changes can be articulated. A sequence where after the introduction of new general purpose and yet locally neutral technology in a leading country with idiosyncratic factors markets, diffusion takes place at fast rates across regions and industries because of the strong increase in total factor productivity levels, the adoption of the new technology makes possible. In so doing however the new general purpose technology is adopted also in countries and regions where the relative prices differ sharply from the original ones. New adopters and other followers will try and increase the benefits of the new technology introducing contingent technological changes that fit better with the local endowment of production factors. The introduction of contingent technologies builds mainly upon the preliminary introduction of radical and general ones.

Contingent technologies can be viewed as the result of learning processes associated with the use of new radical technologies. The overlapping of different generations of biased technologies generates

[7] Irreversibility and switching costs are lower, than in the case of general technologies, but not negligeable in absolute terms. Irreversibility plays a key role in fact in the general model of adjustment by means of technological change, as opposed to standard textbook technical change along a given isoquant and in a given map of isoquant, with no innovation, which consists of a simple change in factor intensity (Antonelli 1995, 1999 and 2001)

localized bumps in the map of isoquants. The introduction of contingent technological changes can be thought of a single step into a dynamic process of adjusting and adapting the bias of a new general purpose technology which takes place in a variety of specific factors markets, according to the local relative endowments. Eventually a new well shaped general production function, with strong symmetric properties, might emerge in the global market, as the result of a sequential introduction of contingent technologies.

The analyses elaborated in the product life cycle context and eventually generalized by the lines of enquiry conducted within the framework of the technological trajectory can find here an important use. The sequence between general and contingent technologies - as defined in terms of factor intensity - in fact may take place with specific features, where the distinctions between the early introduction of major innovations followed by a swarm of minor incremental ones, and the sequence between product and process innovation can be successfully applied.

3. A model of localized inducement of the rate and the direction of technological change

This analysis makes it possible to consider the scope for a localized choice, at the firm level, between the introduction of a new locally neutral technology which only consists in a shift effect and a new technology which mainly consists in a bias.

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 are not able to anticipate correctly all the possible consequences of their decisions in the long term. Bounded rationality leads to a myopic behavior, but does not prevent the capability of agents to choose among alternatives, even if not all the possible consequences are clear at the onset.

Firms which are active in factors markets radically different from those of original introduction of a new locally neutral technology can take advantage of contingent technological strategies and direct the funds, available for intentional learning and research activities, towards the introduction of new technologies which build upon the shift already introduced and are mainly directed towards a change in the relative composition of the productive inputs.

At the other extreme firms which already operate in the proximity of the technological frontier with production functions which already valorize the local endowments and exhibit high levels of output elasticity for locally abundant production factors have no other chance but to elaborate technological strategies finalized to the introduction of actual shifts in the map of isoquants. Research activities directed towards the introduction of general technologies are a necessary outcome of such conditions.

Firms based in intermediate countries instead face the real opportunity to choose between a more-contingent and a more-general technological change. It is clear that the introduction of new general purpose technologies which exhibit the specific mix of output elasticities most convenient with local factors endowments is more profitable than the introduction of contingent technologies which improve the local efficiency of a new general purpose technology introduced elsewhere. The relative costs of the introduction of a radical shift-technology with respect to a bias-technology becomes a crucial factor affecting the choice of firms in intermediate countries.

The access conditions to scientific knowledge, both codified and tacit, play here a major role. When and if the academic and scientific infrastructure is in place and appropriate incentives are at work, the technological communication between the research centers and the business community is also effective as well as the general institutional conditions for the production 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 technologies. On a similar ground 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 introduction of new general technologies, and yet biased, at least for local adopters, instead provide 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 is very important here as all user-producers interactions which make it possible the communication of tacit knowledge. High levels of protection of intellectual property rights in the global economy can prevent the necessary adaptation of new general technological knowledge and delay the introduction of contingent technologies in following countries. All incentives to swifter trade in technological know how, however, building upon strong protection of intellectual property rights may reduce such risks.

The third relevant parameter is provided by the specific conditions of the factors markets. In regions and industries where factors prices are very close, so that the ratio of relative prices is in the proximity of unity, so as the slope of the isocost and the former technology could be stylized as a symmetric production function, the incentive to introduce contingent technologies is clearly very low. In these regions research strategies of firms are necessarily directed towards the introduction of technologies which do not change the factor intensity and mainly consist of a neutral shift. On the opposite regions where the supply of a specific input is abundant and its derived demand very low do provide a unique set of opportunities to direct research strategies towards the introduction of contingent technologies.

On a similar ground in regions where the market prices of production factors are very elastic to all increase in their demand firms are likely to direct innovation strategies towards the introduction of neutral technologies. This amounts to say that a research strategy mainly directed towards the introduction and adoption of contingent technologies can hold until firms are active in regions where the current factor intensity is significantly different from that of countries where shift technologies have been introduced. The difference in relative prices between countries is a prime inducement factor in the selection of innovation strategies.

The choice between the introduction of general and contingent technologies, once the firm has been induced to innovate by the new and unexpected conditions in her product and factor markets can be nicely encapsulated by the analytical framework of a nested frontier of possible adjustments and innovations and an isorevenue.

Firms are induced to change the layout of their production process by the mismatch between the expected factors and products markets condition and the actual ones. The firms however have made irreversible decisions concerning both fixed and human capital and all changes in the levels of inputs, with respect to their plans, are expensive. Adjustments are but necessary: the out-of-equilibrium conditions generated by the mismatch between planned and actual conditions in the markets place generates losses and opportunity costs that cannot be sustained in the long run.

In this model all changes in the production layout and hence all movements in the existing map of isoquants, either on a given isoquant or from an isoquant to another -but still in the same map-, engender switching costs[8]. Formally we provide the following definition:

(31) 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 cope with the new unexpected levels of demand and factors prices and SW stands for switching costs[9].

The firm can either adjust to the factors and products markets conditions changing her position in the existing space of techniques, defined by the existing technology, or react with the introduction of an innovation which makes it possible to change the technology and hence the space of techniques[10]. The firm is now set to consider the fundamental trade-off between the costs of switching engendered by technical changes in the existing technical space and the costs of introducing technological changes which reshape the technical space.

The introduction of a new technology is the result of research and learning activities. The resources available, to face unexpected changes in the products and factors markets, can be both used in the generation of either general or contingent technologies. 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 technologies according to the relative ease of introduction of either kind of new technologies.

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

9 Appropriate tuning of the parameters of equation (31) 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.

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

The firm in other words faces two nested frontiers of possible changes in front of the mismatch between expected and real markets 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 changes or technological ones. The second frontier compares the kinds of technological change, whether contingent or general. The first isorevenue is defined by the absolute levels of the revenue generated by all adjustment activities consisting in both the amount of losses that are saved by the introduction of new techniques and the increase in output made possible by the introduction of the new technologies respectively. The second isorevenue compares the revenue generated by either general or 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 switching technical change and the ratio of biased technological change with respect to shift technological change. Specifically it is a case of maximization for a given isorevenue level set by the amount of adjustment costs that are necessary to reduce the mismatch between expected and actual markets conditions.

Formally we see the following relations:

(32) TC = a(research activities)

(33) tc = b(switching activities)

(34) GTC = c(general research activities)

(35) CTC = d(contingent research activities)

where TC measures the amount of technological innovation necessary to change the technical space and 'tc' measures the amount of technical change necessary to move in the existing technical space; GTC measures the amount of shift technological change and respectively CTC, measures the amount of biased technological change that can be generated with a given amount of innovation dedicated resources[11].

Let us now assume that a frontier of possible adjustments can be considered, such that for a given amount of resources necessary to face the mismatch, firms can generate an amount of either technical change (tc) of technological one (TC) . Nested to the frontier of possible adjustments we find a frontier of possible innovations that can be obtained with the introduction of either general technologies (GTC) or new contingent technologies (CTG).

Formally this amounts to say that:

$$(36)\quad tc = e(TC)$$

$$(37)\quad GTC = f\,(CTC)$$

In order for standard optimization procedures to be operationalized two isorevenue functions need to be set. The first, defined as the revenue of adjustments (RA) compares the revenue that adjustments by switching in the technical space yield (SW), to the revenue of innovation (RI). The second isorevenue confronts the revenue generated by the introduction of general technological changes to the revenues generated by the introduction of contingent technological changes. Formally we see:

$$(38)\quad RA = s\,RW + t\,RI$$

$$(39)\quad RI = r\,GTC + z\,CTC$$

where s and t measure the unit revenue of switching and the unit revenue of innovation; r and z measure respectively the unit revenue of the amount of general and contingent technological generated with the given amount of resources available for innovation and induced by the new and unexpected conditions of the product and factors markets.

[11] The metrics of technological change is defined in terms of rates of total factors productivity, while the metrics of technical change is provided by equation (31).

The system of equation can be solved with the standard tangency solutions so as to define both the mix of contingent and general technological change which in each specific context firms are advised to select and the amount of innovation with respect to switching the may want to prefer. The system of equilibrium conditions is in fact:

$$e'(TC) = t/s$$

(40)

$$f'(CTC) = z/r$$

subject to[12] $TC = GTC + CTC$

$RI = rGTC + zCTC$

The alternatives of the adjustment process are stylized in table 5 where the intercepts on the axes of the frontier of possible adjustments shows respectively the levels of technical and technological change measured in terms of distance in the input space and the isorevenue is set at the level defined by the amount of total adjustments costs the firm need to fund in order to cope with the mismatch between expected and real markets conditions. The analysis of the choice between innovation strategies directed towards the introduction of shift technologies and biased technologies respectively is expressed by Table 6 where the intercept of the vertical axis exhibits the levels of innovation a strategy directed towards the introduction of a shift technology can yield with given resources, available for research activities. On the horizontal axis the intercept shows the levels of innovation a strategy directed towards the introduction of contingent technologies can yield. The slope of the isorevenue can measure the relative gross profitability of either research strategy. The search for the equilibrium conditions makes explicit the rationale of the choice for perspective innovators.

INSERT TABLES 5 and 6 ABOUT HERE

The cases of either only technical change or only technological change and in turn perfectly general technological change or purely contingent technological change seem extreme solutions. Much real world can be found in between such extremes. Firms are induced to innovate by the mismatch

[12] Respectively when the case for output maximization or cost minimization applies

between actual and expected conditions of their production set, necessarily built upon irreversible decisions taken on the basis of myopic expectations which are not met by the disequilibrium conditions in product and factor markets. The direction of technological change is influenced by the relative profitability of introduction of general technological change with respect to contingent technological innovations

The correct direction of the new technologies being introduced can now be considered as the result of two different but complementary processes. In an ex-ante perspective myopic, but creative firms, select the kind of technological change consisting of both a shift and a bias, which in the proper mix, are most appropriate to the specific conditions defined in the marketplace both by the profitability of the introduction of innovations and their relative cost of introduction, including the levels of switching costs. In an ex-post perspective firms which by chance introduced a technological change along the correct direction have higher chances to survive. Firms which introduce innovations with the wrong bias instead are likely to be sorted out by the Darwinist selection mechanism activated in the products market place by the rivalry among firms.

The analysis of the following chapters provides an in-depth assessment of the different factors affecting the relative profitability and the relative costs of introduction of either contingent or general technological change. A preliminary analysis suggests that the profitability of introduction of contingent technologies is positively affected by the barriers to entry and imitation that stem from composition effects for competitors based in countries with different factors endowments.

In turn the introduction of general technologies can rely upon transient monopolistic extraprofits stemming from epidemic diffusion lags based upon information asymmetries. Clearly the sharper is the information asymmetry the higher the incentive to introduce general technologies. The long term shape of the supply schedule for production factors also matters here: the profitability of introduction of contingent technological changes can be severely reduced by the steep supply of the most productive factors and hence the sharp increase of its relative costs because off the introduction of new technologies. Barriers to entry and to exit in upstream sectors may change the relative profitability of both introduction and adoption of new contingent technologies. In general it seems clear by now that industrial dynamics and markets structures play a major role in assessing the profitability of introduction of either technologies.

On the supply side the access conditions to external knowledge and the levels of switching costs are major determinants of the ease of introduction of either technology. The levels of irreversibility of fixed capital, both tangible and intangible, play a major role in this context because they affect directly the amount of resources that are necessary to manage the technical transition from one factor intensity to another, and as such, ceteris paribus, are not available for the generation of new contingent technologies. The generation of contingent technologies may be easier, from the supply side, but less resources are eventually available for their introduction.

The approach elaborated so far clearly belongs to the class of models of induced technological change. The inducement hypothesis elaborates on the assumption that firms generate new technologies when factors costs change and -as in the post-keynesian tradition, when demand increases, at least with respect to their myopic. Our approach differs from the standard inducement mechanism. Structural change here is at the origin of disequilibrium in both products and factors markets. New technologies have horizontal effects upon competitors and vertical effects on direct and indirect customers in downstream industries and direct and indirect suppliers in upstream industries, including labor and financial markets. Firms can cope with disequilibrium, in both factors and products 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 innovations is the disequilibrium in market place. This is the Schumpeterian legacy, much elaborated and enriched by the economics of innovation. The levels of relative prices and specifically composition effects exert however a strong inducement, on the direction of the new technologies being introduced. Relative factors prices induce the direction[13].

[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 made since then along these lines. See David: ‘As soon as one is ready to discard the neoclassical conception of technological progress which insists that innovation and factor substition 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 preliminary attempts to elaborate this point in Antonelli, 1989 and 1990).

The approach elaborated in this book differs also from the traditional inducement hypothesis, as articulated first by Hicks in 1932 with his pathbreaking *'The theory of wages'* . Hicks paves the way to a tradition of analysis of the inducement hypothesis which builds upon the effects of the changes in the relative prices: no attention is paid to the levels of relative prices and to the composition effects. According to the basic hypothesis first introduced by Hicks and elaborated by Binswanger and Ruttan (1978) and recently updated by Ruttan (2001) firms introduce new technologies which save on the factor whose costs have increased. The inducement concerns both the direction and the intensity. An increase of wages in other words, in this class of models, is likely to induce the introduction of labor-saving new technologies. The stronger is the increase of wages and the larger are the effects both in terms of labor saving intensity and in terms of the amount of innovations being introduced.

In the approach elaborated in this book, instead, any increase of wage, as well as all changes in capital markets and in products ones, per se are likely to induce the generation of new technologies, because of the disequilibrium effects in the factors and products markets. Here the inducement to the rate is in place. The increase of wages however in a labor abundant country with a large supply of labor and hence low wages should not induce the introduction of a labor saving technology, but rather of a labor intensive one, because of the powerful composition effects. The inducement to the direction is now different from that expected in traditional inducement models.

The identification of two well distinct inducement mechanisms: the inducement to the introduction of innovations and the inducement to the direction of new technologies seems relevant on three counts. First it provides a more articulated explanation of the substitution effect engendered by the introduction of new biased technologies. Second it accommodates the post-keynesian inducement argument into a single integrated approach. Thirdly, it remedies a basic inconsistency of the basic inducement hypothesis applied to factors markets where the prices of inputs differs sharply and the initial conditions of the production function are asymmetric. Let us analyze them in turn.

The distinction between inducement mechanisms seems able to provide a sensible answer to the well known critique raised by Salter (1960) to the inducement hypothesis elaborated along the lines of the lines paved by Hicks (1932). Salter (1960) noted that firms should be equally eager to save on capital and labor irrespective of the recent increase in the unit costs of either factor. The basic aim of the firm in fact is to reduce total costs. The approach elaborated here takes into account this argument. When relative prices change, firms are drawn into dis-equilibrium condition. Firms can either change their technology or their technique. Irreversibility and switching costs however induce firms to change their technology. The composition effects instead 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 makes a more intensive usage of the factor which is relatively cheaper. This direction-inducement mechanism is activated by the levels of relative prices rather than by their changes. All changes instead, both in relative prices and demand, induce firms to innovate.

In the approach elaborated in this book, the inducement to the introduction and adoption of innovations, as distinct from the inducement of the direction of the new technologies, is not only activated by the changes in the relative factors prices, but also by all changes in the levels of demand. It is clear in fact that when demand levels differ from equilibrium ones, firms are induced to change their technology or their technique. For given switching costs they may want to change their technology. This is the classic kaldorian and generally post-keynesian demand pull effect, elaborated, in order to apply to the economics of innovation, by Schmookler (1966).

The distinction between inducement to innovate activated by disequilibrium conditions in factors and products markets, and the inducement to select a factor intensity for the new technology, seems able to reconcile different strands of the inducement hypothesis and provide a broader and coherent context into which they are complementary rather than alternative.

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 technologies which make the best use of locally abundant production factors will be sorted out in the product markets. Rivalry in products markets can be considered a reliable selection mechanism - a Schumpeterian Darwinism- , able to sort ex-post the correct direction of technological change.

Finally, it is clear that when composition effects are taken into account the rudimental inducement hypothesis according to which an increase in the unit cost of a factor (wage) should induce a specific factor saving (labor saving) innovation may be difficult to apply. The increase of wages in a labor abundant country might induce the successful introduction of a labor saving technology only if a strong shift effect also takes place. In such a country in fact even if wages just increased it seems still 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, stemming from all changes in demand levels and relative factors costs, and the inducement to direct the bias of the new technology, as dictated by the composition effects, seems able to save the inducement hypothesis from the poor assessment of the effects of asymmetric relative prices and output elasticities.

The framework elaborated so far provides a microeconomic understanding to appreciate the static and dynamic role of relative prices as determinants of the direction of technological change at the system level. The hypothesis that technology is not exogenous, but it is the result of the specific market conditions into which agents operate and reflects the historic process into which markets interaction take place, has been advanced repeatedly in the economic literature to explain the direction of technological change at the system level.

Habakkuk (1962) already articulated the hypothesis that American technology was different from British one as the result of the disparity of factor endowments in the two countries. The American economy was characterized by the substantial scarcity of unskilled labor and the relative abundance of natural resources and skilled labor. The British economy was instead characterized by the abundance of unskilled labor and the institutional and geographic scarcity of land and natural resources. According to Habakkuk, this disparity lead not 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 was intrinsically biased towards a labor-saving direction, while the British one was rather capital-saving. David (1975) has further elaborated this frame of analysis suggesting that economic systems are better able to move along technological paths that push them to enhance their technology following and deepening the original bias.

This argument, originally put forward by Habakkuk and David, has been the object of recent and systematic analyses according to which each system is able to introduce new technologies, which are locally progressive and are localized in the range of techniques, defined in terms of factor intensity, that reflect the relative scarcity of production factors (Antonelli, 1995, 1999 and 2001). In this approach technology is endogenous and its direction is strongly path-dependent. According to this line of analysis technological efficiency is very much contingent upon its specific context of application. Each technology and the related bundle of techniques, defined in terms of factor intensity, is appropriate to a set of idiosyncratic market conditions.

4. Conclusions

Because of composition effects, the actual levels of measured total factor productivity of each technology depend upon the specific system of relative prices in each factors market. The direction of technological change in each regional system, characterized by a specific system of relative factors prices can be affected by the composition effects in two ways.

First, the introduction of new technologies is induced by the disequilibrium conditions brought about in each economic system by the structural change which follows the introduction of previous technologies and in general by all changes in relative factors prices and expected demand levels.

Second, for a given inducement to introduce technological innovations firms in each region select the technology which fits better with the specific conditions of the factors markets. Relative factor prices become a selective mechanism which makes it possible to sort among technologies. Over time a region will make consistent choices and select technologies shaped by similar factor bias. Hence composition effects can be endogenized by perspective innovators which direct their technological efforts towards the introduction of technologies which are specifically biased in such a way that they can make the best and more productive use of the production factors which are better available and hence have a lower costs in each specific region. On a general scale technological variety across regions emerges in both cases as the result of respectively the bias in the adoption and the bias in the generation of new technologies that are better appropriate to the specific markets for production factors in each region.

Such a bias in the direction of technological change can be thought of as the result of an intentional ex-ante decision of innovators well aware of the relative scarcity of production factors available in their own inputs markets. Innovative firms, for a given costs of an innovation, will find it more profitable the introduction of new technologies which make a more intensive use of the locally most abundant factor. The bias in the direction of technological change can be also determined ex-post by a selection process among innovators. Those who happened, by chance, to have introduced the technologies which are more intensive in the locally most abundant production factor would be sorted out as the winners of the selection process. The replicator dynamics would force the 'wrong' innovators out of the market and would favor the fast increase of the market shares of the 'correct' innovators.

The direction of technological change in terms of the specific form of the bias sequentially introduced and adopted reflects the specific conditions of local factor markets. Well defined technological paths emerge in each region in the long term as the result of the selection process in the general products markets. The more rigid and idiosyncratic is the endowment of production factors and the system of relative prices and the more specific is likely to be the technological path of each region.

The model elaborated here provides a synthesis of the notions of internal and external path dependence. Internal path dependence takes place when the path along which the firm acts is determined by the irreversibility of her production factors. According to Paul David (1975) the choice of the new technology is influenced by the switching costs firms face when they try and change the levels of their inputs: firms are induced to follow a path of technological change by their internal characteristics. External path dependence is instead determined by external conditions. Brian Arthur (1989) and Paul David (1985) have made the case for external path dependence when new technologies are sorted out by increasing returns to adoption at the system level. The model elaborated here elaborates both upon internal and internal path dependence. Internal path dependence is appreciated because of the role of irreversibility and switching costs that are specific and internal to each firm. External path dependence is contributed by the role of factors endowments and relative prices that induce the direction of technological change.

The exposure of each economic system to the international competition however may change the direction of the technological path. After a new radical and general technology has been introduced, in fact, in each country the search for appropriate technologies may lead to the introduction of new contingent technologies, that is the reshaping of the production function, without any actual increase in potential total factor productivity levels. In more successful cases the new technology can be general, that is be both non-neutral and yet generally progressive.

In any event the introduction of new technologies is clearly the result of an out-of-equilibrium context which pushes the firm to the innovative choice, provided a number of key systemic conditions are available.

This context can provide a unique opportunity to blend the result of much economics of innovation more keen to assess the rate of introduction of innovations together with the technological characterizations of new products and new processes with an analytical framework which elaborates the role of factor intensities and output elasticities. The distinctive element of economics of innovation, the out-of-equilibrium context of analysis, is in fact the basic common thread and the unifying element.

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