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LOCALIZED TECHNOLOGICAL CHANGE AND EFFICIENCY WAGES: THE EVIDENCE ACROSS EUROPEAN REGIONS

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LOCALIZED TECHNOLOGICAL CHANGE AND EFFICIENCY WAGES: THE EVIDENCE ACROSS EUROPEAN REGIONS[1].

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ABSTRACT. Internal labour markets and industrial relations in Continental Europe are characterized by substantial rigidity of employed labour. The rigidity of employed labor adds and augments the irreversibility of fixed capital. This rigidity affects both the rate and the direction of technological change. The irreversibility of both production factors induces the localized introduction of biased technological change directed towards the more intensive use of inputs that are becoming more expensive. The localized introduction of biased technological change contrasts the classical inducement hypothesis according to which new biased technologies are directed towards the most intensive use of inputs that are becoming less expensive. In our theoretical underpinning the localized introduction of biased technological change is induced, instead, towards the more productive use of the inputs that are becoming more expensive because they are characterized by substantial rigidity and irreversibility. Firms, localized in a limited portion of the technical space by the competence and expertise acquired by learning processes in the proximity of the techniques in use and by the quasi-irreversibility of their stocks of both capital and labour, react to the changes in the levels of wages by means of the introduction of new biased technologies directed towards the more intensive use of labour that in the European experience can be characterized as a rigid production factor. The localized introduction of directed and biased technological innovations has clear effects on total factor productivity levels. The empirical evidence on the determinants and the effects of the localized introduction of directed technological changes across a sample of European regions in the years 1995-2004 provides significant support to the hypotheses and confirms both the significant role of the changes in wages in the increase of the output elasticity of labour and its significant effects on multi factor productivity.

KEY-WORDS: BIASED TECHNOLOGICAL CHANGE; INDUCED APPROACH; LOCALIZED TECHNOLOGICAL CHANGE; EFFICENCY WAGES; MULTI FACTOR PRODUCTIVITY GROWTH.

JEL CODES: O33, R11

1. Introduction

The induced innovation approach is back at the centre stage of the economics of technological change. The so-called skill-bias debate has brought new interest in the matter.

The original hypothesis actually dates back to Marx and Hicks (1932: 124-125) according to whom “A change in the relative prices of factors of production is itself a spur to invention, and to invention of particular kind – directed to economizing the use of the factor which has become relatively expensive”. Habbakuk (1962) provided support to this hypothesis showing how, in the American and British historic evidence, through the nineteenth century, labour scarcity pushed firms to generate and introduce labor-saving technologies. The formal analysis provided by Kennedy (1964) and Samuelson (1965) consists in the construction of an innovation possibility frontier, with the typical shape of a production possibility frontier, along which the trade-off between labor-saving and capital-saving innovations can be traced. The relative costs of capital and labor shape the isorevenue that enables the identification of an optimum direction of technological change (Binswanger, Ruttan, 1978). The approach has been criticized for the lack of microeconomic foundations by Salter (1966), but remained on of the cornerstones of the economics of innovation. Ruttan (1997 and 2001) has shown that technological change is characterized by a strong directionality that can be represented in terms of changes in the output elasticity of production factors.

The contributions of Acemoglu (1998 and 2002) have provided an equilibrium approach to the analysis of the endogenous generation of directed technological change. This approach explores the causes of the direction of technological change but does not provide any clue to assess the effects in terms of total factor productivity. More specifically the model elaborated by Acemoglu shows how the introduction of directed technological changes is determined by the changes in the relative prices of production factors: innovations are aimed at making a more intensive use of the inputs that are becoming more abundant. In the US experience in the second part of the XX century this is the case of skilled labor after the college boom. Acemoglu however is not able to relate the changes in the factor intensity of the production process, as dictated by the changing ratios of the output elasticity of the inputs, to the increase in the general economic efficiency. In this equilibrium approach there is no clue about the effects of the introduction of directed innovations on the increase in the efficiency of the production process as measured by total factor productivity.

This is not a surprise: more than thirty years ago Dick Nelson (1973) showed that changes in factor shares are likely to affect the estimates of total factor productivity (TFP). When technological change is not Hicks-neutral, the traditional estimates of TFP may hide the effects determined by the changes in output elasticities. This line of reasoning has been somewhat neglected. Recently, however, it has paved the way to a new flow of empirical studies aimed at understanding the sources of recent growth in Asian countries that rely upon alternative productivity indexes (Nelson and Pack, 1999; Felipe and McCombie, 2001; Fisher-Vanden and Jefferson, 2008).

It is clear that in general any change in factors' share depends on the bias of technological change, and that this holds irrespective of the value of elasticity of substitution (Bailey et al., 2004),

In this paper we aim at elaborating a model to frame the effects of biased and localized technological change on multi factor productivity (MFP) indexes. The interaction between factors markets rigidities and the induced innovation provides a fertile ground enabling the empirical investigation of the relationships between changes in relative prices, changes in factor shares and the dynamics of productivity. Our results supports the idea that Hicks-neutral technological change is only one out of many possible outcomes, and that changes in relative prices are likely to shape the direction of technological change, and hence factors' share. Moreover, a great deal of productivity growth is explained by biased technological change, calling for the identification of a more appropriate productivity index.

The empirical evidence of Continental Europe in the years 1995-2004 stirs our analytical effort because it provides an empirical setting, characterized at the same time by the combination of the strong bargaining power of organized labor, and the fast pace of introduction of biased technological changes directed towards the intensive use of labor, that can be appreciated in a comparative context.

The rest of the paper is structured as it follows. Paragraph 2 frames the analysis and presents a model of localized and directed technological change cum efficiency wages. Paragraph 3 provides some descriptive evidence upon the direction of technological change across European regions in the years 1993. 2004 and presents the econometric tests of the model elaborated in paragraph 2. The conclusions summarize the main results and put them in perspective.

2. The localized technological change approach when efficiency wages matter

2.1 The background

The analysis of the interplay between the irreversibility of production factors and the rate and the direction of technological change fits quite well with the actual, empirical conditions of factor markets in Continental Europe. In Continental Europe internal labour markets are characterized by substantial rigidity: firms face major limitations in the adjustment of employment levels to the changing conditions of both the demand levels and the relative costs of inputs. As a matter of fact, the conditions of the European internal labour markets are such that we can introduce a new stylized fact: both capital and labour, the basic production factors, are rigid. Both the rate and the direction of technological change have been affected by these factors. Technological innovation in the last decades in Continental Europe has been in fact characterized by high levels of biased technological changes induced by the dynamics of wages.

This dynamics has led to the introduction of new localized and biased technologies that were directed towards the more intensive use of production factors that were becoming more expensive.

The institutional characteristics of labour markets and industrial relations in Continental Europe and their effects on the rate and the direction of technological change push to rely upon the localized technological change approach to understand the relations between changes in wages and induced technological change.

The localized technological change approach enables to provide a new frame to analyse both the causes and the effects of directed technological change. When standard factor substitution is impeded by substantial irreversibility of production factors the inducement mechanism can yield a bias towards the more intensive use of the rigid factors that are becoming more expensive. Firms that cannot move on the existing map of isoquants, because of the irreversibility of installed inputs, have an incentive to try and increase the productivity of the existing production factors.

When the irreversibility of production factors is taken into account and the dynamics of labor markets is acknowledged as a primary factor of change, the localized technological change approach seems to reverse the Marxian analysis of induced technological change, and yet to retain its basic flavour (Rosenberg, 1969, 1974, 1976 and Marquetti, 2003). The active role of organized labor supported by effective trade unions pushed firms to try and cope with the twin effects of their bargaining power consisting in the increasing cost of a production factor characterized by substantial rigidity by means of the induced introduction of innovations that made incumbent labor more productive. In so doing firms were able to increase their output without reducing the employment.

The irreversibility of production factors and specifically of the current levels of employment plays a key role in this interpretative framework. Paul David (1975) showed that in the long-term experience of both the US and the UK, the factor intensity varied very little although relative input prices changed considerably. Apparently firms, facing the changing conditions of both product and factor markets, were much more able to react by means of the increase their efficiency, by changing their technology, than by means of the input substitution along existing isoquants. Hence firms were induced to change their technologies moving along a narrow corridor. Paul David identified the origins of this peculiar dynamics, whereby technological change replaces standard substitution, in the irreversibility of production inputs.

When the rigidity of labor inputs exerts a key role, the notion of efficiency wages becomes relevant (Akerloff and Yellen, 1986). The actual effect of the bargaining power of trade unions in fact can be considered a combination of the induced innovation approach with the notion of efficiency wages. The increase in wages cum labor rigidity impedes the movements on the existing map of isoquants and hence limits the traditional substitution of capital to labor. Firms can cope with the increased levels of wages only if they try and introduce technological innovations that make the existing employment more productive. This outcome is all the more plausible if and when efficiency wages enhance the commitment of employees to contribute the innovative efforts of their firms. The tacit competence accumulated by means of learning processes can be valorized and codified. Efficiency wages, in other words, induce more than the solution of organizational failures: they induce the localized introduction of technological change (Shapiro and Stiglitz, 1984).

2.2 The interpretative frame

In the localized technological change approach firms are rooted in a well defined and limited portion of the knowledge and technological space by relevant problems raised by bounded and procedural rationality. The irreversibility of production factors, both tangible and intangible, and the costs of acquiring the technical knowledge that is far away from the competence acquired by means of learning by doing and learning by using reduce the mobility of firms in the technical space designed by the usual map of isoquants. All changes in the market price of production factors and hence in the slope of the isocost raise significant problems in terms of switching costs. Firms search and explore the technical space in the surrounding of their original location and try and adjust their techniques to the new requirements. The adjustment to the new equilibrium conditions can take place either by means of switching activities, moving upon the existing map of isoquants, and specifically, when the change in factor price – for the sake of geometric clarity- is compensated upon the same isoquant, or by means of the generation and introduction of new technologies. Switching activities entail dedicated resources, as much as innovation activities. The introduction of induced technological changes reduce the switching in the existing maps by means of the introduction of new technologies that are closer to the existing location of the firm in the space of techniques.

When the dynamics is initiated by increases in wages stemming from the bargaining power of unionized labor, the substitution of capital to labor is impeded by the strong bargaining power of unions, hence when wages increase, even beyond their marginal productivity, firms cannot rely upon standard substitution processes. Technological change is induced. Yet such a technological change is at the same time localized and directed towards the more intensive usage of the input that is becoming more expensive. The localized introduction of technological change is induced by the effort to maximising the output of a mix of innovation and switching activities, and biased towards the more effective use of the inputs that are becoming more expensive.

Figure 1 provides the basis frame of analysis. Here the firm was in equilibrium in point A. All changes in the slope of the isocosts engendered the compensated change in the wages and capital rental costs induce the firm to move away from point A. If wages increased (and hence relative capital rental costs declined: see isocosts HWI) the firm should move towards the new static equilibrium point B. The exploration in the technical space and the related change in the technology might allow the firm to change the technology and hence to change the shape of the isoquant so as to choose the point D, instead of point B. The firm can prefer to move to point D if the amount of innovation and switching costs that are necessary to change the technology so as to shape the new isoquant T2 are lower than the sheer switching costs that are necessary to reach point B. From a general efficiency viewpoint it should be clear that B and D belong to the same (new) isocosts: hence the new technique D does not allow for any increase in efficiency with respect to the static solution B: it is a new technique but it is not an actual innovation. The exploration activities induced by the change in the slope of the isocost might however lead the firm to point F. In this case the firm has been able to generate a full-fledged technological innovation that allows for the actual increase of the efficiency of the production process. It is clear from Figure 1, in fact, that F belongs to a lower isocosts. The production in F enables the firm to produce as much as in B or D, but at a lower cost. The firm that is able to change the shape of the original isoquant so much as to reach point F will benefit from an actual increase of total factor productivity. Therefore, it should be clear that the equilibrium point F combines the effects of both the shift in the production function and the change in the slope of the isoquant.

INSERT FIGURE 1 ABOUT HERE

The analysis of the slope of the new isoquant confirms that this result is possible when and if the new technology is labour augmenting. Clearly the new biased and directed technology is the result of the localized introduction of a new technology that impinges upon systematic efforts in R&D activities and in the valorisation of learning and tacit competence. This process induces firms to use technological change as a process that minimizes the amount of substitution activities and hence the distance from the original equilibrium condition.

The localized technological change approach contrasts sharply both the textbook and the classical analysis based upon the common assumption of a frictionless world. We see in fact that an increase in wages pushes the standard textbook firm to substitute capital to labour and hence to increase its capital intensity moving leftward on the existing map of the isoquants. The classical firm, following the Marx-Hicks tradition of analysis, would move even farther. The increase in wages would induce the introduction of a new technology that is more capital-intensive and hence a dramatic change in factor intensity. In the classical induced technological change approach, the introduction of new technologies engenders a meta-substitution process that augments the textbook substitution process.

The same Figure 1 provides clear evidence about the likelihood of the introduction of new capital augmenting technologies when the change in the slope of the isocosts stems from the decrease of wages (and the increase in the relative capital rental costs: see isocosts LSI).

The localized technological change approach enables to grasp the causes and the consequences of the introduction of directed technological changes. This result is obtained with a full-fledged microeconomic approach that appreciates the specific details of the generation of technological knowledge based upon learning processes, both internal and external to the firm, and the accumulation of competence, on the one hand, and the identification of the role of bounded and limited rationality and irreversibility that limit the mobility and foresight of the firm in the knowledge space.

As far as the causes are concerned it is clear that, when firms are rooted by limited competence and quasi-irreversibility in a limited portion of the knowledge space, the direction of technological change is induced by the changes in the relative prices of production factors that keep the firm in the proximity of the existing factor intensity and enable the reduction of switching activities. The consequences are clear. Because directed technological change enables to use more intensively and systematically the production factors that are becoming more expensive, it also leads to a generalized increase of the efficiency of the production process, i.e. to an increase of output with a given level of inputs.

2.3 The model

In view of the arguments elaborated so far, we are now able to propose a simple model of localized technological change, in which innovation efforts are stimulated by changes in the relative price of production factors. Let us start by a general Cobb-Douglas production function, representing the actual technology by means of which regions transform inputs into outputs:

$$Y_{i,t} = A_{i,t} K_{i,t}^{\alpha_{i,t}} L_{i,t}^{\beta_{i,t}} \tag{1}$$

The output produced in region *i* at time *t* is a function of the actual levels of capital and labour employed, and of the actual technology signalled by the general efficiency parameter *A* and by factors' output elasticities. Production factors are available at equilibrium prices defined on factor markets, so that the cost function agents have to confront with, appears as follows:

$$C_{i,t} = w_{i,t} L_{i,t} + r_{i,t} K_{i,t} \tag{2}$$

Where *w* and *r* are respectively the unit cost of labour and capital services in region *i* at time *t*. The solution to the cost minimization problem is given by the well known condition:

$$\frac{(\partial C / \partial L)}{(\partial C / \partial K)} = \frac{(\partial Y / \partial L)}{(\partial Y / \partial K)} \tag{3}$$

By total differentiating equation (1), the right hand side of equation (3) turns out to be equal to the slope of the isoquant:

$$-\frac{dK}{dL} = \frac{\beta_{i,t}}{\alpha_{i,t}} \frac{K_{i,t}}{L_{i,t}} \tag{4}$$

And therefore:

$$\frac{w_{i,t}}{r_{i,t}} = \frac{\beta_{i,t}}{\alpha_{i,t}} \frac{K_{i,t}}{L_{i,t}} \tag{5}$$

Thus, in equilibrium relative prices must be proportional to the ratio between labour productivity and capital productivity. Let us now assume that a compensated change in factors costs takes place, for example a reduction in the relative price of capital. This in turn translates into an increase (in absolute value) of the slope of the isocost line. The new isocost would define a new equilibrium point that is characterized by a new combination of capital and labour in the production process. In this standard framework, the change in relative prices fully burdens the capital/labour ratio, as the technology is exogenous by definition. The analytical translation of this line of reasoning can be obtained by rearranging the relationship in equation (5) as follows:

$$\frac{w_{i,t}}{r_{i,t}} = \frac{\overline{\beta_i}}{\overline{\alpha_i}} \frac{K_{i,t}}{L_{i,t}} \tag{6}$$

Where the bars over output elasticities signal that they are constant over time. By taking logs of both sides, and then first-differences, we yield the following:

$$d\log\left(\frac{w}{r}\right)\bigg/dt = d\log\left(\frac{\beta}{\alpha}\right)\bigg/dt + d\log\left(\frac{K}{L}\right)\bigg/dt \tag{7}$$

In other words, the growth rate of relative prices equals the sum of growth rates of capital intensity and of the ratio between labour and capital output elasticities. However, by definition $d\log\left(\frac{\beta}{\alpha}\right)\Big/dt = 0$, and therefore equation (7) boils down to:

$$d\log\left(\frac{w}{r}\right)\bigg/dt = d\log\left(\frac{K}{L}\right)\bigg/dt \tag{8}$$

The main argument of this paper is that changes in relative prices engender changes in the production technology, as long as switching costs are relevant and firms are better off by adjusting to new relative prices by reshaping the technology instead of changing the capital/labour ratio. The extreme version of the argument would maintain that firms choose to bear only innovation costs. This situation is exactly opposite to that represented in Equation (8).

Now both capital and labour levels can be changed by firms only by bearing significant switching costs, and anyway only if there were not factor markets rigidities. These two factors make the capital/labour ratio fixed in this framework. To hold true the identity in equation (5), the ratio between labour and capital output elasticities must change accordingly. This amounts to introduce a new technology for production, generating a new isoquant map like the one represented in Figure (2) by the isoquant Y_2. The the equilibrium point A is clearly on a new (dashed) isocost, but the new isoquant Y_2 identifies an output level higher than Y_1. More precisely, we argue that the increase in output is larger than the increase in total costs. The new equilibrium is such that firms may keep operating in the surrounding of the original capital intensity. Firms may now keep operating in the surrounding of the space of techniques they are used to, as the change in relative prices has been fully compensated by the change of the marginal rate of technical substitution between the two production factors.

INSERT FIGURE 2 ABOUT HERE

From an analytical viewpoint, equation (6) is to be rewritten as follows:

$$\frac{w_{i,t}}{r_{i,t}} = \frac{\beta_{i,t}}{\alpha_{i,t}} \frac{\overline{K_i}}{\overline{L_i}} \tag{9}$$

Where the bars over capital and labour levels signal that they are constant. By taking logs of both sides, and then first-differences, one yields again the relationship in equation (7). However, in this case by one would need to set $d\log\left(\frac{K}{L}\right)\Big/dt = 0$, and the equation would be rewritten as follows:

$$d\log\left(\frac{w}{r}\right)\Big/dt = d\log\left(\frac{\beta}{\alpha}\right)\Big/dt \tag{10}$$

In this extreme situation a change in relative prices is totally transferred to the ratio between labour and capital output elasticities. In particular, firms are induced to change the technology of production by directing their innovation efforts towards the increase in the effectiveness of the production factor that has become relatively more expensive. Should the relative price of labour increase, firms would be willing to undertake research projects aimed at making labour more productive. Vice versa, a decrease in relative prices stemming from an increase of capital rental costs would stimulate firms to introduce technological changes that increase capital productivity[2]..

Because biased technological change is able to make more effective the production factors that have become relatively more expensive, the directionality of the new technology has clear effects on the output and hence on productivity. The multifactor productivity index (MFP) is indeed defined as the Hicks neutral augmentation of the aggregate inputs, weighted by their share in total income. Following Equation (1), using a Cobb-Douglas production function, the growth of MFP (*A*) may be written as follows:

$$d\log A_{i,t}/dt = d\log Y_{i,t}/dt - \overline{\alpha}[d\log K_{i,t}/dt] - \overline{\beta}[d\log L_{i,t}/dt] \tag{11}$$

Where the bars over output elasticities, following the discrete approximation of the Divisia index, refer to the two years average of both   and .

In view of the argument elaborated so far, we are now able to spell out the leading working hypotheses underlying the paper.

[2] Yet, one can hardly argue that the firm is able to completely neutralize the effects in terms of capital/labour ratio. Therefore, it seems more realistic to propose that changes in relative prices engender changes in both capital intensity and in the ratio between output elasticities. However, according to the inducement hypothesis, the effect of the former is expected to be much lower..Moreover, it is clear that by allowing the rate of change of capital/labour to equal zero, one would implicitly accept that the growth in per capita output is totally driven by the shift effect. Neither the original formulation of the model, nor the empirical observation, would be in line with this outcome.

1) Technological change is far from neutral. Firms are constrained by both static and dynamic irreversibilities within a limited portion of the technical space, in the surrounding of the original capital/labour ratio characterizing their production process. In a frictionless world, a compensated change in factor markets conditions woul engender a costless adaptation of firms to the new relative prices, by just changing the proportions between capital and labour so as to move upon the original isoquant . However, the acknowledgement of the crucial role of irreversibilities makes it necessary the account for switching costs.
2) The introduction in the picture of innovation activities as a possible alternative available to firms to adjust to the changing conditions of factor markets enables to reconsider the classical inducement mechanism. Changes in relative prices are therefore expected to induce adaptation efforts grounded on innovation activities aiming at the localized introduction of biased technological change, directed to a more effective use of the production factor that has become more expensive. Technological innovations are in turn the outcome of dedicated efforts to R&D activities and of the accumulation of knowledge via learning dynamics.
3) Innovation efforts induced by changes in relative prices are likely to exert appreciable effects on the effectiveness of production factors, and therefore one would expect to observe such effects to hold also on total factor productivity.

3. Methodology and data

In order to grasp the effects of the localized and induced technological change on factors' output elasticities and eventually on productivity, we first need to calculate proxies of relative prices, output elasticities and total factor productivity. To this purpose we follow a standard growth accounting approach (Solow, 1957; Jorgenson, 1995; OECD, 2001). Let us start by assuming that the regional economy can be represented by a general Cobb-Douglas production function with constant returns to scale as in Equation (1).

Following Euler's theorem, output elasticities have been calculated (and not estimated) using accounting data, by assuming constant returns to scale and perfect competition in both product and factors markets. The output elasticity of labour has therefore been computed as the factor share in total income:

$$\beta_{i,t} = (w_{i,t} L_{i,t}) / Y_{i,t} \tag{12}$$

$$\alpha_{i,t} = 1 - \beta_{i,t} \tag{13}$$

Where w is the average wage rate in region i at time t.

Then the discrete approximation of annual growth rate of MFP in region *i* at time *t* is calculated in a traditional way as follows:

$$\ln\left(\frac{MFP_i(t)}{MFP_i(t-1)}\right) \equiv \ln\left(\frac{Y_i(t)}{Y_i(t-1)}\right) - (1-\overline{\beta})\ln\left(\frac{K_i(t)}{K_i(t-1)}\right) - \overline{\beta}\ln\left(\frac{L_i(t)}{L_i(t-1)}\right) \tag{14}$$

Following the two hypotheses spelled out in the previous section, we may now propose the structural specification to be estimated in the econometric analysis. The basic hypothesis proposes that a change in relative prices of production factors engenders a change in output elasticities as a consequence of intentional efforts towards the localized introduction of biased technological change. This leads us to model the growth rate of output elastiticities as a function of relative prices. Moreover, biased technological change stems from the commitment of resources to innovation activities. Therefore, a proxy for innovation dynamics needs to be inserted in our specification. Finally, we have noticed that one should realistically consider the conditional effects of changes in capital/labour proportion, though the relevance of irreversibilities makes them very weak. Thus such ratio must be included as a control variable in the econometric specification, which turns out to be the following:

$$\ln\left(\frac{\alpha_{i,t}}{\alpha_{i,t-1}}\right) = a + b\ln\alpha_{i,t-1} + c_1\ln\left(\frac{w_{i,t-1}}{w_{i,t-2}}\right) + c_2\ln\left(\frac{(K_i/L_i)_{t-1}}{(K_i/L_i)_{t-2}}\right) + \\ + c_3\ln\left(\frac{TC_{i,t-1}}{TC_{i,t-2}}\right) + \rho_i + \sum\psi t + \varepsilon_{i,t} \tag{15}$$

Where the error term is decomposed in $_i$ and t, which are respectively region and time effects, and the error component $_{it}$. The growth rate of capital output elasticity ( ) is regressed against its lagged level, so as to control for mean reversion effects, the growth rate of real wages (*w*), the growth rate of capital/labour ratio and of patent applications by region *i* Equation (15) can be estimated using traditional panel data techniques implementing the fixed effect estimator.

The adoption of biased technological change enables efficiency gains with respect to the production factor that has become more expensive, and therefore allows for compensating the change in relative prices with a change in the marginal rate of technical substitution between production factors. Moreover, by introducing biased technologies, firms are able to generate fully-fledged technological innovations that also engender an increase in the general efficiency of the production process. The econometric test of the second hypothesis therefore may be carried out by adopting the following specification:

$$\ln\left(\frac{MFP_{i,t}}{MFP_{i,t-1}}\right) = z + g\ln\left(MFP_{i,t-1}\right) + h\ln\alpha_{i,t-1} + m\ln TC_{i,t-1} + \rho_i + \sum\psi t + \varepsilon_{i,t} \tag{16}$$

Where *MFP* is multifactor productivity,   is capital output elasticity and *TC* stands for patent applications per thousand workers. Equation (16) may be estimated by using traditional fixed effect estimators for panel data. However, the application of fixed effect estimators to investigate the determinants of multifactor productivity may yield dynamic biased estimations. A viable way to cope with this problem is to transform equation (16) so as to carry out GMM estimation of coefficient. The econometric specification then turns out to be:

$$\ln\left(MPF_t\right) = z + \psi\ln\left(MFP_{i,t-1}\right) + h\ln\alpha_{i,t-1} + m\ln TC_{i,t-1} + \rho_i + \sum\psi t + \varepsilon_{i,t} \tag{17}$$

where = (g – 1). Such Equation can be estimated through dynamic models for panel data. We carried out the empirical test by means of a dynamic panel data regression, using the generalized method of moments (GMM) estimator (Arellano and Bond, 1991). This estimator indeed provides a convenient framework for obtaining asymptotically efficient estimators in presence of arbitrary heteroskedasticity, taking into account the structure of residuals to generate consistent estimates. In particular, we use the GMM-System (GMM-SYS) estimator in order to increase efficiency (Arellano and Bover, 1995; Blundell and Bond, 1998). This approach instruments the variables in levels with lagged first-differenced terms, obtaining a dramatic improvement in the relative performance of the system estimator as compared to the usual first-difference GMM estimator. The error term is therefore decomposed in i and t, which are respectively regional and time effects, and the error component $_{it}$.

3.1 The data

In order to investigate the relationships between changes in factor markets, directed technological change and MFP, we have drawn data from the Eurostat regional statistics, which gathers together statistical information regarding European regions since 1995.

For what concerns the calculation of the three kinds of MFP index introduced in the previous Section, we needed output, labour and capital services, and the labour and capital shares. As a measure of output (Y_{it}) we used the real GDP (2000 constant prices). Eurostat also provides with estimation of capital stock (K_{it}) and employment, although it does not provide data about hours worked at the regional level. For this reason we used average hours worked at the country level provided by the Groningen Growth and Development Centre, and then calculate total hours worked (L_{it}). Although this does not allow us to appreciate cross-regional difference in average hours worked, nonetheless it allows us to account at least for cross-country differences. The labour share (β_{it}) is calculated using data on the compensation of employees and the GDP according to equation (13), while capital output elasticity has then been calculated following equation (14).

For what concerns the role of formalized innovation efforts in the localized introduction of biased technological change, we decided to use patent applications to European Patent Office (EPO) as proxies of regional innovative activities. The time series provided by the EPO start in 1978, and assign patents to regions according to inventors' addresses. The limits of patent statistics as indicators of innovation activities are well known. The main drawbacks can be summarized in their sector-specificity, the existence of non patentable innovations and the fact that they are not the only protecting tool. Moreover the propensity to patent tends to vary over time as a function of the cost of patenting, and it is more likely to feature large firms (Pavitt, 1985; Levin *et al.*, 1987; Griliches, 1990).

Nevertheless, previous studies highlighted the usefulness of patents as measures of production of new knowledge, above all in the context of analyses of innovation performances at the aggregate regional level (Acs *et al*., 2002). Besides the debate about patents as an output rather than an input of innovation activities, empirical analyses showed that patents and R&D are dominated by a contemporaneous relationship, providing further support to the use of patents as a good proxy of innovation (Hall *et al*., 1986).

Figures 3 to 5 provide us with a preliminary statistical description concerning both the distribution of regions across different values of capital output elasticity, and the change of such distribution over time.

INSERT FIGURE 3 ABOUT HERE

Figure 3 shows the kernel density estimation for the distribution of sampled regions over capital output elasticity for two periods. The continuous line refers to the period 1995-2003, while the dashed line refers to the period 2000-2003. Two important information are conveyed by this former evidence. First of all, there is a wide dispersion of regions across different capital elasticities. These are far from homogeneous, and both the distributions show the existence of more than one peak. Moreover, and more importantly, the distribution changes over time. The shape of dashed line appears to be fairly different from that the continuous line. This means that overall the output elasticity of capital changed over time. The prominent peak around 0.6 suggests that on average, the capital share in national income increased in the early 2000s, with respect to the second half of the 1990s. This evidence yields relevant consequences on the measurement of TFP, in that it is a clear proof that the slope of isoquants is likely to change over time, and across different regions, rather than being constant. Thus, one would expect productivity growth to be strongly affected by the localized introduction of biased technological change.

INSERT FIGURE 4 ABOUT HERE

Figure 4 shows the distribution of sampled regions across capital output elasticities[3]. It is evident that the range of variation is quite large, falling in the interval [0.372, 0.758]. The diagram allows us to characterize different regions according to their marginal productivity of capital, as this latter is strictly related to output elasticity. The darkest areas are those characterized by the highest values of alpha. Regions belonging to this group can be found in Northern Italy, in Greece, mainly in Poland and in Southern Portugal. The dark grey areas are at a lower level of output elasticity, but still quite significant. Most of Eastern Europe regions can be found in this class, along with Central and Southern Italy and central Spain. The median class, roughly centred on 0.5, comprises some Spanish and French regions, as well as all Austrian regions and a few ones from Southern Germany. The two lowermost classes finally include all the UK regions, Northern France and the bulk of German regions.

[3] It must be noted that for the sake of completeness, the descriptive analysis provided in this Section includes also the evidence for the UK, though such data are then not used in the econometric test discussed in Section 4.

A sharp partition clearly emerges from this picture. North European regions appear indeed to be characterized on average by fairly low levels of capital output elasticity, and hence by high levels of labour output elasticity. This supposedly reflects conditions in which factor markets are such that the relative price of labour makes it convenient to direct technological efforts towards the introduction of labour-augmenting innovations. This is likely to be related, above all in the case of France, UK and Norway, to the actual change in industrial structure, characterized by the increasing weight of service sectors and the increasing supply of qualified work. On the contrary, in Southern regions, the persistent specialization in traditional manufacturing regions still makes capital output elasticity higher than that of labour, providing additional explanation to the rejuvenation of productivity gaps with the rest of most advanced countries.

INSERT FIGURE 5 ABOUT HERE

Figure 5 shows the dispersion of capital output elasticity over time for each region. Also in this case, darker regions are those in which the variation over time is higher. The highest variance can be found in Greece, while lower levels are observed in Easter Europe regions, Portugal, Corse and Campania. Some degree of variation can also be observed in Italian, French and UK regions, while most of German and Spanish regions are characterize by basically stable output elasticities over time. It is worth stressing that the quite heterogeneous picture resulting from this descriptive exploration reveals that time stability of output elastiticities, and therefore parallel shifts of the production function, is possible but not necessary. On the contrary, different regions may also be characterized by higher or lower variation of output elasticities, and hence by change in the shape of the isoquants representing the regional production function.

4. Econometric results: determinants and effects of directed innovations

In this Section we provide the results for the econometric estimations of equation (15) and (17). The former aims at assessing the effects of changes of factor costs on factors' output elasticity, so as to test the first hypothesis concerning the localized inducement of biased technological change. Table 1 reports the fixed effect estimations. In column (1) one can find the baseline model, wherein the growth rate of capital output elasticity ( ) is regressed against the growth rate of unit labour cost, while the lagged value of is meant to capture possible mean reversion effects. Our main hypothesis proposes that due to static and dynamic irreversibilities, firms respond to changes in factor costs by introducing technological innovations to increase the effectiveness of the production factor that has become relatively more expensive, so as to adapt the marginal rate of technical substitution between factors accordingly. Therefore, if wages increase, in a context shaped by constant returns to scale one should expect capital output elasticity to fall. The results in column (1) are fully in line with this proposition. The coefficient on the growth rate of wages is indeed negative and significant.

We have also argued that the introduction of biased technological change is the outcome of exploration activities impinging upon systematic innovation efforts. For this reason, in column (2) we introduced the variable *TC*, which stands for the 4 years moving average of patent applications in regions *i*. The coefficient on the growth rate of wages is still negative and significant, while *TC* shows a positive and significant coefficient. Once again, the results seem to corroborate our hypothesis, according to which biased technological change is induced by change in factors costs and are made possible the commitment of dedicated resources to organized innovation activities. Column (3) shows the result of the estimation of the baseline enriched by the inclusion of the growth rate of capital/labour ratio. Indeed, one should realistically assume that any process of introduction of biased technological change entails at least a small change in the proportions of capital and labour used by firms. Our results would suggest that the effects of such variable are somehow negligible, as the coefficient appears to be not significant, though it is positive.

Finally, column (4) presents the results for the fully specified model. The coefficient for the growth rate of labour cost confirms to be negative and statistically significant, while the one for innovation activities is positive and significant. Once again, the coefficient for the growth rate of capital/labour ratio is not significant. All in all, it may be concluded that the results about both the inducement mechanisms engendered by the change in relative prices and the role of innovation activities are quite robust and persistent across different econometric specifications. Moreover, the inclusion of the proxy for innovation activities improves a lot the explanatory power of the model.

INSERT TABLE 1 ABOUT HERE

Table 2 provides the results for the GMM estimation of Equation (17). The MPF level is regressed against its lagged value as well as the lagged value of capital output elasticity, in column (5). As expected, the lagged dependent variable shows a positive and significant coefficient. The output elasticity of capital also yields a negative effect on productivity. This means that an increase in the effectiveness of labour, which follows the increase in its relative price, is likely to yield general efficiency gains in the production process. The dynamics of multifactor productivity are therefore shaped by the introduction of biased technological change. This result is even stronger when the level of innovation efforts are introduced in the model, like in column (6). The statistical significance of   is indeed dramatically improved, while *TC* shows a positive and significant coefficient as well. This result allows us to conclude that systematic innovation efforts have a positive effect not only for the introduction of biased technological change, which ultimately implies a change in the shape of the isoquant, but also on the growth of MFP, which in turn implies the Hicks-neutral shift of the production function. The overall effect of technological change therefore seems to combine both the “bias” and the “shift” components.

INSERT TABLE 2 ABOUT HERE

In columns (7) and (8) we substitute the labour unit cost for capital output elasticity as a regressor. Following the previous estimations, we should expect the dynamics of wages to be positively related to productivity via the mechanisms of biased technological change. The results are definitely coherent with the proposed framework, supporting the idea that the dynamics of factor costs are likely to affect productivity dynamics through the introduction of biased technological change[4].

5. Conclusions

Internal labour markets and industrial relations in Continental Europe are characterized by substantial rigidity of employed labour. This rigidity affects the rate and the direction of technological change. Specifically it induces the localized introduction of non-neutral technological change directed towards the more intensive use of inputs that are becoming more expensive. In our theoretical underpinning the localized introduction of technological change is induced towards the more productive use of the inputs that are becoming more expensive because they are characterized by substantial rigidity and irreversibility. The localized introduction of biased technological change contrasts the classical inducement hypothesis according to which changes in input prices induce new biased technologies directed towards the most intensive use of inputs that are becoming relatively less expensive. The meta-substitution process articulated by the classical hypothesis is impeded by the irreversibility and rigidity of the existing inputs. Firms cannot fire their workers and substitute capital to labor when wages increase because of the strong bargaining power of unions. The rigidity of labor adds to the rigidity of capital, hence they are localized in a tiny technical region by the quasi irreversibility of both production factors. At the same time they are localized in a limited portion of the space of techniques by their limited knowledge and competence based upon learning processes that root their technological knowledge in a technical region that is close to their current factor intensity. Hence they cannot move along existing isoquants when the relative prices of inputs change. They prefer to try and innovate so as to introduce a new and superior technology that makes it possible to reconcile the marginal productivity of labor with the increased wages and is as close as possible to the existing one so as to reduce the amount of switching. This leads to the introduction of new localized and biased technologies that are directed towards the more intensive use of production factors that are becoming more expensive.

Our argument can be considered a direct application of the efficiency wages hypothesis. Strong labor unions are able to obtain an increase in wages and yet to rule out the substitution of capital to labor. Firms pushed to pay wages in excess of short-term productivity levels to their irreversible levels of incumbent employment are induced to try and match the twin constraint of their labor force with the introduction of new technologies that enable to increase their productivity. Technological change will be biased towards the more intensive use of labor when wages increase. Such a process is the result of an out-of-equilibrium context of action where the search for new technologies is induced by out-if-equilibrium conditions and engenders further out-of-equilibrium conditions. The successful introduction of new directed technologies in fact leads to an increase of MFP levels.

[4] It is worth noting that when including in the same regression the unit labour cost and innovation levels, the latter variable is likely to fully explain the variance in the dependent variable. In our framework innovation levels are indeed strongly related, and wages have an effect on productivity only through localized innovation efforts.

The evidence gathered confirms that technological change across the European regions in the decade 1995-2004 has been strongly biased. Technological change was neutral only in a large minority of cases. The introduction of new technologies has affected the output elasticity of production factors. This is the first and most important result of the analysis carried out in this paper: standard economics in fact assumes the neutrality of technological change. A theoretical effort is necessary to understand the determinants and the effects of directed technological change.

The econometric evidence confirms that the localized inducement mechanism in the European firms in the decade 1995-2004 has pushed firms facing a substantial increase in wage levels to introduce new localized technologies that are mainly directed towards the more intensive usage of capital. The analysis of total factor productivity enables to grasp the strong and positive effects of the localized introduction of biased and directed technologies on the general efficiency of the production process.

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Figure 1 – The basic frame of analysis

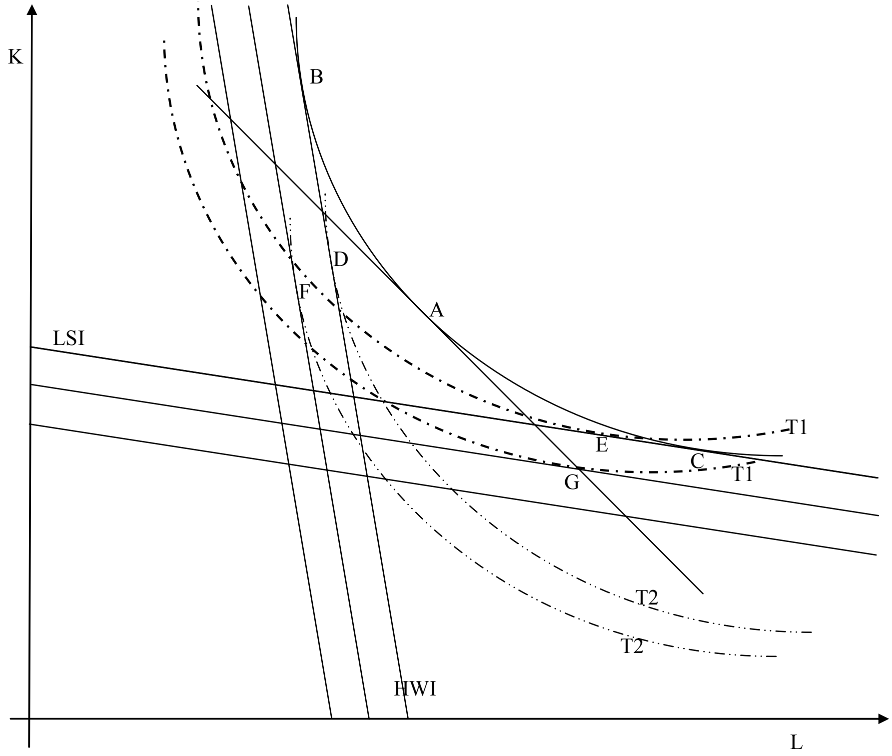

Figure 2 – Introduction of localized technological change

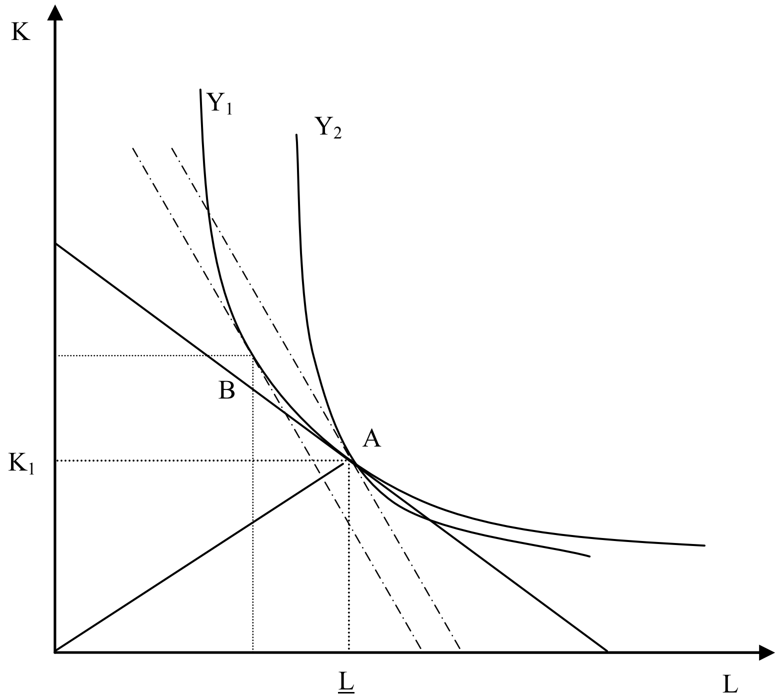

Figure 3 – Kernel density estimation for capital output elasticity

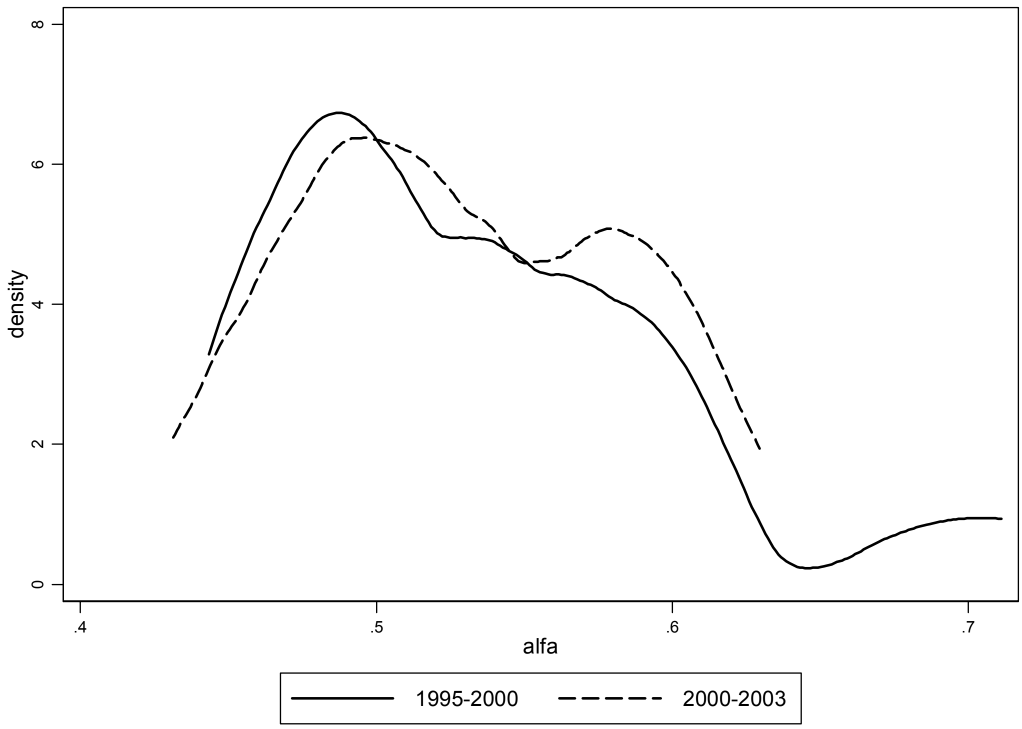

Figure 4 – Average levels of alpha, by region

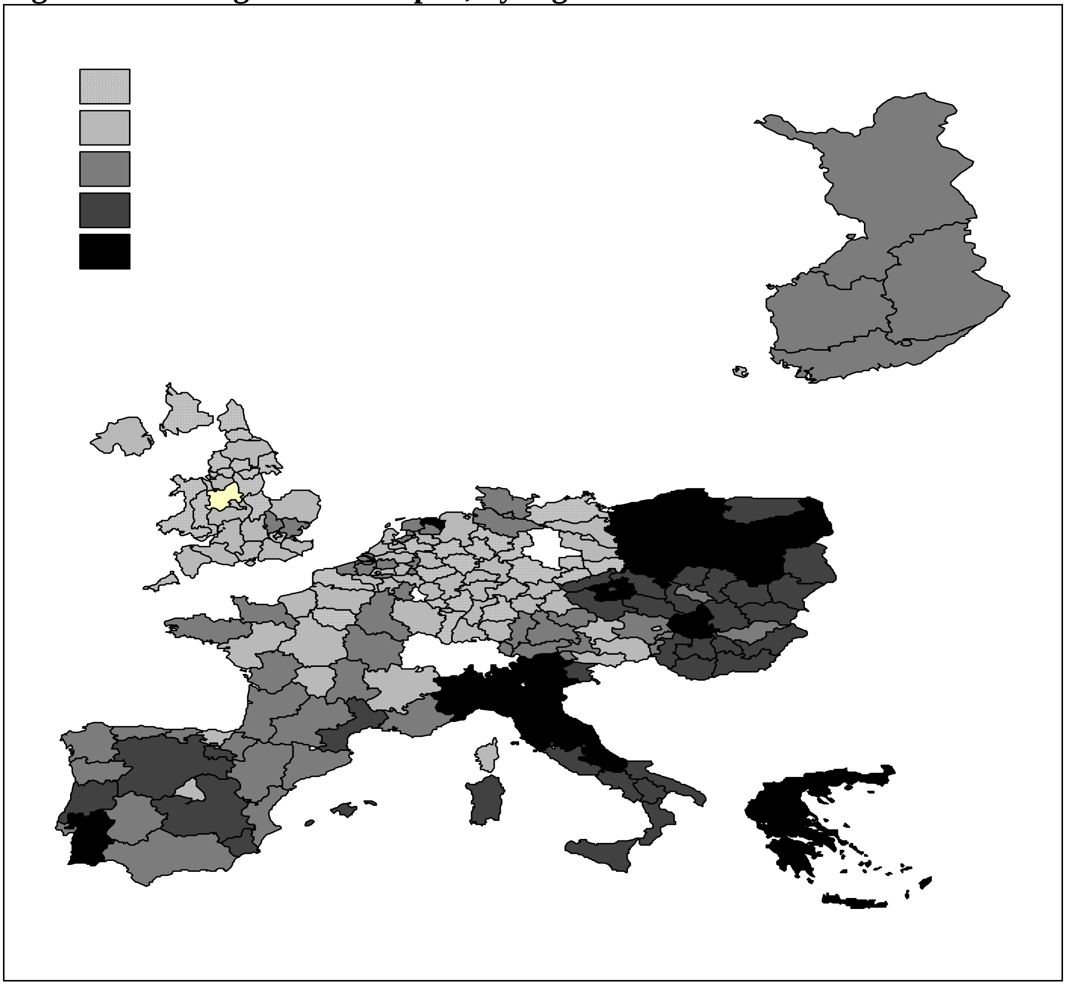

Figure 5 –Time dispersion of alpha (standard deviation), by region

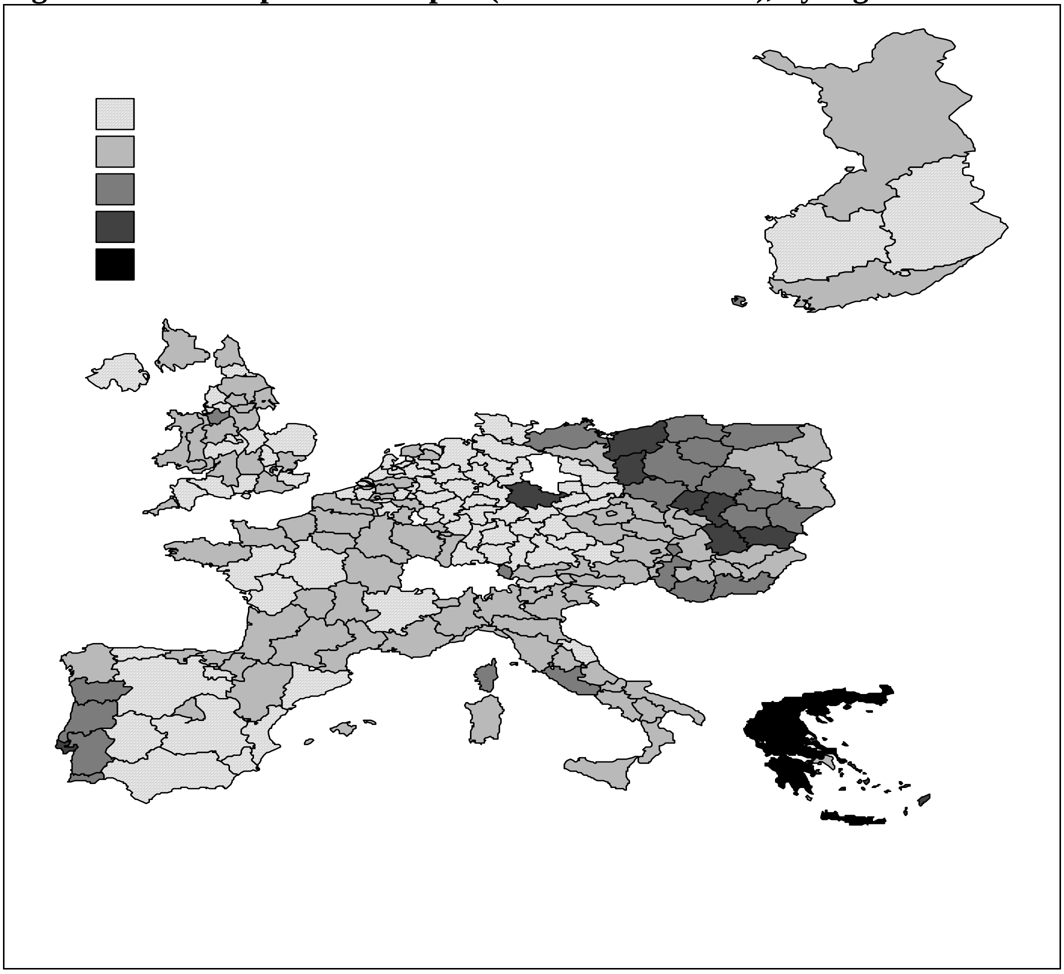

Table 1 - Fixed effect estimation of Equation (16)

	(1)	(2)	(3)	(4)
Dependent Variable	*log($_t$/ $_{t-1}$)*	*log($_t$/ $_{t-1}$)*	*log($_t$/ $_{t-1}$)*	*log($_t$/ $_{t-1}$)*
log($_{t-1}$)	-0.134***	-0.355***	-0.211***	-0.355***
	(0.0190)	(0.0337)	(0.0235)	(0.0421)
log(w_t/w_{t-1})	-0.214***	-0.369***	-0.229***	-0.388***
	(0.0204)	(0.0304)	(0.0279)	(0.0396)
log(TC_t/TC_{t-1})		0.000873*		0.000921*
		(0.000503)		(0.000521)
log[$(K/L)_t/(K/L)_{t-1}$]			0.0107	-0.0106
			(0.00815)	(0.00998)
Constant	-0.0741***	-0.221***	-0.120***	-0.213***
	(0.0121)	(0.0224)	(0.0148)	(0.0281)
Observations	1074	579	820	506
Number of id	127	95	127	95
R-squared	0.245	0.474	0.299	0.448

All regressions include time dummies. *** p<0.01; ** p<0.05; * p<0.1.

Table 2 – Robust GMM-SYS estimation of equation (18)

	(5)	(6)	(7)	(8)
Dependent Variable	*$logMFP_t$*	*$logMFP_t$*	*$logMFP_t$*	*$logMFP_t$*
log(MFP_{t-1})	0.984***	0.930***	0.900***	0.924***
	(0.0153)	(0.0300)	(0.0456)	(0.0340)
log(W_{t-1})			0.0654**	0.0421
			(0.0308)	(0.0269)
log(TC_{t-1})		0.00610***		0.00497***
		(0.00168)		(0.00137)
log($_{t-1}$)	-0.0661*	-0.101***		
	(0.0388)	(0.0382)		
Constant	-0.0191	0.0980	0.0408*	0.0240
	(0.0247)	(0.0635)	(0.0231)	(0.0394)
Observations	1074	710	1074	710
Number of id	127	102	127	102
AR(1) test	-6.84***	-5.71***	-6.68***	-5.78***
AR(2) test	1.50	0.90	1.49	0.84
Hansen test	23.52	99.32	28.62	95.50

Robust standard errors between parentheses. All Models control for region and time fixed effects.
*** p<0.01; ** p<0.05; * p<0.1.
The instruments used in each equation (where available and where the corresponding regressor is included in the model) are: log(MFP_{t-1}); log(MFP_{t-2}); log(W_{t-1}); log(W_{t-2}); log(TC_{t-1}); log(TC_{t-2}); log($_{t-1}$); log($_{t-2}$).