

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

Localized Technological Change and Efficiency Wages across European Regional Labour Markets

This is the author's manuscript

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/139802> since 2016-07-19T10:34:42Z

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)



UNIVERSITÀ DEGLI STUDI DI TORINO

Questa è la versione dell'autore dell'opera:

***Localized Technological Change and Efficiency Wages
across European Regional Labour Markets***

Regional Studies, volume 47, fascicolo 10, 2013,

DOI 10.1080/00343404.2012.690068

La versione definitiva è disponibile alla URL:

http://www.tandfonline.com/doi/abs/10.1080/00343404.2012.690068#.U1ZnDFV_uhs

Localized Technological Change and Efficiency Wages Across European Regional Labour Markets¹.

Cristiano Antonelli
BRICK (Bureau of Research in Innovation, Complexity Knowledge)
Collegio Carlo Alberto
Via Real Collegio 30
10024 Moncalieri (Torino) - Italy

Dipartimento di Economia “S. Cagnetti de Martiis”
Università di Torino
Via Po 53
10124 Torino – Italy

and

Francesco Quatraro (corresponding author)

Groupe de Recherche en Droit, Economie et Gestion (GREDEG)
CNRS and University of Nice Sophia Antipolis
250, rue Albert Einstein
06560 Valbonne, France
Tel. +33 4 93954373
Fax: +33 4 93653798
francesco.quatraro@unice.fr.

BRICK (Bureau of Research in Innovation, Complexity, Knowledge)
Collegio Carlo Alberto
Via Real Collegio 30
10024 Moncalieri (Torino) - Italy

¹ We acknowledge the funding of the European Union Directorate for Research, [with the Grant number 266959 to the research project ‘Policy Incentives for the Creation of Knowledge: Methods and Evidence’ \(PICK-ME\), within the context Cooperation Program / Theme 8 / Socio-economic Sciences and Humanities \(SSH\), in progress at the Collegio Carlo Alberto, the GREDEG and the University of Nice.](#) Authorship is alphabetical and for the purposes of assessment of responsibility, each author contributes equally to the paper.

ABSTRACT. Internal labour markets and industrial relations in Continental Europe are characterized by substantial rigidity of employed labour engendered by the tight conditions of regional labour markets. In regional labour markets with low levels of unemployment, the rigidity of employed labor increases 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 effective use of incumbent inputs that are becoming more expensive, with 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 provides significant support to these hypotheses and confirms the significant role of the changes in wages both on the increase of the output elasticity of labour and on multi factor productivity.

KEY-WORDS: induced approaches; localized technological change; efficiency wages; multi factor productivity growth; regional labor markets.

JEL CODES: O33, R11

1. Introduction

The empirical evidence across Europe shows that substantial changes have been taking place in the direction of technological change in the last decade. Technological change has been far from neutral: actually it exhibits a strong variance across European regions with a bias towards the introduction of labor intensive technologies in core regions characterized by low levels of unemployment and the reverse in peripheral regions with higher levels of unemployment. The analysis of conditions of European labor markets and more generally the identification of the irreversibility of production factors provides useful insights to understand the rate and the direction of technological change. In Continental Europe labour markets internal to firms 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. Such limitations are stronger the lower the levels of unemployment in regional labour markets. 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 as reflect the high levels of employment in external labor markets. These factors affect both the rate and the direction of technological change.

The institutional characteristics of labour markets and industrial relations in Continental Europe push to rely upon the localized technological change (LTC) approach to understand the relations between changes in wages, levels of (un)employment and the rate and the direction of technological change. The rate and direction of technological change in the last decades in Continental Europe has been in fact characterized by the introduction of new labor intensive technologies induced by the dynamics of wages.

In this paper we aim at elaborating a model to analyze the determinants of the direction of technological change and to identify its effects on productivity growth. 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 support 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.

The empirical evidence of regional labour markets in 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 low levels of unemployment and the strong bargaining power of organized labor, and the fast pace of introduction of LTCs directed towards the intensive use of labor, that can be appreciated in a comparative context.

The rest of the paper is structured as 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 1999-2004 and presents the econometric

tests of the model elaborated in paragraph 2. The conclusions summarize the main results and put them in perspective.

2. From the induced technological change hypotheses to the localized technological change approach: the role of labor rigidities

2.1 The background

The induced technological change approach is back at the centre stage of the economics of technological change, revived by the skill-bias debate that has brought new interest in the matter. In this context the LTC framework of analysis can accommodate and integrate three strands of the induced technological change literature: 1) the Marx-Hicks approach, 2) the Samuelson argument and 3) the efficiency wages hypothesis. Let us consider them in turn.

The original hypothesis of the induced technological change approach 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 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 one of the cornerstones of the economics of innovation. Ruttan (1997 and 2001) has proposed a weak inducement hypothesis according to which, next to changes in product market highlighted by Schumpeterian literature, also changes of factor market conditions play a central role in explaining the introduction of technological innovations.

The Samuelson-inducement hypothesis contrast the Hicksian approach and predicts that firms would direct their innovation efforts towards the augmentation of the output elasticity of the input that is locally more abundant irrespective of its, occasional, change in relative price. Hence, according to the Samuelson-inducement hypothesis, firms would be induced to increase the output elasticity of labor, in labor abundant regions, even if wages just increased (Kennedy, 1964; Samuelson, 1965). The Samuelson hypothesis provides an interesting clue to grasp the direction of technological change but does not account for the forces that induce the introduction of new technologies. The contributions of Acemoglu (1998 and 2002) have revived recently the analysis of the endogenous generation of directed technological change showing how innovations are aimed at making a more intensive use of human capital inputs that are becoming more abundant. In advanced countries human capital is now substituting fixed capital as the most abundant factor both in absolute and comparative terms.

In this context the rigidity of labor inputs exerts a key role and the notion of efficiency wages becomes relevant for assessing the rate and the direction of technological change. 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 (Akerloff and Yellen, 1986). Firms have indeed an incentive to set wages above the market-clearing level so as to discourage employees' opportunistic behaviour and shirking (Shapiro and Stiglitz, 1984). The increase in wages cum labor rigidity in fact 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 introduce technological innovations that make the existing employment more productive. This outcome is all the more plausible if and when efficiency wages actually enhance the commitment of employees to contribute the innovative efforts of their firms. The tacit competence accumulated by means of learning processes can be valorised and codified. Efficiency wages, in other words, induce more than the solution of organizational failures: they actually induce the introduction of technological changes biased towards higher levels of labor intensity.

The LTC framework of analysis can accommodate these three strands of literature in a coherent approach that is able to explore 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. Within an analytical framework à la Atkinson and Stiglitz (1969), firms that cannot move on the existing map of isoquants, have an incentive to try and increase the productivity of the existing production factors (Antonelli, 1995).

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 LTC 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). When firms are rooted by limited competence and quasi-irreversibility in a limited portion of the knowledge space, and the rigidity of their labor inputs, the direction of technological change is induced by the changes in their relative prices so as to keep the firm in the proximity of the existing factor intensity and enable the reduction of switching activities. The localized introduction of technological change is stirred by the changes in labor costs and is directed to using more intensively and systematically the labor inputs that are becoming more expensive so as to achieve an increase of output with a given level of inputs, i.e. a generalized increase of the efficiency of the production process.

When the levels of unemployment in labour markets decline, 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 by means of the introduction of biased technological changes (Antonelli, 2003).

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 enhanced by efficiency wages under the constraints of the irreversibility of existing production factors. 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 interaction between the rate and the direction of localized technological change and labour market rigidities is indeed likely to set in motion a circular mechanism wherein firms are themselves the primary engine of the continuous introduction of localized technological change and yet the characteristics of the system play a key role in assessing the duration and the characteristics of the dynamics. This approach enables to grasp how the different aspects of the system into which firms are embedded shapes their capability to react creatively to emerging out-of-equilibrium conditions that alter their expectations and programmes and creates new out-of-equilibrium conditions (Antonelli, 2011).

2.2 The model

In view of the arguments elaborated so far, we are now able to propose a simple model of LTC, 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:

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

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:

$$C_{i,t} = w_{i,t} L_{i,t} + r_{i,t} K_{i,t} \quad (2)$$

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:

$$\frac{w_{i,t}}{r_{i,t}} = \frac{(\partial Y / \partial L)}{(\partial Y / \partial K)} \quad (3)$$

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

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

And therefore:

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

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:

$$\frac{w_{i,t}}{r_{i,t}} = \frac{\bar{\beta}_i}{\alpha_i} \frac{K_{i,t}}{L_{i,t}} \quad (6)$$

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:

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

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 $d \log \left(\frac{\beta}{\alpha} \right) / dt = 0$, and therefore equation (7) boils down to:

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

The main argument of this paper is that changes in relative prices engender directed 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 our argument would maintain that firms choose to bear only innovation costs and avoid all factor substitution. This situation is exactly opposite to that represented in Equation (8). When wages increase, firms, in order to remain in the proximity of the original factor intensity, because of the rigidity of labor, have a clear incentive to introduce new technologies and direct them towards a more intensive use of their labor inputs, and hence in increase in β , that, assuming constant returns to scale, implies a reduction of α .

In this framework firms can change both capital and labour only by bearing significant switching costs that make the capital/labour ratio fixed. 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 (1) by the isoquant Y_2 . The starting point is the equilibrium point A, identified by the tangency between the original isocost and isoquant Y_1 . The new equilibrium point C represents the outcome of localized introduction of directed technological change. 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 induced introduction of LTC based upon the adjustment of the marginal rate of technical substitution between the two production factors.

This amounts to spell out the hypothesis that in contexts where both production factors K and L are irreversible, technological change is induced by changes in relative factor prices and directed towards the modification of the slope of the isoquant through the change of the ratio between output elasticities β and α .

INSERT FIGURE 1 ABOUT HERE

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

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

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

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

In this extreme situation, characterized by high levels of factor irreversibility, a change in relative prices induces the localized introduction of biased technological change that affects the ratio between labour and capital output elasticities such that the output elasticity of the production factor that has become more expensive will increase. This is fully consistent with the efficiency wages argument and, at least in advanced regions where human capital is becoming the most abundant factor, with the Samuelson-Acemoglu hypothesis. Moreover it retains the Hicks-Ruttan assumption according to which technological change is induced by changes in factor markets.

Specifically, if we acknowledge that the rigidity of labor, in internal labor markets, reflects the relative scarcity of labor, in regional labor markets, as measured by low levels of unemployment, we can fully articulate the LTC hypothesis according to which the localized introduction of technological change, stirred by the increase in wages, and supported by the valorization of the tacit competence of incumbent workers, is directed

towards the augmentation of the output elasticity of the existing labor inputs that are locally more scarce and hence more rigid.

The localized introduction of 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:

$$d \log A_{i,t} / dt = d \log Y_{i,t} / dt - \bar{\alpha}[d \log K_{i,t} / dt] - \bar{\beta}[d \log L_{i,t} / dt] \quad (11)$$

Where the bars over output elasticities, following the discrete approximation of the Divisia index, refer to the two years average of both α and β . In so doing we can appreciate to some extent the effects of the change in output elasticity on the difference between the expected output and the actual one, i.e. the residual. The residual is indeed affected both by the neutral shift of the map of isoquants as traditionally estimated through the methodology introduced by Solow (1957), and by the consequences of the changes in the slope of the map of isoquants, determined by the introduction of directed technological change. This effect can be appreciated by taking into account the changes in the output elasticities. The average of output elasticities over two periods enables us to grasp this bias effect (Antonelli and Quatraro, 2010).

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

- 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 technique defined in terms of capital/labour ratio characterizing their production process. In a frictionless world, a compensated change in factor markets conditions would 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 irreversibility of labour within firms is strictly dependent upon the conditions of local labour markets. In regions characterized by high levels of unemployment, trade unions are weaker and hence much less able to contrast the standard substitution of labour with capital. In such regions the increase of unit wages would not induce the localized introduction of new labour intensive technologies. In regions characterized by full employment, on the opposite, internal labour markets are much more rigid and all changes in the levels of employment, at the firm level, bear high levels of switching costs. In these regions firms cannot substitute easily capital to labour. The introduction of localized innovations becomes the most effective, if not the single, way to cope with the increase in unit wages. In sum, we argue that the levels of employment have a strong positive effect on the working of the inducement mechanism. The levels of employment affect directly and positively the localized introduction of

new, more labour intensive technologies, in response to an increase in unit wages.

- 3) 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 both the classical Hicks-inducement and the Samuelson-inducement mechanisms. Changes in wages are in fact expected to induce, and actually favor through the efficiency wages mechanisms, adaptation efforts grounded on innovation activities aiming at the localized introduction of technological change, enhanced by the valorization of tacit competence embedded in the organization and in labor, and directed to the more effective use of the labor inputs that have become more expensive, because of its rigidity that reflects its relative scarcity in the regional labor markets.
- 4) 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

3.1 *The estimation model and econometric procedures*

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 multi factor productivity (MFP). 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:

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

$$\alpha_{i,t} = 1 - \beta_{i,t} \quad (13)$$

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 it follows:

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

Following the 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 technological change. This leads us to model the growth rate of output elasticities as a function of relative prices. In addition, it must be stressed that LTC stems from the commitment of resources to innovation activities. Therefore, a proxy for innovation dynamics needs to be inserted in our specification. Finally, because of the relevance of regional labour markets we also consider the effects of unemployment. Indeed, the unemployment rate plays a key role as it shapes the extent to which trade unions may exert their bargaining power so as to make production factors irreversible. Hence, standard textbook macroeconomics suggests that the lower the level of unemployment, the stronger trade unions power. In such a context, if wage increase firms will be pushed to introduce technological change directed towards a more effective use of labour by increasing its output elasticity β , and hence reducing α . In view of this, our baseline econometric specification is the following:

$$\ln\left(\frac{\alpha_{i,t}}{\alpha_{i,t-1}}\right) = a + b \ln \alpha_{i,t-1} + c_1 \ln\left(\frac{w_{i,t-1}}{w_{i,t-2}}\right) + c_2 \ln\left(\frac{U_{i,t}}{(U_{i,t} + E_{i,t})}\right) + \rho_i + \sum \psi t + \varepsilon_{i,t} \quad (15)$$

Where the error term is decomposed in ρ_i and $\sum \psi t$, which are respectively region and time effects, and the error component ε_{it} . The growth rate of capital output elasticity (α) is regressed against its lagged level, so as to control for possible mean reversion effects, the growth rate of real unit wages (w), and the unemployment rate ($U/U+E$) by region i . Equation (15) can be estimated using traditional panel data techniques implementing the fixed effect estimator.

Moreover the introduction of a few control variables may help grasping the dynamics of the process. First, the effect of agglomeration economies needs to be accounted for and it is traditionally proxied in the literature by the population density (D) per square kilometres. Finally, the relative regional specialization in manufacturing industries (S) can also the results of our estimations (Quatraro, 2009), and therefore needs to be included in the econometric model, which turns out now to be the following:

$$\ln\left(\frac{\alpha_{i,t}}{\alpha_{i,t-1}}\right) = a + b \ln \alpha_{i,t-1} + c_1 \ln\left(\frac{w_{i,t-1}}{w_{i,t-2}}\right) + c_2 \ln\left(\frac{U_{i,t}}{(U_{i,t} + E_{i,t})}\right) + c_3 \ln(D_{i,t-1}) + c_4 \ln(S_{i,t-1}) + \rho_i + \sum \psi t + \varepsilon_{i,t} \quad (16)$$

According to the regional levels of employment, the localized introduction of technological change enables efficiency gains with respect to the labour inputs when 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:

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

Where MFP is multifactor productivity, α 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.

Equations (16) and (17) can be estimated through traditional fixed effect estimators for panel data. However, when analyzing the determinants of TFP growth at the regional level a special focus must be devoted to locational aspects. Regional scientists have indeed showed that geographical proximity may affect correlation between economic variables.

While the traditional econometric approach has mostly neglected this problem, a new body of literature has recently developed, dealing with the identification of estimators able to account for both spatial dependence between the relationships between observations and spatial heterogeneity in the empirical model to be estimated. Former treatment of spatial econometric issues can be found in Anselin (1988), subsequently extended by Le Sage (1999).

The idea behind the concept of spatial dependence is straightforward. The properties of economic and social activities of an observed individual are likely to influence economic and social activities of neighbour individuals. Formally this relationship can be expressed as follows:

$$y_{i,t} = h(y_{j,t}), i = 1, \dots, n, j \neq i \quad (18)$$

The dependence can therefore be among several observations. If this is the case, structural forms like equation (16) are likely to produce a bias in the estimation results. There are different ways to cope with this issue. First, one may apply spatial filters to the sample data, so as to remove the spatial structure and then apply traditional estimation techniques. Second, the relationship can be reframed using a spatial error model (SEM), in which the error term is further decomposed so as to include a spatial autocorrelation coefficient. Third, one may apply the spatial autoregressive model (SAR), which consists of including the spatially lagged dependent variable in the structural equation.

We decided to compare the SAR and SEM models in order to have a direct assessment of the spatial dependence of productivity growth between close regions. However, most of the existing literature on spatial econometrics propose estimator appropriate for cross-sectional data. Given the panel data structure of our sample, we therefore follow Elhorst (2003) extending Equation (16) so as to obtain the SAR (Eq. 19) and the SEM (Eq. 20) specifications:

$$\ln\left(\frac{\alpha_{i,t}}{\alpha_{i,t-1}}\right) = \xi W \ln\left(\frac{\alpha_{i,t}}{\alpha_{i,t-1}}\right) + b \ln \alpha_{i,t-1} + c X_{i,t-1} + \rho_i + \sum \psi t + \varepsilon_{i,t} \quad (19)$$

$$\ln\left(\frac{\alpha_{i,t}}{\alpha_{i,t-1}}\right) = b \ln \alpha_{i,t-1} + c X_{i,t-1} + \rho_i + \sum \psi t + \varepsilon_{i,t} + \phi_t \quad (20)$$

$$\phi_t = \delta W \phi_t + \mu_t, \quad E(\mu_t) = 0, \quad E(\mu_t \mu_t') = \sigma^2 I_N$$

We also extend Equation (17) so as to obtain the SAR (Eq. 21) and the SEM (Eq. 22) specifications:

$$\ln\left(\frac{MFP_{i,t}}{MFP_{i,t-1}}\right) = \psi W \ln\left(\frac{MFP_{i,t}}{MFP_{i,t-1}}\right) + d \ln MFP_{i,t-1} + e Z_{i,t-1} + \rho_i + \sum \psi t + \varepsilon_{i,t} \quad (21)$$

$$\ln\left(\frac{MFP_{i,t}}{MFP_{i,t-1}}\right) = b \ln MFP_{i,t-1} + e Z_{i,t-1} + \rho_i + \sum \psi t + \varepsilon_{i,t} + \phi_t \quad (22)$$

$$\phi_t = \delta W \phi_t + \mu_t, \quad E(\mu_t) = 0, \quad E(\mu_t \mu_t') = \sigma^2 I_N$$

Where X and Z are the vectors of regressors, ζ and ψ are referred to as spatially autoregressive coefficients, ϕ is the spatial component of the error model and W is a weighting matrix. This latter can be defined either as a contiguity or as a normalized distance matrix. In the analysis that follows we chose the second alternative, by building a symmetric matrix reporting the distance in kilometres among the city centre of the regional chief towns.

3.2 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 1995².

For what concerns the calculation of the MFP index, 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

² We acknowledge that the use of administrative regions to investigate represents only an approximation of the local dynamics underpinning economic activities. Indeed administrative borders are arbitrary, and therefore might not be representative of the spontaneous emergence of local interactions. It would be much better to investigate these dynamics by focusing on local systems of innovation. However, it is impossible to find out data at such a level of aggregation. Moreover, the identification of local systems involve the choice of indicators and threshold values according to which one can decide whether to unbundle or not local institutions. This choice is in turn arbitrary, and therefore it would not solve the problem, but it would only reproduce the issue at a different level. Thus we think that despite the unavoidable approximation, our analysis may provide useful information on the dynamics under scrutiny.

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).

The data about the unemployment rates across European regions, as well as those concerning population density, the total regional value added and the regional value added in manufacturing industries have been drawn by the Eurostat regional statistics.

For what concerns the role of formalized innovation efforts in the localized introduction of 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). In table 1 we report the correlation matrix for the variables considered in our empirical estimations.

INSERT TABLE 1 ABOUT HERE

Figures 2 to 4 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 2 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. This evidence conveys important information. 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 technological change.

INSERT FIGURE 3 ABOUT HERE

Figure 3 shows the distribution of sampled regions across capital output elasticities³. It is evident that the range of variation is quite large, falling in the interval [0.372, 0.758]. 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 the core regions such as all the UK regions, Northern France and the bulk of German regions.

A sharp partition 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 the employment conditions of the regional labour markets that make 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 peripheral Southern regions, the persistent specialization in traditional manufacturing regions and higher levels of unemployment still make capital output elasticity higher than that of labour, providing additional explanation to the rejuvenation of productivity gaps with the rest of most advanced countries. It seems clear that human capital is becoming the most abundant factor, both in absolute and comparative terms, in Northern regions, while Southern regions are still characterized by a relative abundance of fixed capital.

INSERT FIGURE 4 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 Eastern Europe regions, Portugal, Corsica and Campania. Some degree of variation can also be observed in Italian, French and UK regions, while most of German and Spanish regions are characterized 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 elasticities, 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.

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.

4. Econometric results: determinants and effects of LTC

In this Section we provide the results for the econometric estimations. Table 2 reports the fixed effect estimations of equation (16). This aims at assessing the effects of changes of factor costs on factors' output elasticity, so as to test the first and main hypothesis concerning the localized inducement of technological change. In column (1) one can find the baseline model, wherein the growth rate of capital output elasticity (α) is regressed against the growth rate of unit labour cost and the unemployment rate, while the lagged value of α 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 is more rigid and has become relatively more expensive, so as to adapt the marginal rate of technical substitution between factors accordingly.

In textbook production theory, when unit wages increase, factors substitution takes place and employment decreases. According to the Euler's theorem in fact the share of total wages on total value added does not change. In our approach instead firms do change their technologies in response to changes occurring in factor markets. Specifically, when unit wages increase, because of irreversibility of both capital and labour, positively associated with levels of unemployment in regional labour markets, firms are induced to introduce LTC directed towards a more effective use of labour. This dynamics is reinforced in core regions where human capital is becoming the most abundant production factor.

Therefore, if wages increase, in a context shaped by low levels of unemployment, labour output elasticity is expected to increase and hence, assuming constant returns to scale, capital output elasticity to fall. The results in column (1) are fully in line with this proposition. The coefficients of the growth rate of wages and unemployment are indeed both significant, being the former negative and the latter positive.

Column (2) shows the result of the estimation of the baseline enriched by the inclusion of the effects of agglomeration economies, proxied by the population density per square kilometres. It is interesting to note that this new regressor does not turn to be significant, and it does not affect the significance of our main variables, i.e. the growth rate of unit wages and the unemployment rate, which keep being respectively negative and positive.

In column (3) we also added the manufacturing specialization index, to mitigate the possible bias that the specialization in of mature and capital intensive activities might introduce in our estimates. Even in this case, the additional control variable did not change the substance of the results.

Finally, column (4) presents the results for the fully specified model. The coefficient for the growth rate of unit wages confirms to be negative and statistically significant, while the one for the unemployment rate keeps being positive and significant. Once again, the

coefficients for the control variables are 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 key role of unemployment are quite robust and persistent across different econometric specifications. The higher the level of unemployment, the lower the power of trade unions, which make it less problematic for firms to make a more intensive use of capital if wages increase, with a given technology. On the contrary, in regional contexts characterized by low levels of unemployment, trade unions are able to introduce a degree of rigidity such that firms may be better off only by increasing the effectiveness of (the irreversible stock of internal) labour.

INSERT TABLE 2 ABOUT HERE

We noted in the previous Section that the analysis of such phenomena at the regional levels may be significantly affected by the spatial structure of the data. For this reason we proposed to check for the robustness of our results by implementing two different estimation techniques, i.e. the SEM and the SAR model.

Table 3 shows the results for the SEM model (Equation (20)). The first column presents the baseline specification of the model, including the growth rate of wages and patents as well as the unemployment rate. Once again, the growth rate of wages shows a negative and significant coefficient, which is robust across all the four specifications. The same applies to the coefficient of the unemployment rate, which is positive and significant across all the specifications. As expected, the decomposition of the error term to account for spatial dynamics engendered an increase in the share of variance explained by the model.

>>>INSERT TABLE 3 ABOUT HERE<<<

Fairly similar evidence is provided by table 4, where the results of the SAR estimations (Equation (19)) are reported. The negative and significant effects of wages growth rates are persistent across all the specifications. The unemployment rate keeps showing a positive and significant effect on the growth rate of capital output elasticity in all the specification but the one presented in column (1). On the whole, the unemployment rate seems to be the variable that was most affected by the inclusion of the spatially lagged dependent variable in the structural form. Interestingly enough, the spatial lag of the dependent variable shows a negative and highly significant coefficient across all the different specifications. This evidence opens up interesting avenues for further research, which goes however beyond the scope of the present paper. It would suggest indeed that the explicit account for spatial dynamics of capital output elasticities can absorb the impact of unemployment rates. In other words, one could think about the effects of labour mobility across neighbour regions, and maintain that the introduction of LTC in a specific area is affected by the relative rather than absolute conditions of local labour markets.

>>>INSERT TABLE 4 ABOUT HERE<<<

So far, empirical results have provided support to the hypotheses that changes in wages are likely to affect the dynamics of capital output elasticities, i.e. they engender the

introduction of LTC. This is all the more important when the unemployment rates increase. The investigation of spatial dependence called for a more articulated view upon the role of unemployment and of the rate of technological change, taking into account the interactive dynamics with neighbour regions.

We can now turn to investigate the relationships between the introduction of LTC and the dynamics of productivity growth. Table 5 presents the results of the fixed estimation of Equation (17).

The MPF growth rate is regressed against the lagged value of MFP level as well as the lagged value of capital output elasticity, in column (1). As expected, the lagged dependent variable shows a positive and significant coefficient. This suggests that a β -convergence process features sampled regions (even though it is not a sufficient condition for this conclusion). 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 LTC. This result is persistent even when the level of innovation efforts are introduced in the model, like in column (2). The sign of the coefficient on α is indeed negative and significant again, while TC (our proxy for the intensity of technological efforts based on patents) shows a positive and significant coefficient. This result allows us to conclude that systematic innovation efforts have a positive effect not only for the introduction of LTC, 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 5 ABOUT HERE

In columns (3) 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 LTC. 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 LTC⁴. These results can be considered an important test of the positive effects of the mechanisms engendered by efficiency wages upon the efficiency of the production process. Such result is also persistent to the inclusion of innovation efforts (TC) in the picture (column (4), which in turn shows a positive and significant coefficient.

However, the issue of spatial dependence is particularly relevant when the dynamics of regional productivity growth are at stake. For this reason we present the estimations of the SEM and SAR models in tables 6 and 7. The results are quite in line with those showed in table 5.

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.

>>>INSERT TABLES 6 AND 7 ABOUT HERE<<<

The coefficient on the output elasticity of capital is negative and significant, suggesting that the decrease in the relative efficiency of capital, and hence an increase in the relative efficiency of labour, engenders an increase in the general efficiency of the production process. Moreover, the substitution of the wage rate for capital output elasticity also yields the expected results, providing further support to the hypotheses that the introduction of LTC stemming from the dynamic of relative factor prices is likely to significantly affect the growth of multi-factor productivity.

5. Conclusions

Internal labour markets and industrial relations reflect the conditions of local factor markets and specifically of regional unemployment. In regions with low levels of unemployment, trade unions have much a stronger bargaining power with clear effects in terms of the substantial rigidity of employed labour. This rigidity affects the rate and the direction of technological change. Specifically it induces the localized introduction of biased technological change directed towards the more intensive use of inputs that are becoming more expensive and yet cannot be dismissed. In our theoretical underpinning LTC is induced towards the more productive use of the existing labour inputs that are becoming more expensive because they are characterized by substantial rigidity and irreversibility.

When local labor markets are characterized by relative scarcity, hence high wages and low levels of unemployment, 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 firms 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 the existing production factors that are becoming more expensive.

Our argument can be considered a direct application of the efficiency wages hypothesis. Strong labour unions are able to obtain an increase in wages and to rule out the substitution of capital to labour, but are able to increase the commitment and dedication of labor force in the valorization of internal competence based upon learning by doing. 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-of-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.

The evidence gathered confirms that technological change across the European regions in the period we considered has been strongly biased and uneven. 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.

The econometric evidence confirms that the localized inducement mechanism in Europe 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 labor. The working of regional labour markets exerts a strong and significant effect on the direction and intensity of the localized introduction of new technologies in response to the increase of unit wages. 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.

The understanding of the economic complexity of technological change enables to grasp the dynamics of the iterative interplay between the determinants and the effects of LTC. A double loop in fact is likely to take place. High levels of employment are at the origin of the increasing in unit wages. Firms however can substitute capital to labour only in regions with high levels of unemployment. In regions with high levels of employment, instead, firms can cope with the increase of unit wages only the localized introduction of new technologies that make a more effective use of the existing labour inputs. The successful introduction of such new technologies is likely to reduce further the levels of unemployment in regional labour markets and hence to push towards the additional increase of unit wages. A self-reinforcing process is clearly at work with important dynamics effects that confirm that technological change is an emerging property of a typical system dynamics.

6. References

- Acemoglu, D. (1998), Why do new technologies complement skills? Directed technological change and wage inequality, *Quarterly Journal of Economics*, 113, 1055-1089.
- Acemoglu, D. (2002), Directed technological change, *Review of Economic Studies* 69, 781-809.
- Acs, Z.J., Anselin, L. and Varga, A. (2002) Patents and innovation counts as measures of regional production of new knowledge, *Research Policy*, 31, 1069-1085.

Akerloff, G.A. and Yellen, J.L. (1986), *Efficiency wages models and the labor market*, Cambridge University Press, Cambridge.

Antonelli, C. (1995), *Localized technological change and industrial dynamics*, Amsterdam, Kluwer.

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

Antonelli, C. (ed.) (2011), *The economic complexity of technological change*, Edward Elgar, Cheltenham.

Antonelli, C. and Quatraro, F. (2010), The effects of biased technological change on total factor productivity. Empirical evidence from a sample of OECD countries, *Journal of Technology Transfer*, 35, 361-383.

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

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

Elhorst, P. J. (2003), Specification and estimation of spatial panel data models. *International Regional Science Review* 26, 244-268.

Griliches, Z. (1990), Patent statistics as economic indicators: A survey, *Journal of Economic Literature*, 28, 1661-1707.

Habbakuk, H.J. (1962), *American and British technology in the nineteenth century: Search for labor saving inventions*, Cambridge University Press, Cambridge.

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

Jorgenson, D.W. (1995), *Productivity Volume 1: Post-war US economic growth*, Cambridge, MA, MIT Press.

Kennedy, C. (1964), Induced bias in innovation and the theory of distribution, *Economic Journal* 74, 541-47.

Le Sage, J.P. (1999), *The theory and practice of spatial econometrics*, Department of Economics, University of Toledo, available at www.spatial-econometrics.org.

Levin, A., Lin, C., Chu, C. (2002), Unit root tests in panel data: Asymptotic and finite-sample properties, *Journal of Econometrics*, 108, 1-24.

Marquetti, A.A. (2003), Analyzing historical and regional patterns of technical change from a classical-Marxian perspective, *Journal of Economic Behavior and Organization* 52, 191-200.

OECD, (2001), *Measuring productivity. Measurement of aggregate and industry-level productivity growth*, Paris.

Pavitt, K. (1985), Patent statistics as indicators of innovative activities. Possibilities and problems, *Scientometrics*, 7, 77-99.

Quatraro, F. (2010), Knowledge Coherence, Variety and Productivity Growth: Manufacturing Evidence from Italian Regions, *Research Policy*, 2010, 39, pp. 1289-1302.

Quatraro, F. (2009), Innovation, structural change and productivity growth. Evidence from Italian regions, 1980-2003, *Cambridge Journal of Economics*, 33, 1001-1022.

Rosenberg, N. (1969), The direction of technological change: Inducement mechanisms and focusing devices, *Economic Development and Cultural Change* 18, 1-24

Rosenberg, N. (1974), Karl Marx and the economic role of science, *Journal of Political Economy* 82, 713-728.

Rosenberg, N. (1976), Marx as a student of technology, *Monthly Review* 28, 56-77.

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

Salter, W.E.G. (1966), *Productivity and technical change*, Cambridge University Press, Cambridge, 2nd edition.

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

Shapiro, C. and Stiglitz, J. E. (1984), Equilibrium unemployment as a worker discipline device, *American Economic Review* 74, 433-44.

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

Figure 1 – Introduction of localized technological change

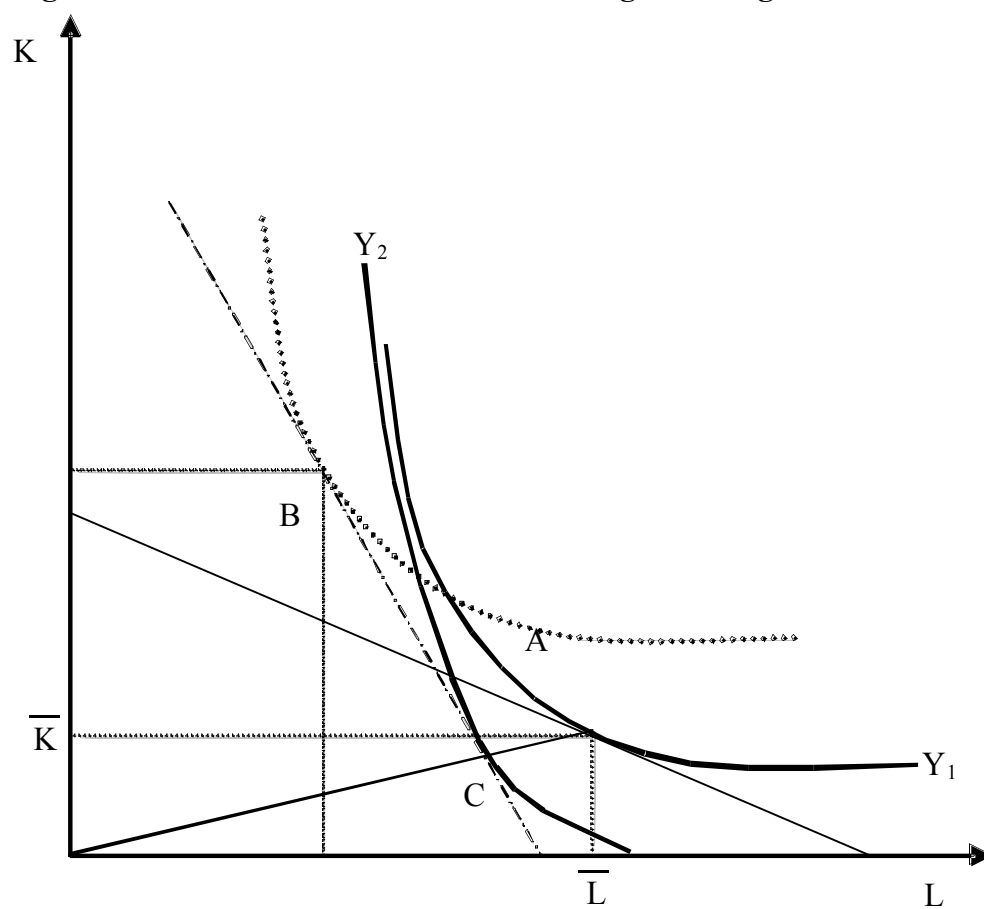


Figure 2 – Kernel density estimation for capital output elasticity

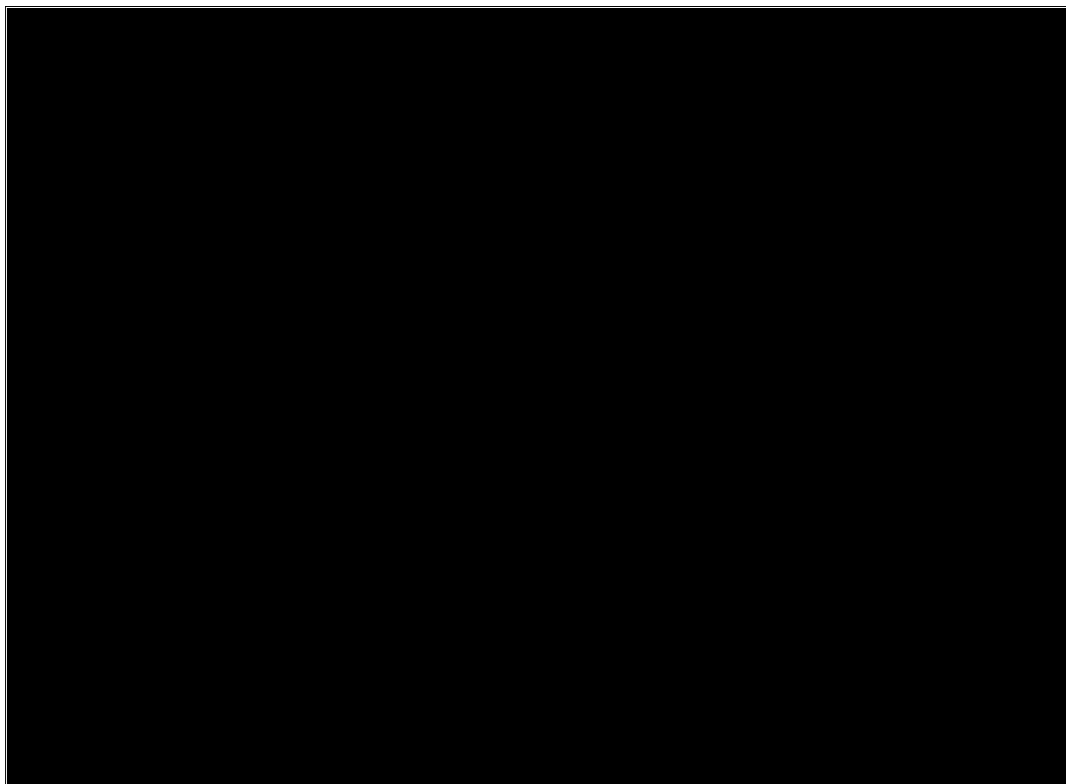


Figure 3 – Average levels of alpha, by region

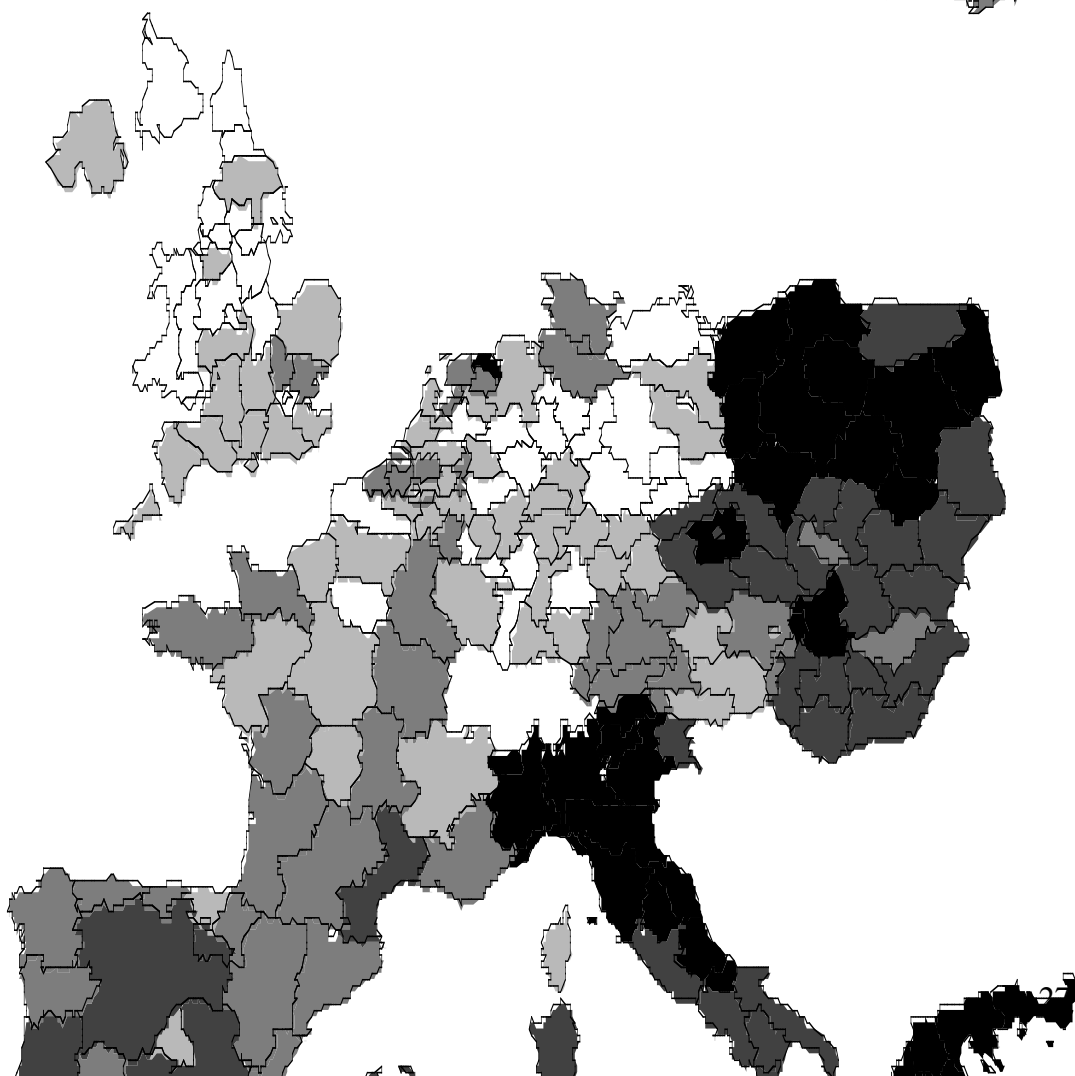
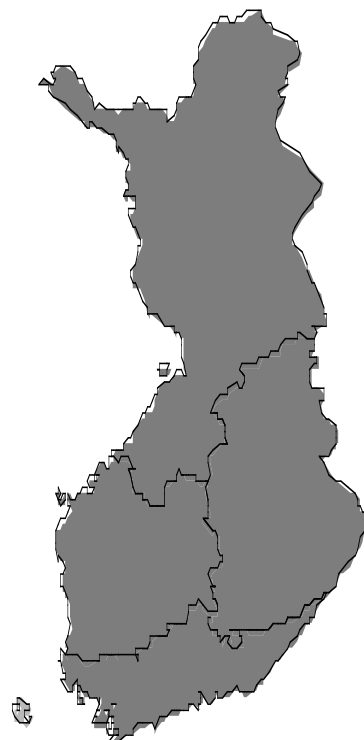
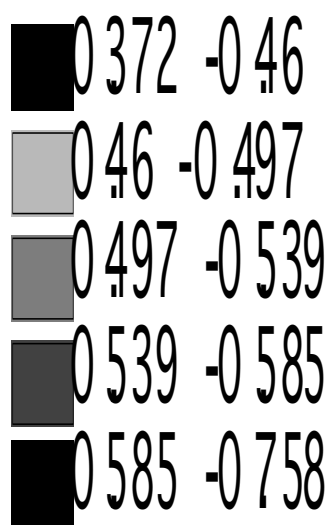


Figure 4 –Time dispersion of alpha (standard deviation), by region

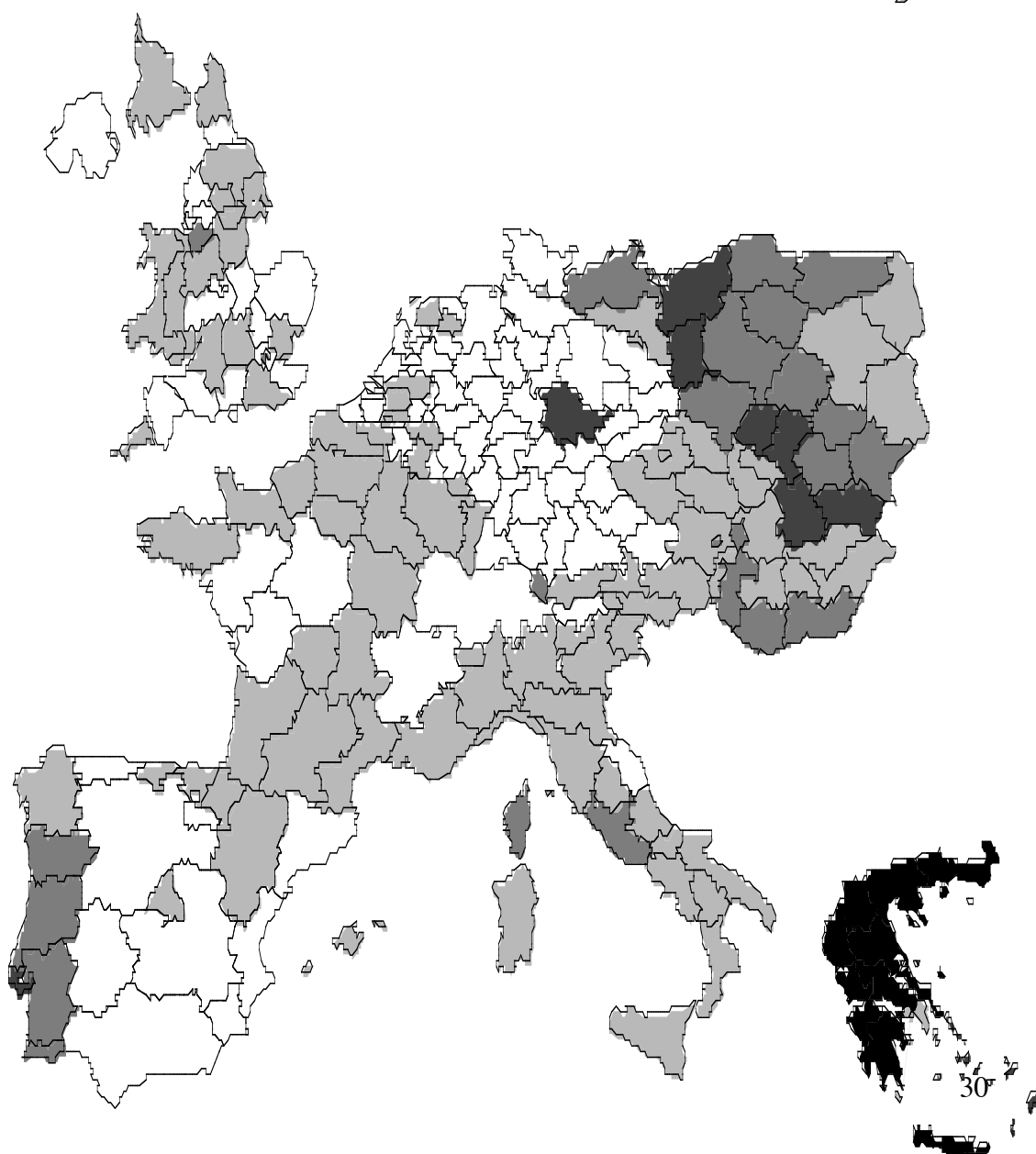
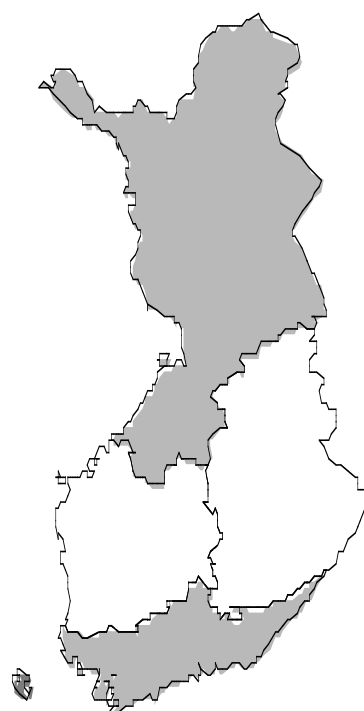
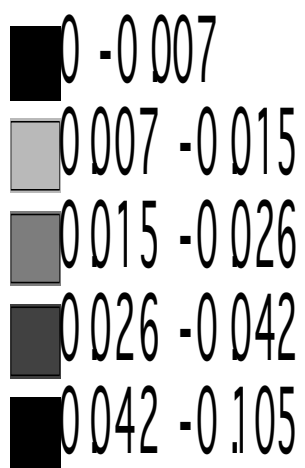


Table 1 - Correlation matrix

	$\log(\alpha_t/\alpha_{t-1})$	$\log(\alpha_{t-1})$	$\log(w_{t-1}/w_{t-2})$	$\log[U_t/(E_t+U_t)]$	$\log(TC_{t-1}/TC_{t-2})$	$\log(D_{t-1})$	$\text{Log}(S_{t-1})$	$\log[(K/L)_t/(K/L)_{t-1}]$
$\log(\alpha_t/\alpha_{t-1})$	1							
$\log(\alpha_{t-1})$	-0.0978	1						
$\log(w_{t-1}/w_{t-2})$	-0.367	0.1319	1					
$\log[U_t/(E_t+U_t)]$	-0.06	-0.1071	-0.0015	1				
$\log(TC_{t-1}/TC_{t-2})$	0.0482	0.038	0.0264	-0.0385	1			
$\log(D_{t-1})$	0.1033	-0.1989	-0.0654	-0.0472	0.0006	1		
$\text{Log}(S_{t-1})$	0.0303	0.0435	-0.0333	-0.4709	0.0373	-0.2981	1	
$\log[(K/L)_t/(K/L)_{t-1}]$	-0.0811	0.265	0.229	-0.0369	0.1336	-0.0841	-0.023	1

Table 2 - Fixed Effect Estimation of Equation (16)

Dep Var	(1) $\log(\alpha_t/\alpha_{t-1})$	(2) $\log(\alpha_t/\alpha_{t-1})$	(3) $\log(\alpha_t/\alpha_{t-1})$	(4) $\log(\alpha_t/\alpha_{t-1})$
$\log(\alpha_{t-1})$	-.796*** (.042)	-.789*** (.042)	-.762*** (.045)	-.764*** (.045)
$\log(w_{t-1}/w_{t-2})$	-.081*** (.021)	-.075*** (.021)	-.064*** (.022)	-.064*** (.022)
$\log[U_t/(E_t+U_t)]$.007* (.005)	.011** (.005)	.010** (.005)	.012** (.005)
$\log(D_{t-1})$.160* (.087)		-.029 (.019)
$\log(S_{t-1})$			-.036** (.018)	.116 (.092)
Constant	-.572*** (.033)	-1.423*** (.466)	-.612*** (.039)	-1.224 (.484)
Observations	588	588	588	588
R-squared	0.474	0.478	0.479	0.481
Number of id	147	147	147	147

All regressions include time dummies. Standard errors between parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.

Table 3 - Emprical Estimations of Equation (20) (Spatial Error Model)

	(1)	(2)	(3)	(4)
Dep Var	$\log(\alpha_t/\alpha_{t-1})$	$\log(\alpha_t/\alpha_{t-1})$	$\log(\alpha_t/\alpha_{t-1})$	$\log(\alpha_t/\alpha_{t-1})$
$\log(\alpha_{t-1})$	-0.787*** (-21.67)	-0.789*** (-21.80)	-0.750*** (-19.47)	-0.755*** (-19.61)
$\log(w_{t-1}/w_{t-2})$	-0.095*** (-5.154)	-0.092*** (-5.045)	-0.079*** (-4.106)	-0.078*** (-4.10)
$\log[U_t/(E_t+U_t)]$	0.009* (1.652)	0.011** (1.926)	0.011** (2.038)	0.012** (2.22)
$\log(D_{t-1})$		0.183** (2.210)		0.152* (1.83)
$\log(S_{t-1})$			-0.048*** (-2.745)	-0.043** (-2.44)
Spat. Aut.	-0.990 (-1.46)	-0.989 (-1.46)	-0.990 (-1.47)	-0.990 (-1.46)
Observations	588	588	588	588
R-squared	0.587	0.591	0.592	0.594
Number of id	147	147	147	147

All regressions include time dummies. t-values between parentheses. *** p<0.01; ** p<0.05; * p<0.1.

Table 4 - Emprical Estimations of Equation (19) (Spatial Autoregressive Model)

Dep Var	(1) $\log(\alpha_t/\alpha_{t-1})$	(2) $\log(\alpha_t/\alpha_{t-1})$	(3) $\log(\alpha_t/\alpha_{t-1})$	(4) $\log(\alpha_t/\alpha_{t-1})$
$\log(\alpha_{t-1})$	-0.770*** (-20.57)	-0.771*** (-20.68)	-0.742*** (-19.00)	-0.747*** (-19.14)
$\log(w_{t-1}/w_{t-2})$	-0.074*** (-3.75)	-0.071*** (-3.61)	-0.064*** (-3.19)	-0.063*** (-3.14)
$\log[U_t/(E_t+U_t)]$	0.008 (1.36)	0.009* (1.60)	0.010* (1.73)	0.011** (1.90)
$\log(D_{t-1})$		0.191** (2.31)		0.165** (1.98)
$\log(S_{t-1})$			-0.042** (-2.35)	-0.036** (-2.03)
W*dep.var.	-0.870*** (-2.70)	-0.901*** (-2.82)	-0.681** (-2.13)	-0.725** (-2.68)
Observations	588	588	588	588
R-squared	0.593	0.597	0.596	0.597
Number of id	147	147	147	147

All regressions include time dummies. t-values between parentheses. *** p<0.01; ** p<0.05; * p<0.1.

Table 5 - Fixed Effects estimation of Equation (17)

Dep Var	(1) $\log(MFP_t/MFP_{t-1})$	(2) $\log(MFP_t/MFP_{t-1})$	(3) $\log(MFP_t/MFP_{t-1})$	(4) $\log(MFP_t/MFP_{t-1})$
$\log(MFP_{t-1})$	-.575*** (.055)	-.598*** (.0537)	-.648*** (.055)	-.640*** (.055)
$\log(\alpha_{t-1})$	-.310** (.160)	-.249* (.156)		
$\log(TC_{t-1})$.041*** (.009)		.028*** (.010)
$\log(W_{t-1})$.214*** (.045)	.155*** (.049)
Constant	1.315*** (.153)	1.590*** (.161)	1.042*** (.158)	1.324*** (.187)
Observations	372	372	372	372
R-squared	0.287	0.333	0.333	0.351
Number of id	93	93	93	93

All regressions include time dummies. Standard errors between parentheses. *** p<0.01; ** p<0.05; * p<0.1.

Table 6 - Empirical estimations of Equation (22) (Spatial Error Model)

Dep Var	(1) <i>log(MFP_{it}/MFP_{t-1})</i>	(2) <i>log(MFP_{it}/MFP_{t-1})</i>	(3) <i>log(MFP_{it}/MFP_{t-1})</i>	(4) <i>log(MFP_{it}/MFP_{t-1})</i>
log(MFP _{t-1})	-0.425*** (-9.483)	-0.469*** (-10.33)	-0.481*** (-10.26)	-0.532*** (-11.20)
log(α_{t-1})	-0.226* (-1.70)	-0.212* (-1.63)		
log(TC _{t-1})		0.027*** (3.86)		0.028*** (4.10)
log(W _{t-1})			0.144*** (3.75)	0.149*** (3.97)
Spat. Aut.	-0.98 (0.14)	-0.99 (-1.46)	-0.99 (-1.46)	-0.98 (-1.46)
Observations	372	372	372	372
R-squared	0.492	0.512	0.507	0.529
Number of id	93	93	93	93

All regressions include time dummies. t-values between parentheses. *** p<0.01; ** p<0.05; * p<0.1.

Table 7 - Empirical estimations of Equation (21) (Spatial Autoregressive Model)

Dep Var	(1) $\log(MFP_t/MFP_{t-1})$	(2) $\log(MFP_t/MFP_{t-1})$	(3) $\log(MFP_t/MFP_{t-1})$	(4) $\log(MFP_t/MFP_{t-1})$
$\log(MFP_{t-1})$	-0.422*** (-9.25)	-0.467*** (-10.05)	-0.479*** (-9.93)	-0.531*** (-10.77)
$\log(\alpha_{t-1})$	-0.23* (-1.74)	-0.216* (-1.67)		
$\log(TC_{t-1})$		0.027*** (3.92)		0.029*** (4.17)
$\log(w_{t-1})$			0.146*** (3.80)	0.151*** (4.02)
W*dep.var.	-1.00** (-2.35)	-1.00** (-2.40)	-1.00** (-2.43)	-1.00** (-2.50)
Observations	372	372	372	372
R-squared	0.509	0.528	0.524	0.545
Number of id	93	93	93	93

All regressions include time dummies. t-values between parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$.