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**The microeconomics of directed technological change.
The evidence at the firm level**

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The microeconomics of directed technological change. The evidence at the firm level[1]

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Abstract

This paper aims at exploring the determinants of the direction of technological change at the firm level of analysis. Following the localized technological change approach, we suggest that firms will respond to change in factor market costs by introducing neutral or biased technological changes according to their innovation and knowledge generation related attributes. In the empirical analysis we use a panel of 1113 companies listed on UK and the main continental Europe financial markets (Germany, France and Italy) for the period 1995-2003. We find that small firms, relying more on tacit knowledge than on formal research and development activities, and less able to appropriate the benefits of their technological innovations are more likely to introduce biased technological change in order to make a more intensive use of the factor that has become more abundant.

Key words: biased technological change, localized technological change, innovation

JEL classification: O3, O33

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1. Introduction

There is large and growing evidence at the aggregate level that technological change introduced in the last years has been characterized by a strong bias directed towards the more intensive use of fixed and human capital. The debate has concentrated on both the determinants and the effects of such a directionality of technological change at the aggregate level (Acemoglu, 1998). The direction of technological change has been interpreted as a result of the effort to appreciate the relative abundance of production factors such as tangible and intangible capital. Advanced countries have been able to introduce radical innovations that were more efficient both in absolute and relative terms. In other words advanced countries have been able to change both the position and the shape of the map of the isoquants that represent the new technologies (Acemoglu and Zilibotti, 2001; Hall and Jones, 1999). Countries less able to master the generation of technological knowledge and to shape its direction have been much less able to take advantage of the benefits stemming from the introduction of new technologies conceived and designed in advanced countries (Caselli and Coleman, 2006).

While the debate on the causes and consequences of the direction of technological change has flourished with much empirical investigations at the aggregate level, little analysis has been provided on the microeconomics of biased technological change. At the firm level the direction of technological change is not homogeneous as it exhibits consistent differences and substantial variance across firms. So far little attention has been paid to exploring the determinants of the variance in the direction of technological change at the firm level. No attempts have been made to appreciate the effects of the characteristics of firms, instead of countries, on the direction of technological change. Yet the direction of technological change and the bias of new technologies vary at the firm level as much as their characteristics such as size, command of technological knowledge, and types of innovations being introduced (Scherer, 1984).

The paper aims at filling this gap. Section 2 implements the framework of analysis provided by the localized technological change approach so as to elaborate a microeconomic analysis of the determinants of biased technological change. Section 3 provides an econometric analysis of the hypotheses highlighted in section 2 based upon a dedicated data base covering 1113 public companies active in 10 different sectors and 4 European economies for the period from 1995 to 2003. The conclusions summarize the results of the analysis.

2. The localized introduction of biased technological changes

The localized technological change approach provides an integrated analytical frame that enable to integrate the theory of production and the theory of the firm into a broader economics of innovation. In the localized technological change approach firms are induced to innovate by the mismatch between their expectations and the actual conditions of product and factor markets. Substantial irreversibilities and cognitive limitations reduce the possibility of firms to adapt to the new and unexpected product and factor market conditions by means of the traditional movements in the existing map of isoquants. Relevant switching costs are in fact requested both to move along existing isoquants when the relative cost of production factors change and across isoquants when the demand is different from the planned output. Switching activities are required to change the endowments of tangible and intangible capital stocks and to acquire the necessary competence and knowledge about production techniques that are far away from the specific conditions in terms of factor intensity and output levels associated with the original equilibrium levels. In order to reduce the switching costs stemming from the need to cope with changes in the relative costs of inputs in factor markets and in the demand levels with respect to the expected ones, firms consider the opportunity for searching and generating new technological knowledge and introduce new technologies that enable them to fit in the new product and factor markets. The active introduction of technological change and hence the change in the map of the isoquants becomes an alternative to the passive adaptation consisting in technical changes upon the existing map of isoquants.

Firms differ both in terms of the levels of cognitive limitations and the amount of switching costs. The changing balance between these factors has a direct bearing on the types of innovation and the characteristics of technological changes introduced. In the localized technological change approach, in fact, the introduction of technological change is induced by the trade-off between switching costs and innovations costs. The relative costs of switching and innovation stem both from external and internal factors. High switching costs stemming from tense industrial relations can be specific to a country or, rather, to a firm because of its characteristics, such as size, organization procedures, types of management. For the same token innovation costs may be low for the large stocks of competence and high levels of efficiency in the generation of technological knowledge internal to individual firms or for the knowledge externalities made available by high quality of local pools of external knowledge and important scientific infrastructure localized in proximity.

The microeconomic exploration of the determinants of technological change within the framework of the localized technological change approach enables to implement a consistent interpretation of the broad array of factors that cause the rate and the direction of technological change. The localized technological change approach builds upon the tradition of the induced technological change, but enables to accommodate much a broader range of outcomes and determinants within the same integrated framework. Let us articulate this claim. First, in the induced technological change approach technological change cannot be neutral. According to the approach established by Hicks (1932) and implemented by Ruttan (1997, 2001), technological changes are introduced by firms to face the change in the relative prices of production factors and can be considered as a form of augmented factor substitution. According to the line of analysis synthetized by Samuelson (1965), technological change is induced by the opportunities to make the best use of locally more abundant factors. In both versions, the induced technological change is necessarily biased. Second, in the induced technological change approach there is no room to accommodate the demand pull hypothesis elaborated by Kaldor (1981). The localized technological approach instead accommodates the demand-pull hypothesis as well as the case of both neutral and biased technological changes induced by the change in the relative prices of inputs. All changes in the original localization in the map of isoquants in fact engender switching costs that can be avoided by means of the introduction of technological changes. Technological innovations are induced by the effects of changes in demand and in factor costs because of irreversibility and cognitive limitations. The actual direction and intensity of localized technological change will depend upon the relative weight of cognitive limitations and major irreversibilities of the innovating firms' stocks of tangible and intangible capital.

According to its original formulation, technological change is localized by the source of competence and knowledge that is acquired mainly if not exclusively by means of learning by doing, learning by using and learning by interacting. The origins of such 'tacit' knowledge limit the ray of possible innovations. As Atkinson and Stiglitz (1969) note "knowledge acquired through learning by doing will be located at the point where the firm (or economy) is now operating" (p. 574). In order to introduce technological innovations such firms rely mainly if not exclusively upon a form of localized technological knowledge based upon the skills of the workforce active at the plant level and implemented in the interactions with customers and clients. Localized technological knowledge has been built out of learning activities. It is the result of bottom-up processes of induction based upon tacit knowledge that is eventually implemented and codified. Firms can improve the technologies they have been able to practice and upon which they have acquired a distinctive competence that is characterized by an idiosyncratic and narrow scope of application. Localized technological knowledge cannot be easily stretched and applied far away from its original locus of accumulation. These firms are not able to command a broad and codified base of scientific knowledge and to extract out of it, with the typical top-down deductive procedure, a wide range of new possible applications that can characterize all the range of production techniques represented on the full isoquant.

The original notion of localized technological change has been implemented systematically so as to appreciate not only the role of technological opportunities stemming from localized learning processes, but also the constraints to the mobility of firms, along the existing isoquants, stemming from the irreversibility of production factors and the rigidity of industrial relations. The irreversibility of production factors and the rigidity of industrial relations can engender switching costs that need to be accounted when firms try and cope with changes in the levels of unit wages. According to the actual levels of switching costs firms will be able to change the factor intensity of their production process and combine it with the introduction of new technologies that increase the output efficiency of the production process by means of changes in the position of the maps of isoquants. Another relevant aspect of the localized technological change approach that has been implemented so far concerns the representation of the new localized technology. The original specification of Atkinson and Stiglitz, although quite informally, represented the new technology as a single technique, instead of a new full map of isoquants shaped by the combined effects of the technological opportunities stemming from localized knowledge and the constraints of the switching costs. In our approach, the new technology, induced by a change in the levels of unit wages and localized by local knowledge and varying levels of switching costs, can be represented by a full map of isoquants that are shaped by the constrained quest for the efficiency represented by the slope of the new isocost (Antonelli, 2010).

In Figure 1 firms in equilibrium in region A explore the surroundings techniques within the limits of the ray OA. Firms try and move from region A in the attempt to produce the same quantity with a lower amount of inputs and, hence, to increase their efficiency by means of new technologies (Farrell, 1957). The farther they move away from A along the isocline and the more expensive is both the generation of the necessary technological knowledge and the introduction of technological innovations, respectively, because of missing competence and switching costs. The new techniques that allow for the most intensive use of cheaper inputs are likely to engender the most effective results in term of output.

The localized technological change approach enables not only to set forth the hypothesis that firms with low innovation costs and high switching costs will innovate more than firms with low switching costs and high innovation costs, but also to explore the determinants of the direction of technological change.

When factor costs change the textbook firm would simply adapt to the factor markets conditions by means of the traditional substitution along existing isoquants reaching the new equilibrium point B identified on the old isoquant by the slope of the new isocost. In the localized technological change approach firms rooted by high levels of irreversibility and cognitive limitations will try and remain in the proximity of the original equilibrium technique, identified by the isocline OA in Figure 1, by means of the introduction of localized technological changes. A fully localized technological change consists in the introduction of a new technology that enables the firm to stay along the original isocline OA that links the origin to the old equilibrium so as to keep the same technique, defined in terms of factor intensity, upon which learning processes have been taking place. Technological change will be mainly if not fully neutral and will consist mainly if not only of a strong shift effect that enables the firm to move along the isocline OA towards the new equilibrium point C in Figure 1, moving the map of isoquants towards the origin until it reaches the new isocost and actually going beyond.

Technological changes, introduced by firms that are less rooted in a specific production context because of the lower irreversibility of their stock of tangible and intangible capital and less able to command a strong technological base that enables them to actually introduce new original technologies, may try and blend technical change with technological change so as to introduce directed instead of neutral technological change with a strong(er) bias effect. These firms in fact will introduce a new localized and directed technology that combines the shift with a bias effect in favor of the production factor that has become relatively less expensive. In so doing these firms will be moving along the new isocline OD in Figure 1 and find a new equilibrium point on the new isocost.

We can now articulate the hypothesis that firms can be characterized according to a set of attributes that qualify the likelihood that they will introduce neutral or biased technological changes. Table 1 provides a synthesis of the main issues and contrasts of the two groups of firms according to their size, the features of their innovation process whether based upon scientific knowledge or localized skills (Acs and Audretsch, 1988 and 1990; Rothwell and Dodgson, 1994).

Insert Table 1 about here

The innovation process practiced by small and medium size firms active in quality-intensive industries relies primarily upon tacit knowledge acquired by means of repeated learning activities that are highly idiosyncratic with respect to the limited range of techniques that each firm has been able to practice in the past. Research activities are seldom identified and rarely formal R&D laboratories with clear assignment of scientific tasks can be found. New technological knowledge is the product of informal activities although it relies upon the wide and deep participation of a variety of functional activities implemented within the firm ranging from production to procurement and especially marketing (Stoneman, 2010).

The access to external knowledge available within industrial clusters is a major source of technological knowledge and provides substantial inputs to the innovation process of these firms (Rogers, 2004; Beaudry and Swann, 2009). For small firms the search for efficiency cannot rely upon major shift effects for the limited depth of their competence and the limited access to codified technological knowledge generated by means of formal R&D activities. Small firms pay much a stronger attention to the positive effects of the bias in favor of the output elasticity of capital i.e. the factor that is becoming less expensive and is more abundant.

Large firms are able to complement the competence acquired by means of localized learning process with formal R&D activities performed intra-muros, and clearly identified with explicit procedures and protocols. Research activities are conducted by highly qualified personnel with formal doctoral training, are fed by systematic relations with the academic community and generate a flow of discoveries and original applications that can be successfully embodied in new products, protected by patents (Arvanitis, 1997). Large firms can introduce technological knowledge that has a wide scope of application and can feed the introduction of such a wide array of technological innovations that often lead to the diversification of firms and creation of new industries. Hence large corporations can rely upon major shift effects in that they can generate major product innovations that enable them to move along the original isocline (Vaona and Pianta, 2008).

Small firms, on the opposite, rely almost exclusively, upon localized knowledge that enables mainly the introduction of incremental process innovations. The search for efficiency, engendered by the changes in the levels of unit wages, takes place locally and is directed towards technologies that enable to substitute as much as possible, given the constraints of switching costs, the factor – labor – that is both in absolute and relative terms becoming more expensive. Localized technological change, induced by the increase of unit wages, and practiced by small firms, will consist more of a bias effect directed towards the more intensive use of the factors that are locally more abundant.

Bounded exploitation strategies are also explained by appropriability conditions. Large corporations and new, science-based firms can rely upon the credible enforcement of intellectual property rights and specifically upon patents to increase the appropriability of the rents stemming from the introduction of their technological innovations because of their strong content in terms of originality and priority. Large firms, protected by intellectual property right regimes can afford the risks of introducing major product innovations that enable them to move along the original insoclines. Small firms active in quality intensive industries can take much less advantage of intellectual property rights to increase the appropriability of the rent stemming from the localized introduction of new technologies based upon tacit knowledge. The application to patent offices is quite expensive and the screening process, based upon the search for originality and priority of the technological content, does not favor them. Hence small firms rely more systematically upon secrecy and especially upon time-lags and favor the introduction of process innovations. This leads to the selection of biased technologies that are characterized by a strong intensity of inputs that are locally abundant and becomes an effective source of barriers to entry and to imitation for other firms based in regions with different factor markets. Appropriation strategies hence clearly favor the exploitation of new technologies in the proximity of existing techniques.

In sum we set forth the hypotheses that technological change introduced by i) small firms, ii) relying more on tacit knowledge than on formal R&D activities, and iii) less able to appropriate the benefits of their technological innovations is more likely to be characterized by a stronger bias in favor of capital intensive process innovations.

3. Empirical investigation

3.1 Methodology

In order to explore the determinants of the direction of technological change at the firm level of analysis, we first need to calculate output elasticities. We start assuming the two-factor Cobb-Douglas production function as follows:

$$Y_{it} = A_{it} L_{it}^{\beta_{it}} K_{it}^{\alpha_{it}} \qquad (1)$$

The output produced by firm *i* at time *t* is a function of the actual levels of capital and labour employed, and of the actual technology signaled by the general efficiency parameter *A* and by factors' output elasticities.

Following Euler's theorem, we calculate output elasticities by assuming constant returns to scale and perfect competition in both product and factors markets (Link, 1987). The output elasticities of labour and capital can therefore be computed as follows:

$$\beta_{it} = w_{it} L_{it} / Y_{it} \qquad (2)$$

$$\alpha_{it} = 1 - \beta_{it} \qquad (3)$$

where w_{it} and Y_{it} are respectively average wages per employee and value added for firm *i* at time *t*, both deflated using a two-digit industry deflator at 1995 basic prices. L_{it} is the number of employees for firm *i* at time *t*.

Following the hypotheses presented in Section 2, we can propose the equation to be estimated in the econometric analysis. Our basic hypotheses suggest that different firms will respond to change in factor market costs by introducing neutral or biased technological change depending on the attributes of their innovation routines and the basis of their technological knowledge. Following the localized technological change approach, we expect that firms stuck by high switching costs but able to complement their tacit knowledge with formal R&D activities will introduce neutral technological changes. On the contrary, firms less able to generate technological knowledge will introduce biased technological change in order to increase the technological congruence and, consequently, will increase the output elasticity of the factor that has become more abundant. This leads us to model the direction of technological change, proxied by the changes in the output elasticity of capital, as a function of factor market costs and firms' attributes as follows:

$$\ln\alpha_{it} = \lambda_1 + \lambda_2 \ln\alpha_{it-1} + \lambda_3 \ln(w_{it}/w_{it-1}) + \lambda_4 \ln Size_{it-1} + \lambda_5[\ln(w_{it}/w_{it-1}) * \ln X_{it-1}] + \sum\psi_t + \varepsilon_{it} \quad (4)$$

where $\ln(w_{i,t}/w_{i,t-1})$ and $\ln Size_{i,t-1}$ are respectively the growth rate of unit wages and deflated sales for firm i at time $t-1$. $X_{i,t-1}$ aims at capturing firm's attributes with respect to the generation of technological knowledge with a bundle of indicators measuring R&D expenses and intangible assets including patents. We include the interaction term between wages rate of growth and $X_{i,t-1}$, the proxy for firm's innovation and knowledge related attributes, in order to verify its impact on the directionality of technological change. The sign of the interaction term's coefficient will reveal the impact of the $X_{i,t-1}$ variable on the output elasticity of capital given the dynamics of firm's wages. A positive sign on the interaction term will tell us that, when the average wages increase, firms with high level of the $X_{i,t-1}$ variable will respond by increasing α_{it}, i.e. introducing biased technological change.

The inclusion of the lagged dependent variable in the model requires dynamic estimation techniques. Moreover, we have a large N and small T panel data set where there may be arbitrarily distributed fixed individual effects. Following the literature on dynamic panel estimators (Arellano and Bond 1991; Blundell and Bond 1998; Bond 2002), the model is thus estimated using the generalized method of moments (GMM) methodology. In particular, we use the first-difference GMM. In this approach the predetermined and endogenous variables in first differences are instrumented with suitable lags of their own levels. First-differencing the equations eliminates a potential source of omitted variable bias in estimation.

3.2 Dataset and variables description

In this paper we use a panel dataset of firms which are publicly traded in UK, Germany, France and Italy. For all the countries, the period of observations goes from 1995 to 2003. Our prime source of data is Thomson Datastream. We pooled the dataset by adding also information on firms' patent applications at the European patent office. Finally we included information at the industry level from the Groningen Growth and Development Centre[2].

Our final dataset consists of a balanced panel of 1113 active companies. Sample firms operate in all sectors of the economy and have been classified according to the Groningen Growth and Development Centre 10-sector classification which is based on the ISIC revision 3 one. As Thomson Datastream use the ICB industry classification at the four-digit level, in Appendix A we provide the sectoral concordance used to link the three classifications.

Appendix B reports the sample distribution by country and industry. Manufacturing covers about 41% observations in UK, 52% in Germany, 48% in France and 50% in Italy. Finance, Insurance, and Real Estate companies are also highly represented in our sample (about 27% observations in UK, 29% in France, 24% in Germany and 31% in Italy), while each of the other economic groups includes around or less than 10% observations in each country.

The dependent variable included in our model is the output elasticity of capital computed according to equations 2 and 3. Table 2 shows the sample distribution of production factors elasticities by year. The series highlights a convergence of α and β in the period analysed. As far as the explanatory variables are concerned, $lnSize_{it-1}$ is the logarithm of firm's sales. The growth rate of unit wages is computed as the log ratio between w_{it} and w_{it-1}, where the unit wage is the total cost of wages paid by the company divided by the number of employees. We further include the interaction term between the growth rate of unit wages and three firm's innovation related variables. First, the variable $lnR\&D_{it-1}$ is computed as the log ratio between research and development expenses and sales for firm i at $t-1$. Second, the variable $lnIA_{it-1}$ is the ratio between the book value of intangible assets and total assets in logarithm. The book value of intangible assets is taken by firms' balance sheets and includes goodwill, patents, copyrights, trademarks and also other expenses such as organizational and capitalized advertising cost. Goodwill represents assets arising from the acquisition of other companies and is measured as the excess cost paid for the assets purchased over the book value ascribed in the acquiring firm's balance sheet. Finally, $Patents_{it-1}$ is a dummy variable taking value 1 if the firm holds at least a patent. These variables should capture effectively the variance across firms in terms of capability

[2] These data were originally published and described in Van Ark (1995).

to command the generation of technological knowledge and reflect the traditional partition on high and low tech activities (See Table 1). Descriptive statistics are presented in Table 3.

Insert Tables 2 and3 about here

4. Results

The results of the econometric estimations are shown in Table 4. The results of the post-estimation tests are included in Table 4. AR(1) and AR(2) are tests for first-order and second-order serial correlation. Sargan is a test of the over-identifying restrictions for the GMM estimators. As expected, negative first-order serial correlation is found in the Arellano-Bond AR(1) test. The Arellano-Bond AR(2) test indicates the validity of instruments. The validity of lagged levels dated t-3 as instruments in the first-differenced equations is accepted by the Sargan test of overidentifying restrictions at the 10% level in all regressions with the exception of column 4 and 5 where the test accepts the validity of instruments at the 1% and the 5% level, respectively.

We first regress the log output elasticity of capital on his lagged value. As shown in column 1, the coefficient on the lagged value of alfa is smaller than 1. Hence, the smaller the value of the elasticity of capital at *t-1* the higher is its value at time t. There is convergence for sample companies in the period under scrutiny towards the substitution of labour with capital.

Insert Table 4 about here

Results in column 2 show that an increase in the cost of labor has a negative effect on the output elasticity of capital. In order to retain the stability of factor intensity firms may be induced to direct technological change towards an increased use of the factor that became more expensive, even if they are locally scarce. In such conditions the technological efficiency of the production process may be reduced by some input inefficiency: firms will make a less intensive use of cheaper inputs and will insist in using the old factor intensity, by means of a reverse directionality (Antonelli, 1995 and 2003).

Yet, we are interested in the determinants of the direction of technological change. The negative sign on the variable controlling for firm size (column 3) reveals that while large firms introduce neutral technological change, small firms introduce biased technological change, i.e. they increase the output elasticity of capital at time *t*. This is in line with our expectations.

In order to verify the hypothesis that firms can be characterized according to a set of attributes that influence the direction of technological change induced by the increase of unit wages, our model includes the interaction term between the growth rate of wages and firm's innovation related attributes. Column 4 to 6 report the results for $\ln(w_{it}/w_{it-1}) * \ln R\&D_{it-1}$, $\ln(w_{it}/w_{it-1}) * \ln IA_{it-1}$ and $\ln(w_{it}/w_{it-1}) * \ln Patents_{it-1}$, respectively. The interaction term between wages rate of growth and R&D expenditures at *t-1* is found to be negatively and significantly ($p<0.01$) correlated with the output elasticity of capital at time *t*. This confirms that firms investing high resources in formal research and development activities rely upon major shift effects and introduce a fully localized technological change in order to remain on the original isocline. On the contrary, firms that rely more on tacit knowledge and informal learning dynamics introduce biased technological change. Their knowledge base is weaker and cannot rely fully on the shift effects, hence they must try and adjust the input composition by introducing a bias in the new technology aimed at increasing their technological congruence so as to increase the equilibrium use of production factors that have become cheaper. If we look at the terms capturing the effects of intangible assets and patents on the output elasticity of capital, we find that in both the specifications presented in column 5 and 6 the interaction terms are negatively and significantly correlated to the dependent variable ($p<0.01$). This findings confirm our hypotheses that firms better able to command the generation of technological knowledge and to appropriate the returns of their innovation activities react to an increase of unit wages by introducing neutral technological innovations that enable them to move along the original insocline. On the opposite, firms that can not afford expensive knowledge generation and appropriation strategies like respectively systematic R&D activities able to complement internal learning or the acquisition of other knowledge intensive companies and intellectual property rights, rely on the introduction of biased technological change in order to make a more intensive use of the local abundant factor. Hence, they react to an increase in unit wages by increasing the output elasticity of capital.

5. Conclusions

In this paper we have investigated the determinants of the direction of technological change at the firm level of analysis. Our basic idea is rooted in the localized technological change approach and suggests that firms' attributes influence the direction of technological change induced by changes in factor market costs. In particular, we state that firms stuck by high irreversibility and strong command of technological knowledge react to changes in input costs by introducing neutral technological changes that take advantage of the competence and tacit knowledge acquired in the original technique defined in term of factor intensity, in so doing they fully rely localized technological knowledge. On the contrary, firms with lower switching costs and lower intensity of technological knowledge introduce biased technological change in order to increase the technological congruence and, consequently, increase the output elasticity of the factor that has become more abundant.

The econometric analysis have focused on a panel of 1113 public companies listed on four European countries (UK, Germany, France and Italy) in the period going from 1995 to 2003. Our findings confirm that while large companies, building on localized technological knowledge but able to implement it with codified knowledge acquired by means of formal R&D and better able to appropriate the returns of their innovation activities, are more likely to introduce neutral technological changes, small firms, relying more on localized and tacit knowledge acquired by means of learning dynamics, but less able to implement it with formal R&D activities and less able to appropriate the benefits of their technological innovations, are more likely to introduce biased technological change in order to make a more intensive use of the factor that has become more abundant.

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TABLE 1. THE DIRECTIONS OF LOCALIZED TECHNOLOGICAL CHANGE

TYPES OF INNOVATION PROCESSES/MAIN FEATURES	TECHNOLOGICAL CHANGE BASED UPON SHIFT EFFECTS	TECHNOLOGICAL CHANGE BASED UPON BIAS EFFEFCT
MAIN SOURCE OF KNOWLEDGE	SCIENTIFIC DISCOVERIES	COMPETENCE
KNOWLEDGE GENERATION	RESEARCH AND DEVELOPMENT	LEARNING BY DOING AND BY USING
FORM OF KNOWLEDGE	MAINLY CODIFIED	MAINLY TACIT
SCOPE OF APPLICATION	LARGE	NARROW
TYPES OF INNOVATION	RADICAL & PRODUCT	INCREMENTAL PROCESS & CREATIVE ADOPTION
APPROPRIATION	PATENTS	SECRECY AND TIME LAGS
EXPLORATION	GLOBAL SOURCING ON THE INTERNATIONAL SCIENTIFIC FRONTIER	LOCAL KNOWLEDGE SOURCING WITHIN CLUSTERS
EXPLOITATION	GLOBAL PRODUCT MARKETS	LOCAL FACTOR MARKETS
FIRMS	CORPORATIONS&SCIENCE BASED YOUNG FIRMS	SMALL AND MEDIUM SIZE
INDUSTRIES	HIGH TECH	QUALITY INTENSIVE
REPRESENTATION IN PRODUCTION THEORY	LABOR INTENSIVE TECHNOLOGICAL CHANGE WITH STRONG SHIFT EFFECTS	CAPITAL INTENSIVE TECHNOLOGICAL CHANGE WITH STRONG BIAS EFFECTS

Table 2 – Sample production factors elasticities by year

$$\beta_{it} = w_{it} L_{it} / Y_{it} \tag{2}$$

$$\alpha_{it} = 1 - \beta_{it} \tag{3}$$

Year	α	β	α+ β
1995	0.418	0.582	1.000
1996	0.435	0.565	1.000
1997	0.425	0.575	1.000
1998	0.438	0.562	1.000
1999	0.441	0.559	1.000
2000	0.440	0.560	1.000
2001	0.463	0.537	1.000
2002	0.448	0.552	1.000
2003	0.435	0.565	1.000

Table 3 – Descriptive statistics

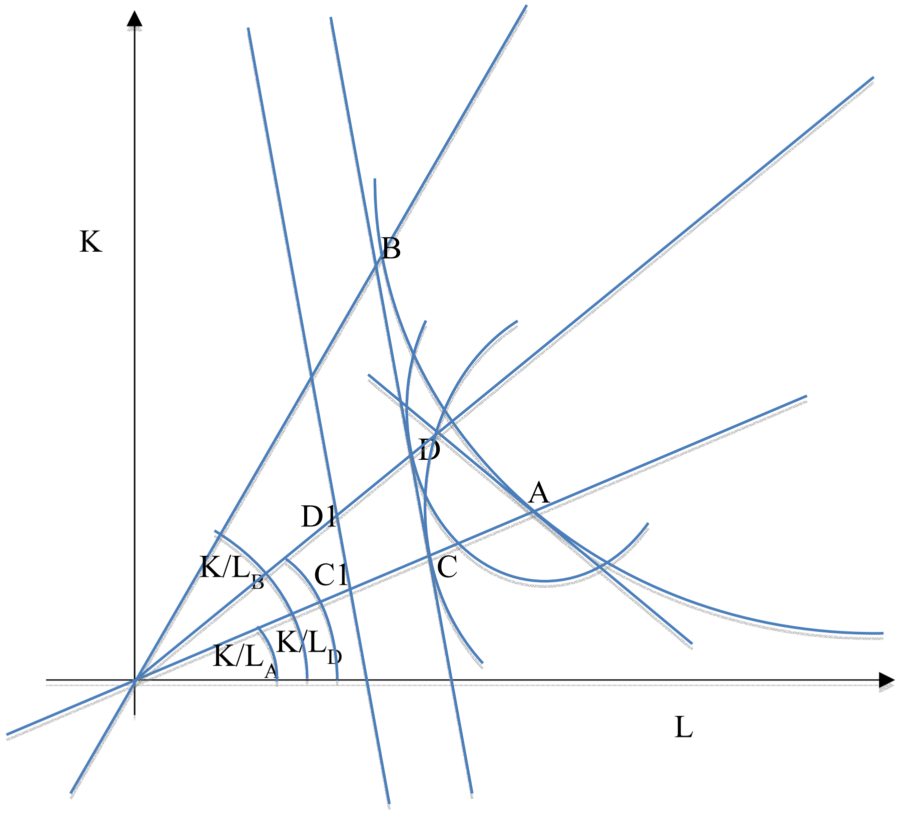
	obs.	*mean*	*std. dev*	*min*	*max*
$\ln\alpha_{it}$	10017	-0.9639481	0.5818202	-7.136785	0
$\ln\alpha_{it-1}$	8904	-0.9603627	0.5752905	-7.136785	0
$\ln(w_{it}/ w_{it-1})$	8893	0.0714427	0.368695	-7.142705	7.247954
$\ln Size_{it-1}$	8896	16.08716	2.772896	5.347107	23.65579
$\ln(w_{it}/ w_{it-1})$ * $\ln R\&D_{it-1}$	2805	-0.1157062	1.304551	-28.73244	-28.73244
$\ln(w_{it}/ w_{it-1})$ * $\ln IA_{it-1}$	6732	-0.0965345	1.128948	-35.71825	36.33765
$\ln(w_{it}/ w_{it-1})$ * $Patents_{it-1}$	8893	0.0041039	0.1043013	-3.403005	5.505905

Table 4 - Results of first difference GMM Regressions

$$\ln\alpha_{it} = \lambda_1 + \lambda_2 \ln\alpha_{it-1} + \lambda_3 \ln(w_{it} / w_{it-1}) + \lambda_4 \ln Size_{it-1} + \lambda_5 [\ln(w_{it} / w_{it-1}) * \ln X_{it-1}] + \sum \psi_t + \varepsilon_{it} \quad (4)$$

Dep. Var. $\ln\alpha_{it}$	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES						
$\ln\alpha_{it-1}$	0.175***	0.202***	0.241***	0.123***	0.146***	0.239***
	(0.0281)	(0.0280)	(0.0305)	(0.0312)	(0.0295)	(0.0305)
$\ln(w_{it}/ w_{it-1})$		-0.183***	-0.192***	-0.337***	-0.440***	-0.185***
		(0.0313)	(0.0332)	(0.0563)	(0.0359)	(0.0318)
ln $Size_{it-1}$			-0.0679***	-0.0675***	-0.0669***	-0.0665***
			(0.0181)	(0.0194)	(0.0170)	(0.0181)
$\ln(w_{it}/ w_{it-1})$ * ln $R\&D_{it-1}$				-0.0431***		
				(0.0164)		
$\ln(w_{it}/ w_{it-1})$ * ln IA_{it-1}					-0.0630***	
					(0.0104)	
$\ln(w_{it}/ w_{it-1})$ * $Patents_{it-1}$						-0.202***
						(0.0781)
$\Sigma\psi_t$	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7791	7781	7774	2365	5697	7774
Number of ID	1113	1112	1111	403	993	1111
Number of instruments	18	19	20	21	21	21
Wald Test χ^2	105.43	133.91	124.02	149.58	261.50	158.95
Prob > $\chi2$	0.000	0.000	0.000	0.000	0.000	0.000
Sargan test $\chi2$	11.97	13.62	14.57	18.54	16.60	14.58
Prob> $\chi2$	0.287	0.191	0.148	0.046	0.084	0.148
AR(1)	-7.05	-6.62	-6.66	-4.44	-5.23	-6.61
Prob> z	0.000	0.000	0.000	0.000	0.000	0.000
AR(2)	-0.95	-0.23	-0.13	0.45	0.41	-0.07
Prob> z	0.341	0.818	0.898	0.651	0.685	0.941

Figure 1 - The localized introduction of technological changes



Appendix A - Sectoral concordance table

Sector name	Groningen Growth and Development Centre 10-sector database	Datastream	ISIC
Agriculture, Forestry, and Fishing	01-05	1733, 3573	45, 01-02
Mining and Quarrying	10-14	1771-1779	10-12, 13-14
Manufacturing	15-37	533-587, 1353,1357, 1737-1757, 2353, 2713-2757, 3353-3537, 3577-3726, 3743-3785, 4535-4577, 5557, 5752, 9572-9578	5,15-36
Public Utilities	40-41	7535-7577	40-41
Construction	45	3728, 2357	45
Wholesale and Retail Trade, Hotels and Restaurants	50-55	2797, 5333-5379, 5753, 5757	51-55
Transport, Storage, and Communication	60-64	2771-2779, 5553, 5751, 5759-6575	60-63, 64
Finance, Insurance, and Real Estate	65-74	2791-2795, 2799, 5555, 8355-9537	65-70, 71-74
Government Services	75-85	4533	85
Community, Social and Personal Services	90-99	5377, 5755	80,90-93

Appendix B - Firms and observations by country and industry

	UK		*Germany*		*France*		*Italy*	
	Firms	*%.*	*Firms*	*%.*	*Firms*	*%.*	*Firms*	*%.*
Agriculture, Forestry, and Fishing	5	1.68	4	0.76	3	1.63	2	1.92
Mining and Quarrying	5	1.68	7	1.33	4	2.17	0	0
Manufacturing	121	40.60	274	51.99	88	47.83	52	50.00
Public Utilities	9	3.02	24	4.55	7	3.80	8	7.69
Construction	13	4.36	14	2.66	5	2.72	4	3.85
Wholesale and Retail Trade, Hotels and Restaurants	45	15.10	35	6.64	13	7.07	3	2.88
Transport, Storage, and Communication	18	6.04	36	6.83	10	5.43	3	2.88
Finance, Insurance, and Real Estate	80	26.85	128	24.29	53	28.80	32	30.77
Government Services	1	0.34	4	0.76	1	0.54	0	0
Community, Social and Personal Services	1	0.34	1	0.19	0	0	0	0
Total	*298*	*100*	*527*	*100*	*184*	*100*	*104*	*100*