The Effects of Biased Technological Change on Total Factor Productivity. Empirical Evidence from a Sample of OECD Countries[1].

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ABSTRACT.

Technological change is far from neutral. The empirical analysis of the rate and direction of technological change in a significant sample of 10 OECD countries in the years 1971-2001 confirms the strong bias of new technologies. The introduction of new and biased technologies affects the actual levels of total factor productivity when it matches the characteristics of local factor markets so that locally abundant inputs become more productive. In turn the matching between the bias of technological change and the relative abundance of production factors can be considered as the result of a path dependent process where the quality of the local knowledge infrastructure plays a central role in shaping the direction.

JEL Classification Codes: O33

Key words: Biased technological change; Total factor productivity growth; Knowledge infrastructure.

1. Introduction

The issue of directed technological change (TC) has recently received new attention, due to the identification of a strong bias of new information and communication technologies towards high-skilled labour (Acemoglu, 1998; Hollenstein, 2004; Goldin and Katz, 2008).

The recent contributions by Acemoglu and Zilibotti (2001) and Caselli and Coleman (2006) however fail to appreciate the effects of biased technological change on total factor productivity (TFP) growth, because they do not take into account the conditions of factor markets. Yet, it is clear that where inputs are not equally abundant and hence the slope of the isocost differs from unity, the introduction of biased technological innovations and the consequent change in the slope of isoquants do affect both output and the growth of TFP (Samuelson, 1965).

In this paper we disentangle the effects of such bias on productivity from the standard consequences of the shift of the production function. We investigate the direction of TC for a sample of OECD countries and exploring both its effects on TFP within a growth accounting framework, and its determinants over the period 1971-2001. We show that: 1) the distinction between biased and neutral TC is empirically relevant, 2) the matching between the bias of TC and the relative factor prices are important triggering factors of the actual change in the efficiency of the production process; 3) the introduction of biased TC, along a direction that is able to match the characteristics of the local factor markets, is the result of a dynamic process shaped by persistence and made possible by the levels of technological command that a country is able to display.

The remainder of the paper is organized as follows. In Section 2 we recall the basic elements about the relationship between change in the production function and technological innovation. In Section 3 we describe an original methodology to appreciate the effects of biased TC upon total factor productivity measures. In Section 4 we present the statistical evidence about the actual changes in output elasticities that have been taking place in a large sample of representative countries in the years 1971-2001 (Section 4.1) and show the results of our calculations. In Section 5 we enquire the determinants of biased TC. The concluding remarks follow in Section 6.

2. Biased Technological Change and Productivity

The concept of input-bias hardly represents a novelty. Hicks (1932) elaborates the Marxian intuitions and argues that TC is a form of meta-substitution. When the cost of a factor increases firms are induced to introduce new biased technologies to reduce its use. Kennedy (1964) stresses the role of the levels of factor costs, as opposed to the rates of change. When the relative prices of an input are high, firms are induced to move along the innovation possibility curve and introduce biased innovations to reduce its use. Samuelson (1965) confirms that the 'rational' direction of TC should be labour-intensive, in labour abundant countries, even if wages increase. Ruttan (1997 and 2001) provides a comprehensive synthesis of the induced TC hypothesis combining the two strands of analysis. Antonelli (2003 and 2006) presents a model where the changes in factor prices induce the rates of TC while the levels of relative factor price induce the direction.

Despite the revival of directionality, and its venerable origins, very few attempts may be found in the literature addressing the measurement of biased TC. David (2004) has provided an outstanding study of the long-term trends of the direction of TC in the American economic history. The author stresses that standard growth accounting exercises calculating the traditional 'residual' are mistaken in ignoring the effects of factors-deepening, and argues that the dynamics of US economic growth of XIX and XX centuries can be featured according to the different directions of technological change in the two periods.

Within the growth accounting framework, Bernard and Jones (1996) acknowledge that the standard TFP measure is not sufficient in contexts characterized by differences also in factors' elasticities. They develop an index they call "total technology productivity", which accounts for both differences in the traditional "*A*" term and in factors' exponents. However such an index is sensible to the level of capital intensity used as a benchmark, and anyway it does not account separately for the effect of biased TC.

The basic assumption of the theory of production is that a two-way relationship exists between the technology and the production function. All changes in technology affect the production functions well as all changes in the production function reflect the changes in technology. The changes in technology may engender both a shift of the isoquants and a change in their slope. When technological change is neutral the effect consists just in the shift of the map of isoquants towards the origin. When technological change is biased, the isoquants change both position and slope. Clearly the changes in the values of the output elasticity of basic inputs, as reflected in the changes in the slope of the isoquants, signal the introduction of biased technological change (see Figure 1). Hence the changes in the levels of total factor productivity can be considered as a reliable indicator of the consequences of technological change only if both the effects on the position (the shift) and on the slope of the isoquants are accounted.

>>> INSERT FIGURE 1 ABOUT HERE <<<

Indeed the matching between the direction of TC and the relative levels of the endowments has powerful effects on the actual efficiency of the production process. It is straightforward to see that the introduction of capital intensive technologies in a capital abundant country increases output, more than in a labour abundant one.

The neglect of the effects of biased TC on TFP dates back from the original contribution of Solow (1957). As it is well known Solow allows the change in the output elasticity of capital, as measured by its share on income, and does not account for its effects (Solow, 1957: p. 315, Table 1, col. 4). The US case in the years 1909-1949, which Solow analyzed using a Cobb-Douglas based growth accounting methodology, provides clear evidence about the stability of factor shares and hence the substantial neutrality of technological change.

The recent empirical evidence and the new debates instead show the empirical relevance of the new biased technological change. Here-hence the interest in the matter.

3. The Methodology

In order to single out an index for the effects of biased TC on TFP, we elaborate upon the so-called "growth accounting" methodology, which draws upon the seminal contribution by Solow (1957) further implemented by Jorgenson (1995) and OECD (2001). In order to confront directly our approach with the seminal contribution by Solow (1957), we shall rely on a Cobb-Douglas production function.

Within this context, this paper presents a novel methodology to disentangle the effects of biased TC on productivity growth, so as to separate out the sheer effects of the shift of the production function, from the effects of the changes in isoquants' slope. When TC is biased, and the basic inputs are not evenly abundant, the matching between the output elasticities and the relative factor prices has powerful effects on total factor productivity (Antonelli, 2003).

Let us outline the main passages in what follows. The output Y of each country i at time t, is produced from aggregate factor inputs, consisting of capital services (K) and labour services (L), proxied in this analysis by total worked hours. TFP (A) is defined as the Hicks-neutral augmentation of the aggregate inputs. Such a production function has the following specification:

$$Y_{i,t} = A_{i,t} \cdot f(K_{i,t}, L_{i,t}) \qquad (1)$$

The standard Cobb-Douglas takes the following format:

$$Y_{i,t} = A \cdot K_{i,t}^{\alpha_{i,t}} \cdot L_{i,t}^{\beta_{i,t}} \qquad (2)$$

If we take logarithms of equation (2), we can write TFP as follows:

$$\ln A_{i,t} = \ln Y_{i,t} - \alpha_{i,t} \ln K_{i,t} - \beta_{i,t} \ln L_{i,t} \tag{3}$$

Where $\alpha_{i,t}$ and $\beta_{i,t}$ represent respectively the output elasticity of capital and labour for each country at each year, and $\alpha + \beta = 1$.

Next, following Euler's theorem as in Solow (1957), we assume that output elasticities equal the factors' shares in total income, as we consider constant returns to scale and perfect competition in both factor and product markets. In view of this, the output elasticity of labour is:

$$\beta_{i,t} = \frac{w_{i,t} L_{i,t}}{Y_{i,t}} \tag{4}$$

and hence:

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

The measure of *A* obtained in this way, accounts for "any kind of shift in the production function" (Solow, 1957: 312), and it might be considered a rough proxy of TC (Link, 1987). By means of it Solow intended to propose a way to "segregating shifts of the production function from movements along it". Solow is right if and when technological change is neutral, and/or factors are equally abundant. Instead, the effects of biased technological innovations introduced in countries where factors are not equally abundant, are made up of two elements. Besides the shift effect one should also account for the bias effect, i.e. the direction of TC.

Once we obtain the TFP accounting for the shift in the production function, we can investigate the impact of the bias effect with a few passages. First of all we get a measure of the TFP which accounts for the sum of both effects (for this reason we call it *total-TFP* or *TTFP*), by assuming output elasticities unchanged with respect to the first year observed. At each moment in time the log of total-TFP is equal to the difference between the log of the output and the log of inputs weighted by their elasticities fixed at the first observed year:

$$\ln TTFP_{i,t} = \ln Y_{i,t} - \alpha_{i,t=0} \ln K_{i,t} - \beta_{i,t=0} \ln L_{i,t} \quad (5)$$

Once the coefficients have been calculated, it is possible to estimate the expected GDP, which would have been produced each year, after the increase in input levels had the output elasticity of factors remained unchanged.

Next we get the bias effect (*BTFP*) as the ratio between the two indexes, i.e. the Solow index and the total TFP (TTFP) we introduced above:

$$BTFP_{i,t} = \frac{TTFP_{i,t}}{A_{i,t}} \quad (6)$$

The index obtained from Equation (6) is straightforward and easy to interpret. Indeed its critical value is one. When *BTFP* in one country is above (below) one, then its technological activity is characterized by a high (low) directionality, and the slope of isocosts differs from unity.

4. Data and Descriptive Evidence

The data used for the analysis are drawn from the OECD. In particular the cross-country time series of GDP (*Y*) at PPP of million US dollars (2000 constant prices) have been drawn by the Economic Outlook[2], while the series on employment, worked hours, compensation of employees and fixed capital stock have been found in the OECD Stan

[2] Available online at the web address: http://caliban.sourceoecd.org/vl=7365690/cl=24/nw=1/rpsv/ij/oecdstats/16081153/v115n1/s1/p1

Database. Data on capital stock (K) and employees' compensation ($w \cdot L$) have been deflated by using the PPP index implicit to GDP data (2000 constant prices)[3]. Finally we have drawn the time series concerning patent applications to the European Patent Office (EPO) and to the US Patent and Trademark Office (USPTO), business expenditure for R&D (*BERD*) and government R&D expenditure (*GOVERD*), from the OCED Science and Technology indicators[4].

4.1 Directed TC: The Changing Output Elasticites of Labour

In order to show how much pervasive the issue is, it is worth looking at the data concerning the output elasticity of labour (see Equation (4)). Indeed, should TC consist just of a shift in the production function, one would observe no change in output elasticities, which clearly reflect the slope of the isoquant. On the other hand, it is clear that according to the Euler theorem the share of revenue of each factor depends exclusively upon its output elasticity (Solow, 1957; Ruttan, 2001). This, actually, makes quite surprising the neglect of the dynamic implications of a change in output elasticities. Table 1 shows that the claims about the stability of factor shares (Gollin, 2002) are limited to the US evidence[5]. The international evidence, instead, confirms that output elasticity of labour indeed varies over time, and is also characterized by remarkable cross country differences.

>>>INSERT TABLE 1 ABOUT HERE<<<

>>>INSERT FIGURE 2 ABOUT HERE<<<

[3] Available online at the web address: http://caliban.sourceoecd.org/vl=7365690/cl=24/nw=1/rpsv/ij/oecdstats/16081307/v265n1/s1/p1/

[4] Available online at the web address: http://caliban.sourceoecd.org/vl=7365690/cl=24/nw=1/rpsv/cw/vhosts/oecdstats/16081242/v209n1/contp1-1.htm

[5] In this respect, Keay (2000) derived a TFP index using a translog cost function, showing for the US and the Canadian case a significant variance of factors' shares across industries.

The data clearly show a common pattern: in almost all the countries considered labour output elasticities increase until late 1970s and early 1980s, and then decrease (see also Figure 2). Within this common pattern, an important difference relates to how much elasticities decreased after such a peak. In the case of Belgium and France the reduction was smooth enough to allow the elasticity to stick above the initial level. The former displays a growth rate of 15% in the last decade, then a decrease of -9% in the second decade, and finally an increase 0.6%. The latter is characterized by a growth of 12% in the first decade, and then a decrease of -8% and of -0.8% in the second and third decade respectively.

A second group of countries is instead characterized by a steeper decline after the late 1970s peaks. Such countries are Finland, Italy, Netherlands, Norway Sweden and the UK. The rate of decrease over the whole period, ranges from -20% in the case of Italy to -3% in the case of the UK. Remarkable declines may be devised also in Finland (-14%) and Norway (-9%).

A last group of countries consists of Denmark and the U.S.[6], wherein output elasticites are pretty stable over time. In the first case one may observe a decrease of -0.2%, while in the latter there is an increase of just 0.06%.

Looking at cross-country differences in output elasticity is indeed as much appealing. Besides the generalized trend stressed above, one can distinguish among countries in which labour elasticity remains above 0.5, those in which it remains below 0.5, and

[6] Coherently with what Solow (1957) found analyzing the American evidence of the first half of 1900s.

finally those in which it goes from above (below) to below (above). Countries belonging to the first group are the U.S. and Denmark, where the coefficient is stable over time, together with U.K. and Sweden. The only country in the second group is Italy, where one can find the lowest elasticity in 2001. Finally, elasticity goes from below to above 0.5 in France and Belgium, while the reverse happens in the Netherlands, Norway and Finland.

From this preliminary evidence, it is clear that stability is just one of the possible patterns that output elasticities exhibit over time. Moreover, countries differ both with respect to the levels of relative efficiency of production factors, and to their evolution over time. The empirical evidence confirms that not only the production function is subject to shifts over time, but also to changes in its shape. This is true both diachronically within the same country, and synchronically across different countries.

4.2 Biased TC and TFP

Data show that output elastiticites exhibit a great degree of variance both across countries and over time. This evidence is quite clear and yet much overlooked, and hence it makes the analysis of biased TC imperative in order to gain a better understanding of the causes and the effects of innovation patterns on productivity growth.

Tables 2 to 4 present the results of our calculations for the countries in the sample. Table 2 reports the evolution of the standard TFP index *à la* Solow. At a general level, such index is featured by a steady increase until 1981, and then followed by a substantial decrease along the 1980s, followed by stabilization along the 1990s. However, a deeper look into the national specificities, reveals interesting differences and some exceptions. Belgium and Denmark are featured by a steep increase of Solow TFP until 1981, and then followed by a less steep decline. In the case of Belgium the minimum is reached in 1989, while in Denmark it occurred in 1986. France follows a very similar dynamics, as productivity grew until 1982, the fell apart until 1989. In all of these countries productivity dynamics along the 1990s were very stable.

In Sweden Solow TFP began to grow after 1973 until 1978. Then it fell abruptly until 1983, keeping on decreasing at a slower rate until 1995. Finally, in the late 1990s productivity started again growing. The Netherlands are instead characterized by twin peaks in the first decade, in 1975 and 1979. Then productivity fell until 1985, and stabilized in the following decade, and finally slightly decreased in the second half of 1990s.

The evidence about Norway is somehow more puzzling. Growth rate of Solow TFP increased until 1978, then decreased suddenly, and then went up again reaching the maximum in 1988. Along the early 1990s growth rates were sort of stable, and finally decreased in the second half of the decade. Finland and Italy display a particular dynamics, in that productivity speeded up until the early 1990s and the started slowing down at a faster rate. The U.K. is instead characterized by a different trend: the growth rate slowed down considerably since 1975 to 1996, and then started increasing. The only country showing a genuine increasing trend in the growth rate is the U.S., of course interrupted by a slowing down in the early 1980s and early 1990s.

>>>INSERT TABLE 2 ABOUT HERE<<<

The evidence about the TTFP is reported in Table 3. The dynamics of this index are better behaved. Indeed all countries in the sample show accelerating growth rates. Such a generalized result strongly supports the need for investigating non-shift effects. Cross-country comparison reveals that the TTFP grew substantially in two Northern countries, i.e. Norway and Finland. Moreover, there is a clustering of countries (Italy, France, Netherlands and U.K.) around the same value in 2001 (1.5). Then in the same year Sweden and Belgium are featured by slightly lower growth rates. Denmark and U.S. display a peculiar dynamics. The former is indeed characterized by a fast increase until 1981, followed by a period of stability. The latter shows up a smooth growth until late 1980s, and then reached stability in the early 1990s.

>>>INSERT TABLE 3 ABOUT HERE<<<

Table 4 provides finally the synthetic index of BTFP, combining the Solow TFP and TTFP. Values above the unity signal a predominance of innovation efforts aimed at shaping the technology with a bias that is consistent with the features of local factor markets, therefore technological change is biased towards the intense use of locally abundant factors. Values below the unity signal that technological change is directed towards the intense use of locally scarce factors. Values very close to 1 witness a neutral technological change.

>>>INSERT TABLE 4 ABOUT HERE<<<

The evidence in the table suggests that sampled countries may be grouped in three broad classes, according to three cases introduced above (see Figure 3):

a) Countries substantially diverging from 1 downwards. In such countries, like France and Belgium, the direction of technological change is not consistent with the relative abundance of inputs;

b) Countries where the index substantially diverged from 1 upwards. They are the majority of the countries in the sample, i.e. Italy, Finland, Netherlands, Sweden, U.K. and Norway. Innovation efforts within such contexts have been characterized by the introduction of innovations that make intensive use of locally abundant factors;

c) Finally there are countries where the index does no drift away considerably from 1. They are Denmark and the US. In these countries TC has been substantially neutral.

>>>INSERT FIGURE 3 ABOUT HERE<<<

This evidence confirms that the matching between the specific direction of TC and the static and dynamic characteristics of local factor markets has a powerful effect on the evolution of the actual levels of the general efficiency of the production process. Such a relationship is characterized by a significant variance both cross-countries and over time. Moreover, it is worth emphasizing that the new index of biased TC has significant implications in terms of country rankings based on productivity. Indeed, countries showing low levels of traditional TFP levels, like Italy, turns out to show better performances when looking at the BTFP index. On the contrary, countries with relatively high levels of TFP, like France, are likely to shift backward in the ranking when looking at the BTFP indexes.

5. Econometric Results: The Determinants of Biased TC

The increase in total factor productivity that stems from the bias of TC towards the intense usage of locally abundant factors can take place as long as each country has an advanced knowledge infrastructure that makes it possible to command the direction of TC (Nelson, 1993; Malerba, 2004). This is even more relevant in countries able to access technological knowledge produced elsewhere, wherein learning dynamics are key to guiding innovation efforts towards the adaptation to the conditions of local factor markets.

The matching between the direction of TC and the evaluation of the structure of endowments can only take places within long term dynamics. Such a matching is the result of a long term process where the increase in the bias effect at each period in time reflects the efforts made in the past (David, 1975).

Hence we can synthesize our hypotheses with the following functional relationship:

$$BTFP_t = f(BTFP_{t-1}; T_{t-1}) \tag{7}$$

Where *BTFP* stands for the bias effect of technological innovations on TFP, calculated according to equation (6), and *T* is a measure of the intensity of technological efforts.

In order to implement and test the functional relationship in equation (7) we propose the following econometric specification:

$$\log(BTFP)_{i,t} = a + b\log(BTFP)_{i,t-1} + c\log(TECH)_{i,t-1} + \sum_{j=1}^{T}\lambda_j t_j + \eta_i + \varepsilon_{i,t} \tag{8}$$

Where *TECH* is a vector of technological variables. In particular we include the following variables: *BERDINT* is the intensity of private research efforts, calculated as the ratio between BERD and GDP, *GOVERDINT* is the intensity of government expenditure in R&D, *PATINT* is the intensity of patenting activity, measured as the ratio between the sum of EPO and USPTO patents and GDP for each country.

It is fair to note that the countries in the sample, while all belonging to OECD, are characterized by heterogeneous institutional contexts. For this reason we investigate the dynamics of biased TC by means of a dynamic model for panel data accounting for country effects[7]. We carried out the empirical test by means of a dynamic panel data regression, using the generalized method of moments (GMM) estimator (Arellano and Bond, 1991). This estimator indeed provides a convenient framework for obtaining asymptotically efficient estimators in presence of arbitrary heteroskedasticity, taking into account the structure of residuals to generate consistent estimates. In particular, we use the GMM-System (GMM-SYS) estimator in order to increase efficiency (Arellano and Bover, 1995; Blundell and Bond, 1998). This approach instruments the variables in levels with lagged first-differenced terms, obtaining a dramatic improvement in the relative performance of the system estimator as compared to the usual first-difference GMM estimator. Therefore in Equation (7) the error term is already decomposed in η_i and $\Sigma\lambda t$, which are respectively country and time effects, and the error component ε_{it}.

In Table 5 we report the results of the estimations. The first column investigates the effects of technological activity and path dependence by considering the joint effects of lagged patenting intensity and lagged levels *BTFP* on the actual levels of *BTFP*. The

[7] Before proceeding to the econometric estimation, we checked for the presence of unit root by using the test proposed by Levin et al. (2002). The test statistic is a modified version of the augmented Dickey-Fuller procedure, featured by a mean and variance correction to account for heterogeneity and the bias typical of OLS estimates of dynamic panels. The results support the rejection of the null hypothesis of unit root.

patenting behaviour is indeed a measure of the output of scientific and technological efforts (Griliches, 1990; Pavitt, 1985). Due to the large amount of resources to be committed, and to the detailed screening to which patents are subject, this variable can be considered as a reliable proxy of high-quality and effective innovation efforts carried out within private R&D institutions. The coefficient for patent intensity has the expected sign, i.e. positive, and is statistically significant. This supports the idea that the efforts aimed at directing TC towards the more intensive use of local abundant factors can take place only through a sustained and qualified technological activity. The lagged level of *BTFP* is meant to grasp the effect of persistence on such efforts. The coefficient is positive and statistically significant, and therefore it corroborates the hypothesis of path-dependence in the directionality of technological efforts. Moreover, the magnitude of the coefficient also provides important information, in that the result can be interpreted in terms of convergence of *BTFP*. The coefficient of the lagged dependent variable is - slightly - less than 1, meaning that the levels of biased TC are –slowly- converging. This suggests that not only dynamic irreversibilities are at stake, but they display their effects in the long term.

>>> INSERT TABLE 5 ABOUT HERE <<<

In Model 2 the growth rates of public and business R&D intensity are added as covariates in the regression. The coefficients for patent intensity and lagged *BTFP* preserve their sign and statistical significance, although the former is now is slightly larger than in the previous model. For what concerns R&D intensity, only the coefficient for government expenditure turns out to be significant and positive, while business R&D is not significant. Since this result may be due to the fact that business R&D and patent applications are highly correlated, in Model 3 we drop the intensity of patenting from the regression. The magnitude for the lagged levels of *BTFP* is similar to the previous models, and still only government R&D expenditure shows a positive and significant coefficient.

The results of the econometric test provide strong support to our hypotheses about the determinants of the TFP effects engendered by the introduction of biased TC. The importance of the availability of an advanced knowledge infrastructure is confirmed by the significance of both patenting activity and of the commitment of public resources to R&D activities. The access to high-quality pools of public knowledge allows firms to enhance their innovative efforts directed towards the introduction of biased of technologies that take advantage of the specific conditions of local factor markets.

6. Conclusions

The direction of TC has powerful effects upon total factor productivity. As such it deserves much more attention than it currently receives. When the bias introduced in the production function by the introduction of a non-neutral technology favours the use of locally abundant production factors, the general efficiency of the production process is enhanced. In some cases the productivity enhancing effects of the bias are larger than the traditional shift effects. The literature has paid much attention to the shift effects and almost ignored the bias effect.

The introduction of new biased technologies can be considered as the result of an effective knowledge infrastructure that displays its effects in terms of technological command only in the long term. The results of the empirical work carried out in this paper confirm that the direction of TC matters and deserves careful analysis.

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., F. Zilibotti, F. (2001), Productivity differences, *Quarterly Journal of Economics*, 116, 563–606.

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

Antonelli, C., (2006), Localized technological change and factor markets: Constraints and inducements to innovation**,** *Structural Change and Economic Dynamics* 17, 224-247.

Arellano, M. and Bond, S.R., (1991), Some tests of specification for panel data: monte carlo evidence and an application to employment equations, *Review of Economic Studies*, 58, 277-297.

Arellano, M. and Bover, O., (1995), Another look and the instrumental-variable estimation of error-components models, *Journal of Econometrics*, 68, 29-52.

Bernard A. B., Jones C. J., (1996), Comparing apples to oranges: Productivity convergence and measurement across industries and countries, *American Economic Review*, 86, 1216-1238.

Blundell R.W and Bond S.R., (1998), Initial conditions and moment restrictions in dynamic panel data models, *Journal of Econometrics*, 87, 115-143.

Caselli, F., Coleman, I.W.J., (2006), The world technology frontier, *American Economic Review*, 96, 499–522.

David, P. (1975), *Technical choice, innovation and economic growth: Essays on American and British experience in the nineteenth century*, London, Cambridge University Press.

David, P., (2004), The tale of two traverses. Innovation and accumulation in the first two centuries of U.S. economic growth, SIEPR Discussion Paper No 03-24, Stanford Univesrsity.

Goldin, C. D. and Katz L. F., (2008), *The race between education and technology*, Belknap Press of Harvard University Press, Cambridge, Mass.

Gollin, Douglas, 2002, Getting income shares right, *Journal of Political Economy* 110, 458–74.

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

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

Hollenstein, H., (2004), Determinants of the adoption of Information and Communication Technologies (ICT): An empirical analysis based on firm-level data for the Swiss business sector, *Structural Change and Economic Dynamics*, 15, 315-342.

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

Keay, I. (2000) Canadian manufacturers' relative productivity performance, 1907-1990, *Canadian Journal of Economics*, 33, 1049-1068.

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

Link, A.N., (1987), *Technological change and productivity growth*, London, Harwood Academic Publishers.

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

Malerba, F. (ed) (2004), *Sectoral systems of innovations. Concepts, issues and analyses of six major sectors in Europe*, Cambridge, Cambridge University Press.

Nelson, R.R., (1993), *National systems of innovation: A comparative study*, Oxford, Oxford University Press.

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.

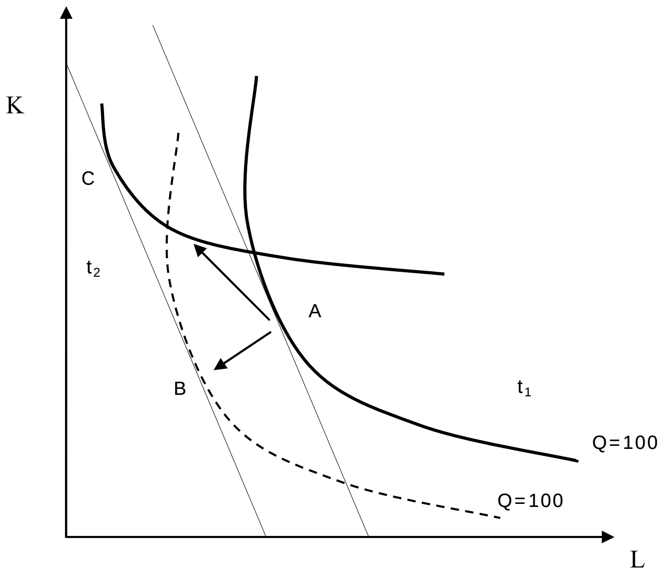
Ruttan, V.W., (1997), Induced innovation evolutionary theory and path dependence: Sources of technical change, *Economic Journal,* 107, 1520-1529.

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

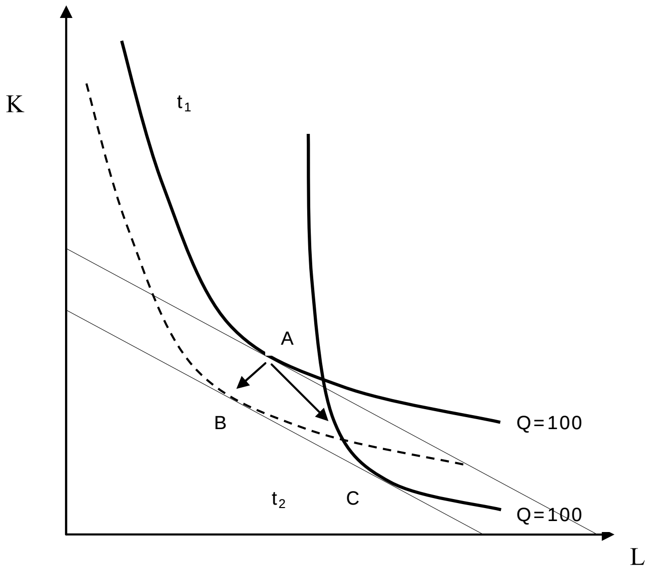
Samuelson, P., (1965), A theory of induced innovation along Kennedy, Weiszacker lines, *Review of Economics and Statistics* 47, 343-56.

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

Figure 1 - Biased vs. Neutral Technological Change



1a) Capital-intensive technological change



1b) Labour-intensive technological change

The economy at time t_1 is on the equilibrium point A. At time t_2, the introduction of neutral TC makes the isoquant shift towards the origin in a parallel way, the new equilibrium point being B. The introduction of biased TC also causes a change in the slope of isoquant, and the new equilibrium point is now C. The direction of TC reflects the structure of relative prices. The top diagram shows the case of capital-intensive TC in contexts characterized by relatively high wage levels. The top diagram shows the case of labour-intensive TC in contexts characterized by relatively low wage levels.

Figure 2 – Dynamics of Output Elasticites in Sampled Countries, 1971 - 2001

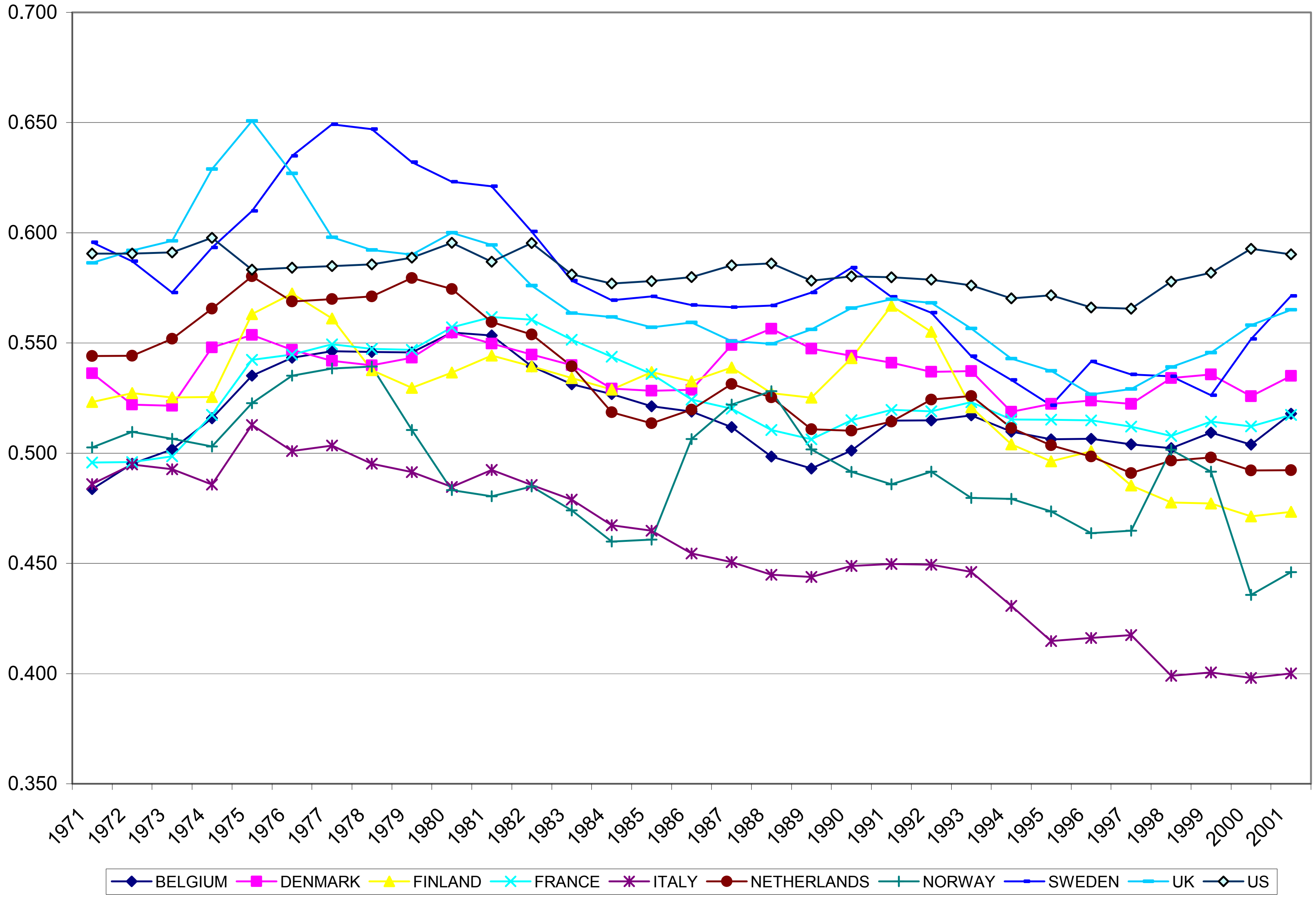


Figure 3 - Dynamics of BTFP

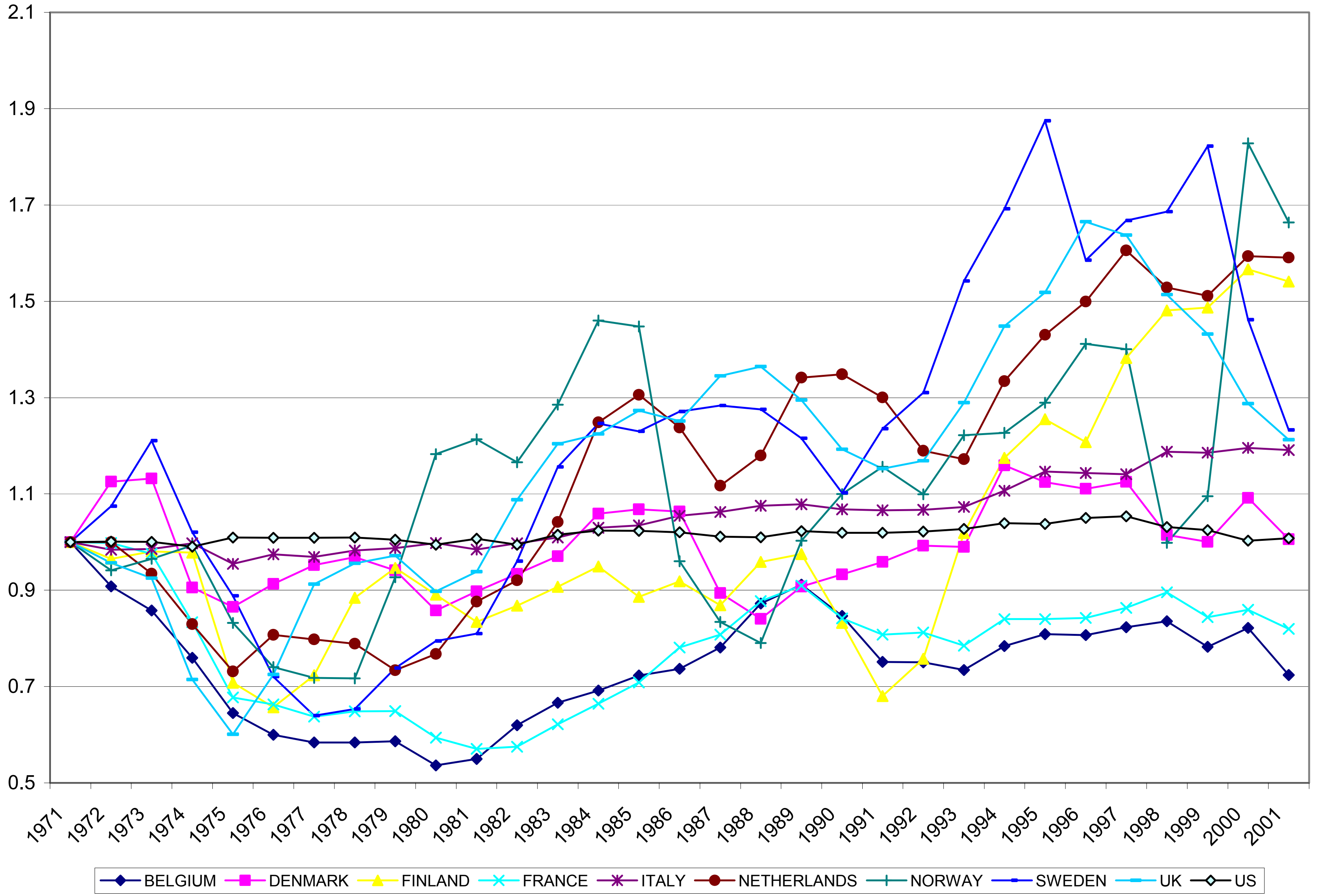


Table 1 – Labour output elasticity, 1971 – 2001

	BELGIUM	DENMARK	FINLAND	FRANCE	ITALY	NETHERLANDS	NORWAY	SWEDEN	UK	US
1971	0.484	0.536	0.523	0.496	0.486	0.544	0.503	0.596	0.586	0.591
1972	0.495	0.522	0.527	0.496	0.495	0.544	0.510	0.587	0.592	0.591
1973	0.502	0.521	0.525	0.499	0.493	0.552	0.506	0.573	0.596	0.591
1974	0.516	0.548	0.526	0.517	0.486	0.566	0.503	0.593	0.629	0.598
1975	0.535	0.554	0.563	0.542	0.513	0.580	0.523	0.610	0.651	0.583
1976	0.543	0.547	0.572	0.545	0.501	0.569	0.535	0.635	0.627	0.584
1977	0.546	0.542	0.561	0.549	0.503	0.570	0.538	0.649	0.598	0.585
1978	0.546	0.540	0.538	0.547	0.495	0.571	0.539	0.647	0.592	0.586
1979	0.546	0.543	0.530	0.547	0.491	0.579	0.510	0.632	0.590	0.589
1980	0.555	0.555	0.537	0.557	0.485	0.574	0.483	0.623	0.600	0.595
1981	0.553	0.550	0.544	0.562	0.492	0.560	0.480	0.621	0.594	0.587
1982	0.539	0.545	0.539	0.561	0.486	0.554	0.485	0.601	0.576	0.595
1983	0.531	0.540	0.534	0.551	0.479	0.539	0.474	0.578	0.564	0.581
1984	0.527	0.529	0.529	0.544	0.467	0.519	0.460	0.569	0.562	0.577
1985	0.521	0.528	0.537	0.536	0.465	0.514	0.461	0.571	0.557	0.578
1986	0.519	0.529	0.533	0.524	0.454	0.520	0.506	0.567	0.559	0.580
1987	0.512	0.549	0.539	0.520	0.451	0.531	0.522	0.566	0.551	0.585
1988	0.498	0.556	0.527	0.510	0.445	0.525	0.528	0.567	0.550	0.586
1989	0.493	0.547	0.525	0.506	0.444	0.511	0.502	0.573	0.556	0.578
1990	0.501	0.544	0.543	0.515	0.449	0.510	0.491	0.584	0.566	0.580
1991	0.515	0.541	0.567	0.520	0.450	0.514	0.486	0.571	0.570	0.580
1992	0.515	0.537	0.555	0.519	0.449	0.524	0.492	0.564	0.568	0.579
1993	0.517	0.537	0.521	0.523	0.446	0.526	0.480	0.544	0.557	0.576
1994	0.510	0.519	0.504	0.515	0.431	0.511	0.479	0.533	0.543	0.570
1995	0.506	0.522	0.496	0.515	0.415	0.504	0.474	0.522	0.537	0.572
1996	0.506	0.524	0.501	0.515	0.416	0.498	0.464	0.542	0.527	0.566
1997	0.504	0.522	0.485	0.512	0.417	0.491	0.465	0.536	0.529	0.566
1998	0.502	0.534	0.478	0.508	0.399	0.497	0.502	0.535	0.539	0.578
1999	0.509	0.536	0.477	0.514	0.400	0.498	0.492	0.526	0.546	0.582
2000	0.504	0.526	0.471	0.512	0.398	0.492	0.436	0.552	0.558	0.593
2001	0.518	0.535	0.473	0.517	0.400	0.492	0.446	0.571	0.565	0.590

Source: Elaborations on OECD data. Labour output elasticity is calculated following equation (4)

Table 2 – Evolution of TFP, by Country (1971 = 1)

	BELGIUM	DENMARK	FINLAND	FRANCE	ITALY	NETHERLANDS	NORWAY	SWEDEN	UK	US
1971	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1972	1.148	0.887	1.081	1.023	1.043	1.057	1.138	0.950	1.090	0.991
1973	1.248	0.905	1.086	1.058	1.074	1.168	1.093	0.871	1.159	0.996
1974	1.420	1.176	1.106	1.274	1.093	1.401	1.073	1.074	1.509	1.021
1975	1.677	1.319	1.514	1.645	1.151	1.637	1.277	1.244	1.825	1.051
1976	1.869	1.225	1.705	1.744	1.194	1.578	1.447	1.520	1.554	1.053
1977	1.948	1.217	1.609	1.887	1.213	1.552	1.528	1.721	1.275	1.031
1978	1.982	1.217	1.410	1.907	1.224	1.588	1.688	1.791	1.245	1.017
1979	2.051	1.290	1.378	1.927	1.237	1.742	1.351	1.609	1.247	1.016
1980	2.211	1.491	1.455	2.103	1.215	1.669	1.112	1.495	1.359	1.050
1981	2.392	1.574	1.563	2.240	1.255	1.524	1.070	1.503	1.371	1.055
1982	2.202	1.499	1.508	2.343	1.271	1.470	1.116	1.274	1.195	1.085
1983	2.125	1.457	1.468	2.240	1.285	1.330	1.023	1.062	1.102	1.066
1984	2.061	1.308	1.461	2.131	1.277	1.118	0.948	0.992	1.064	1.036
1985	1.950	1.252	1.596	2.027	1.302	1.056	1.016	0.992	1.032	1.043
1986	1.918	1.200	1.582	1.826	1.294	1.113	1.506	0.979	1.083	1.063
1987	1.803	1.446	1.700	1.742	1.294	1.242	1.764	0.963	1.006	1.085
1988	1.551	1.598	1.516	1.591	1.275	1.175	1.881	0.955	0.961	1.102
1989	1.441	1.499	1.470	1.530	1.287	1.047	1.577	0.974	0.997	1.094
1990	1.519	1.499	1.777	1.654	1.287	1.057	1.568	1.081	1.102	1.119
1991	1.797	1.508	2.335	1.758	1.299	1.114	1.578	1.003	1.192	1.151
1992	1.827	1.485	2.277	1.795	1.328	1.226	1.722	1.002	1.211	1.156
1993	1.900	1.527	1.871	1.921	1.424	1.273	1.538	0.913	1.136	1.136
1994	1.836	1.330	1.721	1.813	1.424	1.144	1.561	0.834	1.028	1.116
1995	1.763	1.330	1.567	1.840	1.365	1.067	1.513	0.745	0.988	1.105
1996	1.787	1.344	1.625	1.841	1.360	1.006	1.373	0.879	0.904	1.090
1997	1.737	1.291	1.394	1.833	1.375	0.935	1.334	0.862	0.915	1.080
1998	1.699	1.391	1.302	1.758	1.302	0.995	1.782	0.849	0.965	1.100
1999	1.824	1.435	1.307	1.834	1.298	0.999	1.703	0.782	1.035	1.111
2000	1.744	1.305	1.269	1.807	1.281	0.963	1.074	0.989	1.177	1.137
2001	1.984	1.427	1.275	1.901	1.284	0.971	1.223	1.188	1.258	1.156

Source: Elaborations on OECD data. TFP has been calculated according to Equation (3). We arbitrarily set 1971 = 1 and use the fact that A(t+1) = A(t) (1+ΔA(t)/A(t)) to reconstruct the time series.

Table 3 – Evolution of TTFP, by Country (1971= 1)

	BELGIUM	DENMARK	FINLAND	FRANCE	ITALY	NETHERLANDS	NORWAY	SWEDEN	UK	US
1971	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1972	1.042	0.998	1.043	1.021	1.026	1.057	1.071	1.020	1.043	0.992
1973	1.071	1.024	1.065	1.033	1.059	1.091	1.055	1.054	1.071	0.997
1974	1.079	1.065	1.081	1.062	1.090	1.162	1.065	1.096	1.078	1.011
1975	1.081	1.141	1.072	1.114	1.098	1.197	1.063	1.104	1.097	1.061
1976	1.121	1.118	1.120	1.156	1.164	1.274	1.071	1.095	1.127	1.062
1977	1.137	1.158	1.164	1.204	1.176	1.239	1.097	1.100	1.164	1.040
1978	1.158	1.179	1.247	1.236	1.203	1.253	1.210	1.170	1.190	1.026
1979	1.202	1.215	1.303	1.250	1.221	1.278	1.252	1.188	1.211	1.021
1980	1.186	1.279	1.296	1.249	1.213	1.281	1.315	1.187	1.220	1.044
1981	1.314	1.413	1.303	1.277	1.236	1.335	1.298	1.217	1.286	1.062
1982	1.365	1.399	1.309	1.346	1.268	1.353	1.301	1.224	1.300	1.078
1983	1.416	1.414	1.332	1.393	1.297	1.385	1.315	1.228	1.327	1.083
1984	1.425	1.385	1.387	1.416	1.315	1.396	1.384	1.236	1.302	1.061
1985	1.410	1.336	1.414	1.436	1.347	1.378	1.470	1.220	1.313	1.067
1986	1.413	1.276	1.453	1.426	1.365	1.377	1.446	1.244	1.355	1.084
1987	1.409	1.293	1.477	1.408	1.375	1.387	1.471	1.236	1.353	1.098
1988	1.353	1.343	1.453	1.396	1.371	1.386	1.487	1.218	1.312	1.113
1989	1.314	1.360	1.433	1.392	1.387	1.404	1.581	1.184	1.291	1.119
1990	1.286	1.398	1.479	1.392	1.375	1.425	1.724	1.191	1.315	1.140
1991	1.350	1.445	1.588	1.420	1.385	1.449	1.825	1.239	1.374	1.173
1992	1.370	1.474	1.725	1.458	1.416	1.458	1.893	1.313	1.416	1.181
1993	1.395	1.512	1.906	1.508	1.527	1.493	1.879	1.408	1.464	1.167
1994	1.439	1.541	2.021	1.524	1.576	1.527	1.915	1.412	1.488	1.160
1995	1.426	1.496	1.967	1.546	1.564	1.527	1.951	1.397	1.500	1.147
1996	1.442	1.493	1.962	1.552	1.555	1.508	1.937	1.393	1.505	1.145
1997	1.430	1.453	1.926	1.583	1.569	1.501	1.868	1.437	1.499	1.138
1998	1.419	1.411	1.928	1.574	1.546	1.521	1.779	1.432	1.461	1.134
1999	1.427	1.435	1.943	1.548	1.539	1.509	1.865	1.425	1.483	1.138
2000	1.433	1.425	1.988	1.553	1.532	1.534	1.963	1.446	1.515	1.140
2001	1.437	1.435	1.965	1.558	1.529	1.544	2.035	1.465	1.526	1.166

Source: Elaborations on OECD data. TTFP has been calculated according to Equation (5). We arbitrarily set 1971 = 1 and use the fact that $A(t+1) = A(t)\,(1+\Delta A(t)/A(t))$ to reconstruct the time series.

Table 4 – Evolution of BTFP, by Country (1971 = 1)

	BELGIUM	DENMARK	FINLAND	FRANCE	ITALY	NETHERLANDS	NORWAY	SWEDEN	UK	US
1971	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1972	0.908	1.126	0.965	0.998	0.984	1.000	0.941	1.074	0.957	1.001
1973	0.858	1.132	0.981	0.976	0.985	0.935	0.965	1.210	0.925	1.000
1974	0.760	0.905	0.978	0.833	0.997	0.830	0.993	1.020	0.714	0.991
1975	0.645	0.866	0.708	0.677	0.955	0.732	0.832	0.888	0.601	1.009
1976	0.600	0.913	0.657	0.663	0.974	0.807	0.740	0.720	0.725	1.009
1977	0.584	0.952	0.724	0.638	0.969	0.798	0.718	0.640	0.912	1.009
1978	0.584	0.969	0.884	0.648	0.982	0.789	0.717	0.653	0.956	1.009
1979	0.586	0.941	0.946	0.649	0.988	0.734	0.927	0.738	0.972	1.005
1980	0.536	0.858	0.891	0.594	0.998	0.767	1.182	0.794	0.898	0.994
1981	0.549	0.898	0.834	0.570	0.984	0.876	1.213	0.810	0.938	1.007
1982	0.620	0.934	0.868	0.575	0.997	0.921	1.166	0.960	1.088	0.994
1983	0.666	0.971	0.907	0.622	1.009	1.041	1.286	1.156	1.204	1.015
1984	0.692	1.059	0.950	0.664	1.030	1.248	1.460	1.246	1.224	1.024
1985	0.723	1.068	0.886	0.709	1.034	1.306	1.448	1.230	1.273	1.023
1986	0.737	1.064	0.919	0.781	1.054	1.237	0.960	1.271	1.251	1.020
1987	0.781	0.894	0.869	0.808	1.063	1.117	0.834	1.283	1.345	1.011
1988	0.872	0.840	0.959	0.877	1.075	1.180	0.790	1.276	1.365	1.010
1989	0.912	0.908	0.975	0.910	1.078	1.341	1.003	1.216	1.295	1.023
1990	0.847	0.933	0.832	0.841	1.068	1.349	1.100	1.102	1.193	1.019
1991	0.751	0.959	0.680	0.808	1.066	1.300	1.156	1.235	1.153	1.019
1992	0.750	0.993	0.758	0.812	1.067	1.190	1.099	1.310	1.169	1.022
1993	0.734	0.990	1.019	0.785	1.073	1.172	1.222	1.542	1.289	1.027
1994	0.784	1.159	1.175	0.840	1.107	1.334	1.227	1.692	1.448	1.039
1995	0.809	1.125	1.255	0.840	1.146	1.431	1.289	1.874	1.518	1.038
1996	0.807	1.110	1.208	0.843	1.143	1.499	1.411	1.585	1.665	1.050
1997	0.823	1.125	1.382	0.864	1.141	1.606	1.400	1.668	1.637	1.053
1998	0.835	1.015	1.481	0.896	1.188	1.528	0.998	1.686	1.514	1.031
1999	0.782	1.000	1.487	0.844	1.186	1.511	1.095	1.822	1.432	1.025
2000	0.822	1.092	1.567	0.860	1.196	1.594	1.828	1.462	1.287	1.003
2001	0.724	1.006	1.541	0.820	1.191	1.591	1.663	1.233	1.212	1.008

Source: Elaborations on OECD data. BTFP has been calculated according to Equation (6). We arbitrarily set 1971 = 1 and use the fact that $A(t+1) = A(t)\,(1+\Delta A(t)/A(t))$ to reconstruct the time series.

Table 5 – Results of GMM System One Step Robust Estimation

	Model 1	Model 2	Model 3
Constant	0.041	0.006	0.059
	(0.061)	(0.060)	(0.058)
$Log(BTFP)_{t-1}$	0.937***	0.957***	0.950***
	(0.044)	(0.043)	(0.044)
$Log(PATINT)_{t-1}$	0.018**	0.030**	
	(0.006)	(0.013)	
$Log(BERDINT)_{t-1}$		-0.044	-0.013
		(0.028)	(0.014)
$Log(GOVERDINT)_{t-1}$		0.049**	0.063**
		(0.022)	(0.028)
N. Obs.	200	200	200
Hansen/Sargan χ^2	6.66	1.19	1.69
AR(1)	-1.87**	-1.77**	-1.80**
AR(2)	-0.99	-0.98	-1.01

Dependent variable: $Log(BTFP)_t$
Notes: *** p <0.01, ** p<0.05.Robust standard errors between parentheses. All models include country and time fixed effects. The instruments used in each equation (where available and where included in the model) are:
$log(BTFP)_{t-1}$, $log(BTFP)_{t-2}$, $log(BTFP)_{t-3}$, $log(PATINT)_{t-1}$, $log(PATINT)_{t-2}$, $log(PATINT)_{t-3}$, $log(BERDINT)_{t-1}$, $log(BERDINT)_{t-2}$, $log(BERDINT)_{t-3}$, $log(GOVERDINT)_{t-1}$, $log(GOVERDINT)_{t-2}$, $log(GOVERDINT)_{t-3}$.