department of economics
"S. Cognetti de Martiis"

Via Po, 53 – 10124 Torino (Italy)
Tel. (+39) 011 6704917 - Fax (+39) 011 6703895
URL: http//www.de.unito.it

WORKING PAPER SERIES

Directed Technological Change and Total Factor Productivity.
Effects and Determinants in a Sample of OECD Countries, 1971 – 2001

Cristiano Antonelli e Francesco Quatraro

Dipartimento di Economia "S. Cognetti de Martiis"

Laboratorio di Economia dell'Innovazione "Franco Momigliano"

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Directed Technological Change and Total Factor Productivity. Effects and Determinants in a Sample of OECD Countries, 1971 – 2001[1].

Cristiano Antonelli

and

Francesco Quatraro (*)

Laboratorio di Economia dell'Innovazione "F. Momigliano"
Dipartimento di Economia "S. Cognetti de Martiis"
Università di Torino
Via Po 53
10124 Torino

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 and its effects on the actual levels of total factor productivity. This is not surprising for two reasons. First, because the introduction of new and biased technologies can be considered as the result of a clear inducement mechanism exerted by the characteristics of factor markets. Second, because the introduction of radical innovations, such as new information and communication technologies, provides innovators with a strong competitive advantage and feeds the creative destruction of old incumbents. Imitators, especially if based in other factor markets, can try and resist the decline by means of the systematic effort to adapt them to the structure of local endowment. The bias effect is the ultimate result of their creative adoption.

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(*) Corresponding author: francesco.quatraro@unito.it. Tel: +390116704980. Fax: +390116703895.

1. Introduction

In the recent years there has been renewed interest in the issue of directed technological change (TC), due to the identification of strong bias of new information and communication technologies (ICTs) towards high-skilled labour (Acemoglu, 1998).

Along the methodological lines elaborated by Griliches (1969), since the early 1990s, a stream of studies has explored the effects of ICTs on the relative wage structure and found a positive effect of computerization on the demand of skilled workers (Berndt et. al., 1992; Barthel and Sicherman, 1997; Haskel and Martin, 2001; Haskel and Heden, 1999). This debate has little explored the broader issues of the determinants and effects of the changing output elasticity of production factors (Acemoglu, 2002).

The concept of input-bias hardly represented a novelty. Hicks (1932) elaborates the Marxian intuitions and argues that technological change is a form of meta-substitution. When the cost of a factor increases firms are induced to introduce 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 technological change should be labour-intensive, in labour abundant countries, even if wages increase. Ruttan (1997 and 2002) 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 technological change 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 technological change in the American economic history. Fare et al. (1997) have elaborated a methodology to decompose the Malmquist index of total factor productivity (TFP) in three parts, i.e. a shift, an input-bias and an output-bias term (Managi and Karemera, 2004).

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.

In this paper we aim at filling this gap, by investigating 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 the distinction between biased and neutral TC is empirically relevant, and that relative prices and firms' innovation efforts are important triggering factors.

The remainder of the paper is organized as follows. In Section 2 we provide statistical evidence about the actual changes in output elasticities that have been taking place a large sample of representative countries in the years 1971-2001. Section 3 presents an original methodology to appreciate the effects of biased TC upon total factor productivity measures. Section 4 shows the results of our calculations. In Section 5 we enquire the determinants of biased TC. The concluding remarks follow in Section 6.

2. Preliminary Statistical Evidence

In order to show how much pervasive the issue is, it is worth looking at the data concerning the output elasticity of labour[2]. Indeed, should TC consist just of a shift in the production function, one would not observe any 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. The proof may of course be found in any undergraduate textbook in microeconomics. This, actually, makes quite surprising the neglect of the dynamic implications of a change in output elasticities. Table 1 shows instead that output elasticity of labour is far from stable over time, and is also characterized by remarkable cross country differences.

INSERT TABLE 1 ABOUT HERE

[2] See Section 3 for details about the calculations.

INSERT FIGURE 1 ABOUT HERE

The data show clearly 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 1). 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 elasiticity 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.[3], 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 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, and 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 glance at pretty simple evidence, it is clear that stability is just one of the possible patterns output elasticities may show over time. Moreover, countries differ according to the relative efficiency of production factors, and its evolution over time. The empirical evidence

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

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.

This evidence is quite clear and yet much overlooked. This makes the analysis of biased technological change imperative in order to gain a better understanding of the causes and the effects of innovation patterns on productivity growth.

3. The Implications for TFP measures: Methodology

In order to single out an index of biased technological we elaborate upon the calculation of total factor productivity (TFP). In this respect two different approaches may be followed. One the one hand there is the so-called "growth accounting" methodology, which draws upon the seminal contribution by Solow (1957). On the other hand, a new methodology has been recently elaborated by Fare et al. (1997), who developed a Malmquist index of TFP, using nonparametric estimates of production frontiers. Supporters of this methodology claim that it has at least two advantages: i) no information about factor price is needed, and ii) it is decomposable in two parts, one related to efficiency changes, and the other related to technological changes (Kruger, 2003).

In this paper we adopt the former approach, following the recent methodological progresses (Jorgenson, 1995; OECD, 2001). The choice is due to the fact that in the assessment of biased TC, Malmquist-like TFP indexes lose their advantages. Indeed, Managi and Karemera (2004) show that constant returns to scale need to be assumed, like in the standard approach. Moreover, along the lines of Hicks biased TC is strictly related to changes in factor prices, and hence it is unavoidable to gain information about it.

This methodology is elaborated in Antonelli (2002, 2003 and 2006) and applied in Antonelli and Quatraro (2007). Le us recall here the main passages. 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 shape:

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

Whose standard Cobb-Douglas takes the following format:

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

If we take logarithms of equation (1), we can write TFP as follows:

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

Where $\alpha_{i,t}$ and $\beta_{i,t}$ represent the factors' share in total factor income for each country at each year, and $\alpha + \beta = 1$.

Such a measure accounts for "any kind of shift in the production function" (Solow, 1957: 312), and it can be considered a rough proxy of technical change. By means of it Solow intended to propose a way to "segregating shifts of the production function from movements along it". But the change in the technology of the production function is made up of two elements. Besides the shift effect one should account for the bias effect, i.e. the direction of TC.

Once we get the TFP accounting for the shift in the production, 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 both effects (for this reason we call it *total-TFP*), by assuming output elasticities unchanged with respect to the first year observed:

$$\ln A_{i,t}^{TOT} = \ln Y_{i,t} - \alpha_{i,t=0} \ln K_{i,t} - \beta_{i,t=0} \ln L_{i,t} \quad (4)$$

Next we get the bias effect as the ratio between the two indexes we introduced above, i.e.:

$$A_{i,t}^{BIAS} = \frac{A_{i,t}^{TOT}}{A_{i,t}} \quad (5)$$

The output elasticities have been calculated by assuming constant returns to scale, and focusing on labour's elasticity, which is computed as the factor share in total output:

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

and hence:

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

Once the coefficients have been calculated, it is possible to estimate the GDP that would have been produced each year, had the marginal productivity of factors remained unchanged:

$$\hat{Y}_{i,t} = K_{i,t}^{\alpha} L_{i,t}^{\beta} \qquad (6)$$

$\alpha = \alpha_{1970}$ and $\beta = \beta_{1970}$

The difference between the logarithm of actual GDP and the logarithm of the figure yielded using equation (6), gives us the index of total-TFP.

4. The Evidence about the Changes in Productivity Indexes

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 have been drawn by the Economic Outlook, while the series on employment, worked hours, compensation of employees and fixed capital stock have been found in the OECD Stan Database. Data on capital stock (*K*) and employees' compensation ($w \cdot L$) have been deflated by using the PPP index implicit to GDP data. Finally we have drawn the time series concerning general expenditure for R&D (GERD), business expenditure on R&D (BERD) and government R&D expenditure (GOVERD), from the OCED Science and Technology indicators.

Tables 2 to 4 present the results of our calculations for the countries in the sample[4]. Table 3 reports the evolution of the standard TFP index *à la* Solow. At a general level, TFP shift is featured by a steady increase until

[4] Since absolute levels of TFP indexes have no meaning per se, Tables 2 to 4 give a flavour of the dynamics of productivity. To make cross-country comparison easier, we normalized growth rates with respect to 1971. In particular what we show in the tables is an index of the kind: $S = 1 + \frac{x_t - x_0}{x_0}$. Where x is the productivity index, and $t \in [1971,2001]$. On the one hand this allows us to see which country grows and which one does not. On the other hand one would expect that countries with lower initial levels would show up higher growth rates on average (and *viceversa*).

1981, and then followed by a substantial decrease along the 1980s, and a substantial stabilization along the 1990s. A deeper look into national specificities reveals however interesting differences and some exceptions. Belgium and Denmark are featured by steep increase of TFP shift 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 productivity 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 TFP shift 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 TFP total 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 TFP total 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 a synthetic index of biased TC, combining shift and total TFP. The threshold value of the index is of course 1. Values above the unity signal a predominance of innovation efforts aimed at shaping the technology with a bias that is consistent with the local features of the system. Values below the unity signal the predominance of the shift effect. Values very close to 1 witness an innovation strategy in which the evolution factor markets and technologies are coordinated so as to be coherent.

By construction, the index gets value 1 at time 0. For this reason we show here the normalized growth rates obtained the same way as in the previous tables. Hence, the values at each year may be interpreted as the extent to which the index departs from 1.

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 2):

a) Countries substantially diverging from 1 downwards. In such countries, France and Belgium, the shift effect overwhelmed the bias;
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 dominated by creative adoption processes: the Italian case is especially relevant[5]. Technologies developed elsewhere have been adapted to local conditions of factors markets, so as to use systematically the cheapest input.

[5] Italian firms indeed excel in the adoption of new technologies, introduced abroad and in their eventual adaptation to the local factor markets. The small size of Italian firms prevented the implementation of systematic intramuros R&D and the weak scientific and technological infrastructure reduced the chances to generate radical innovations. As a consequence the Italian economy is very much based upon traditional industrial sectors while new high-tech industries have much a smaller weight than in other economies (Quatraro, 2007).

c) Finally there are countries where the index does no drift away considerably from 1. They are Denmark and the US. In such context factors endowments evolved coherently with the direction of technological change.

INSERT FIGURE 2 ABOUT HERE

5. The Determinants of Biased Technological Change

According to the inducement hypothesis, as elaborated so far, the introduction of new radical technologies and the characteristics of factor markets are likely to shape the direction of innovation efforts. Thus, in capital abundant countries, at the time of the introduction of ICTs, the increase of wages is likely to trigger research efforts directed towards the introduction of new biased technologies with labour-saving effects. This amounts to propose the following specification:

$$A_{BIAS} = \alpha + \beta \cdot wph + \varepsilon \qquad (7)$$

Where *wph* is wage per hour, and β is expected to be negative. The directionality of technological change is biased, that is induced by the levels of wages and it takes place by means of intentional formalized R&D efforts, which are carried out both within public institutions and within private companies. Thus, one would expect that general R&D expenditure have a significant impact. Moreover, disentangling public and private expenditure, one may also expect private R&D efforts to significantly and positively affect the generation of biased TC. This leads us to the following extended specifications:

$$A_{BIAS} = \alpha + \beta \cdot wph + \gamma_1 \cdot GERD \qquad (8)$$

$$A_{BIAS} = \alpha + \beta \cdot wph + \gamma_2 GOVERD + \gamma_3 BERD + \varepsilon \qquad (9)$$

Where we expect $\beta_1 < 0$, γ_1 significantly different from 0 and $\gamma_3 > 0$.

Since we are interested in the dynamics of biased TC, the dependent variable of our regression will be the index *S*, described in note 4, instead of the index in levels.

Before proceeding to the econometric estimation, we must address the serious problems of autocorrelation that are quite usual when productivity measures are concerned. Hence we test whether the index of biased TC, derived in Sections 3 and 4, is $I(1)$. Our sample size makes the use of standard large-sample based unit roots tests unreliable. For this reason we make explicit use of the panel structure of the data and check 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.

We tested the null hypothesis of unit root both with and without the trend component. The yielded *t*-statistics are respectively -9.33 and -5.69, which allow us to reject the null hypothesis respectively at 1% and 5% confidence level.

In order to develop a dynamic model of biased TC, 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 fixed effect model for panel data. We carried out the empirical test by means of a dynamic panel data regression, using the generalized method of moments (GMM) estimator proposed by 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. While we are aware that the estimator subsequently introduced by Arellano and Bover (1995) and Blundell and Bond (1998) has better performances in presence or random walk-like variables, we preferred to use the difference estimator as we cannot assume that changes in the instrumented variables are not systematically related to fixed effects.

The econometric specification would hence become:

$$S_{i,t}^{BIAS} = \alpha \cdot S_{i,t-1}^{BIAS} + \beta \cdot wph_{i,t} + \gamma \cdot \log T_{i,t} + \sum_{j=1}^{T} \lambda_j t_j + \eta_i + \varepsilon_{i,t} \qquad (10)$$

Where S_t and S_{t-1} are respectively concurrent and lagged value of biased TC index, *wph* is wages per hour and *T* is a vector of science and technology related variables. In particular three regressions will be run, considering respectively i) general R&D; ii) public and private R&D; iii) patent applications. The fixed-effect decomposition of the error term consists of 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 considers general R&D expenditure (GERD) together with *wph*. The latter regressor is significant and negative, while the former is positive and significant. At this stage we are able to maintain that inducement mechanisms do affect the introduction of biased TC, and that the undertaking of R&D activities represents a triggering factor. In column 2 we disentangle public and private R&D expenditure. The coefficient on *wph* preserves its sign and significance, public R&D expenditure is not statistically significant, and private R&D is positive and significant. It is also worth noting that when the private component is disentangled from general R&D, the standard error of *wph* significantly decreases.

INSERT TABLE 5 ABOUT HERE

Finally, in column 3 we substitute patent applications for R&D expenditure as a proxy of innovation activity. Since the sample puts together the U.S. and nine European countries, we had to consider patents submitted both to the EPO and to USPTO. The variable *PATENT* is obtained as the ratio between the sum of the patents submitted to the two patent offices, and real GDP. The sign and significance of *wph* are unchanged, although the magnitude of the coefficient is much higher (in absolute terms). It is interesting to note that the coefficient of the patenting activity is significant and positive. This means that firms' formalized innovation efforts are directed towards the introduction of biased TC. Firms are far from passively adopting technologies generated elsewhere. They instead undertake adaptation efforts directed to shaping the new technologies on the basis of the characteristics of local factors markets.

6. Discussion

The distinction between shift-TFP and bias-TFP has interesting implications for the economics of innovation. Since the seminal contributions by Schumpeter (1934 and 1942) the distinction between radical and incremental TC has received much attention in the literature. Radical innovations are rarely introduced in the economic systemic, causing a discontinuity which is followed by a stream of sequential incremental innovations aimed at adjust the system to the new technology, and vice-versa (Mokyr, 1990).

The two different parts that define the total TFP, can be thought as the outcome of the introduction of radical and incremental TC, respectively. The shift in the production function is engendered by a radical change in the production technology, while the bias is the result of the technological manipulation of the envelope of factor complementarities. ICT provide to day clear evidence about the matter. On the one hand, in fact ICT are a clear case of GPT (General Purpose Technologies) that exert a pervasive and generalized effect within the system, due to the great number of contexts they can be implemented and applied. They can be considered the result of intentional R&D efforts carried out within the boundaries of firms, taking advantage of new scientific breakthrough carried out by universities and research centres. As such, they turn out to have a strong science-based nature. The introduction of such radical and generic innovations leads to a clear shift effect such that all the map of isoquants is pushed towards the origin with no changes in the shape of each output line.

After the introduction of the new radical GPT, the innovating country gains a strong competitive advantage. Imitating countries can face the new competitive pressure only if they try and adapt the new technology to their own specific factor endowments. Creative adoption consists of a sequence of adjustments of the original GPT to the local factor markets. These adjustments in fact take place through a sequence of incremental technological innovations and rely on localised learning process and the accumulation of tacit knowledge. The idiosyncratic factors characterizing the context of utilization of the technology are likely to shape the innovation process, whose outcome hence turns out to be strongly path dependent. Such adaptation leads to the introduction of a bias, i.e. a change in the shape of the production function (Antonelli, 2003).

Much empirical evidence confirms that ICT provided the opportunity for a wave of incremental innovations that were often the result of creative adoption and local adaptation. Economic agents based in imitating countries had a strong incentive to try and adapt the new technology to the conditions of local factor markets, in a creative way, aiming at exploiting the locally most abundant production function. In so doing adaptive agents fed the diffusion process of the new GPT and yet changed the direction of TC with respect to the intensity of use of production factors. In capital-abundant countries where skills were scarcer than in the US, the creative adoption of ICT pushed many countries to introduce a bias in favour of capital. The creative adoption of ICT parallels an increase in the output elasticity of fixed capital. Similar processes have been taking place through the XX century with respect to the introduction and diffusion of the gale of innovations based upon engineering (Antonelli, 2003).

Along these lines, the evidence provided so far is consistent with both empirical and theoretical analyses provided by the literature. It is indeed hardly surprising to find that the shift and the bias effect are pretty balanced in the US economy, where ICTs originated. Therein factor endowment and technology coevolved so as to give rise both to a shift and to a change in the shape of the production function. Such coherence may be regarded as the main strength of the US system and the explanation of increasing productivity differentials with EU countries.

The European evidence, instead, suggests that the efforts to direct technological change so as to take advantage of the local factor market conditions, have played a major role with relevant effects in terms of total factor productivity growth and a sensible bias in the new technologies being introduced (Timmer and Van Ark, 2005).

7. Conclusions

The direction of technological change 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.

This is surprising also from a theoretical viewpoint for two reasons. First, following a well established literature, the introduction of new and biased technologies can be considered as the result of a clear inducement mechanism exerted by the characteristics, both static and dynamic, of factor market. Hence it is clear that, for a given asymmetry in the relative factor costs, the new technology will be more efficient, the larger is the bias. The search for the bias has been the guiding factor. Second, the introduction of radical innovations, such as new information and communication technologies, provides innovators with a strong competitive advantage and feed the creative destruction of old incumbents. Imitators, especially if based in other factor markets, can try and resist the decline by means of the creative adoption of the new technologies. The diffusion of information and communication technologies has been taking place along with a systematic effort to adapt them to the structure of local endowment. The bias effect is the ultimate result of the creative adoption.

The results of the empirical work carried out in this paper confirm that the direction of technological change matters and deserves careful analysis.

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Figure 1 – Dynamics of Output Elasticites in Sampled Countries, 1971 - 2001

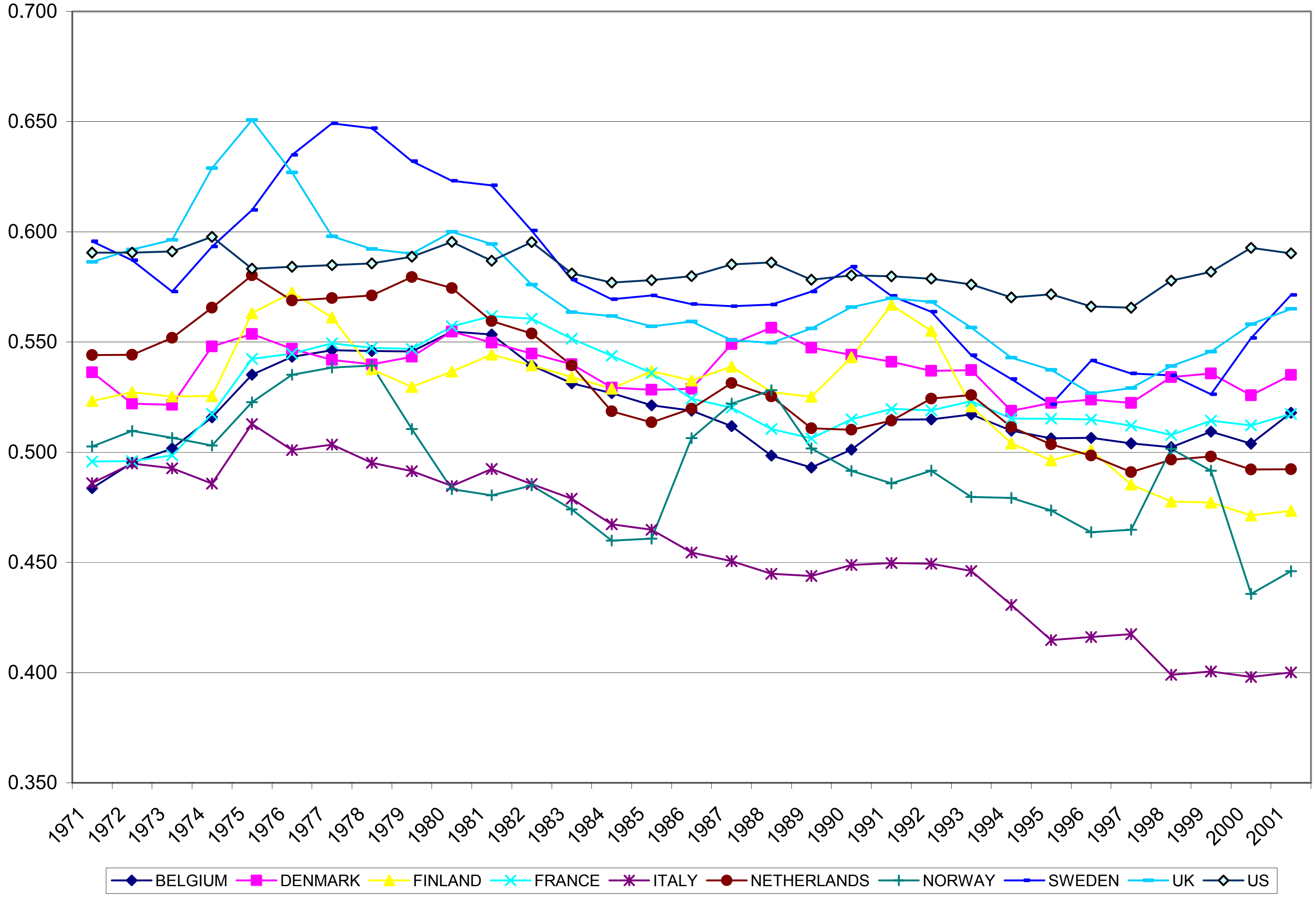

Figure 2 - Dynamics of TFP-Bias Index

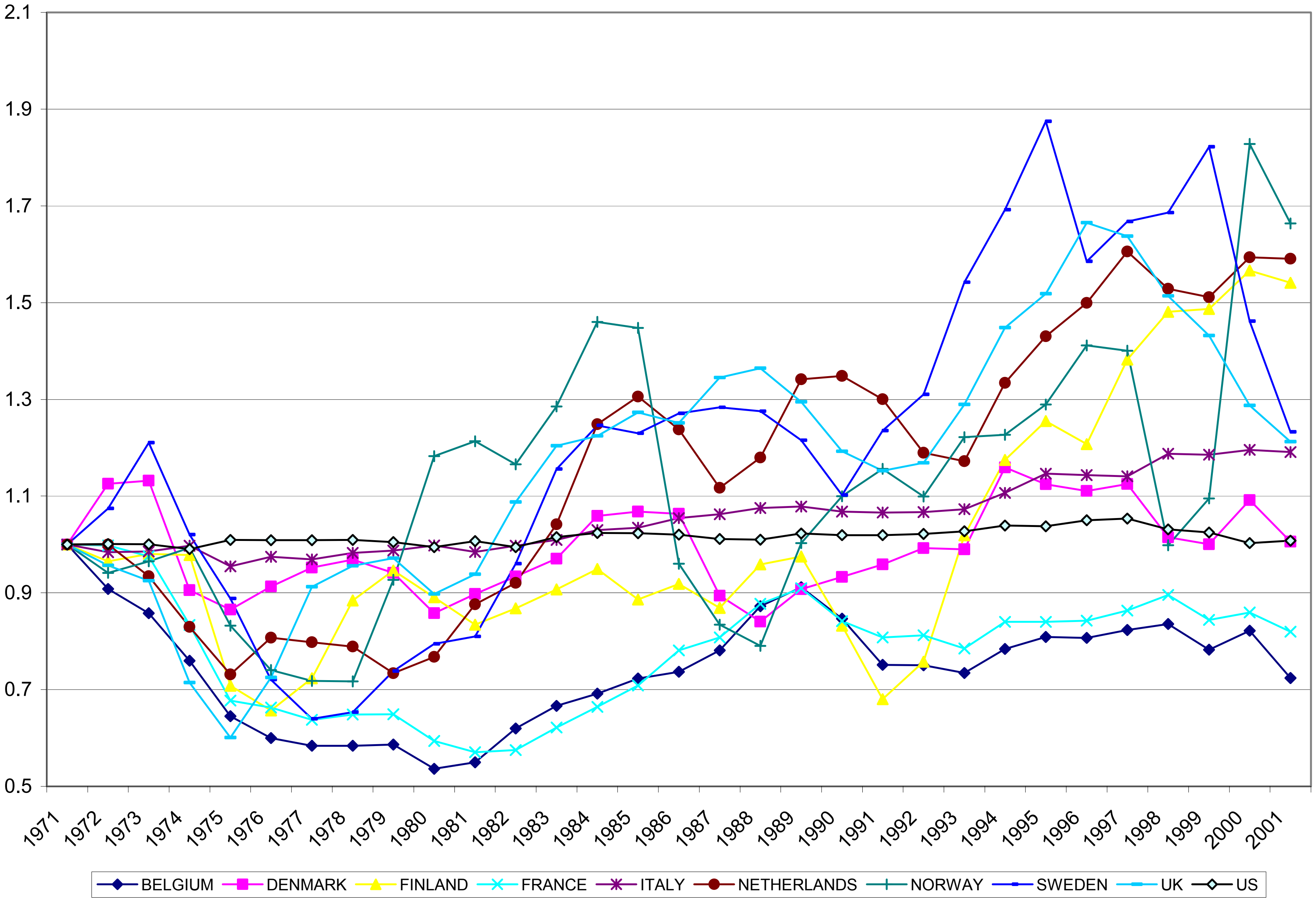

Table 1 – Labour output elasticity, 1971 – 2001

	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.

Table 2 - TFP Shift Effect (allowing output elasticities to change), 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.

Table 3 - TFP Total Effect (assuming fixed output elasticities at t_0), 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.

Table 4 – Ratio between TFP Total and TFP Shift, 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.

Table 5 – Results of GMM One Step Robust Estimation

	Model 1	Model 2	Model 3
S_{t-1}	.852***	.842***	.565***
	(.021)	(.0.26)	(.096)
WpH	-.123**	-.150***	-.424***
	(.069)	(.058)	(-.156)
logGERD	.113**		
	(.058)		
logGOVERD		-.004	
		(.041)	
logBERD		.10**	
		(.048)	
logPATENT			.240***
			(.059)
Sargan	4.53	2.95	7.02
AR(1)	-2.60***	-2.60***	-2.23**
AR(2)	-1.52	-1.53	-1.18

Dependent variable: S_t

Key: *** p <0.01, ** p<0.05

Note: robust st. err. between parentheses. The instruments used in each equation (where available and where the corresponding regressor is included in the model) are: $Abias_{t-1}$, $Abias_{t-2}$, WpH_{t-1} , WpH_{t-2} , WpH_{t-3} $logGERD_{t-1}$, $logGERD_{t-2}$, $logGERD_{t-3}$, $logBERD_{t-1}$, $logBERD_{t-2}$, $logBERD_{t-3}$, $logGOVERD_{t-1}$, $logGOVERD_{t-2}$, $logGOVERD_{t-3}$, $logPAT_{t-1}$, $logPAT_{t-2}$, $logPAT_{t-3}$.