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Comparing TFP Catching-up and Capital Deepening in US and European Growths: A Directional Distance Function Approach

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Abstract

In Solow's model the income convergence between countries arises from two main sources: a capital deepening effect resulting from the diminishing returns of the production technology and a technological transfer/diffusion effect related to Total Factor Productivity (TFP) differences. A large literature has been devoted to analyze these effects but most of the studies suffer from three weaknesses by defining the US as the a priori technological leader, by using a parametric functional form and by assuming constant returns to scale for the technology. Our paper offers an alternative approach based on a non-parametric programming framework and the estimation of directional distance functions. We explicitly separate country TFP differences into two components: a technology effect and a scale effect to study the catching-up process on each of them. We also analyze the role of the capital deepening effect by introducing a relevant measure of the structural efficiency which reveals inefficiencies due to changes in input-ratio differences. Our empirical work focuses on 15 European countries (EU) and the US over the period 1980-2004. We use time series procedures to test for convergence for individual countries or sub-sets of countries.

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1. Introduction

Relating to the convergence debate, it is well known that two processes lead to income convergence between countries: (1) capital deepening linked to its property of diminishing returns and (2) technological transfer/diffusion related to Total Factor Productivity (TFP) differences. The neoclassical standard theory assuming perfect capital mobility and identical technology, devoted most attention to the first process. In addition, standard growth theory presumes that technological progress is exogenous and is available to all at no cost and thus it says little about technology adoption. This was a restrictive assumption needed at that initial step of advance of the growth theory (Solow, 1994). Some researchers such as Jorgenson (1995), and Durlauf and Johnson (1995) had come to the conclusion that identical production technologies assumption may not hold. Abramovitz (1986) adopts a less radical approach by considering a common available technology but countries may differ in their ability to recognize, incorporate and use it. He introduced the concept of "social capabilities" to explain productivity gaps among countries. Therefore interest in cross-country TFP differences has become a key element to investigate economic growth (Islam, 2003).

Since the end of the eighties, many empirical studies focusing on international comparison of TFP have revealed that differences in technology may contribute to gaps in TFP levels[1]. As TFP is an empirical measure of technology, the concept of TFP-convergence investigates whether countries are able to catch up in terms of highest observed TFP levels and how income convergence depends on both TFP growth rates and initial TFP levels. For example among others, Dowrick and Nguyen (1989) study TFP-convergence running a cross section regression of the TFP growth rates with the initial levels of TFP of fifteen OECD countries. They find significant evidence of TFP catch-up among developed countries. Nevertheless their analysis suffers from the restrictive assumption of a common capital-output ratio for all countries of the sample. With an aim of studying the interaction between technical change and the capital deepening component, Wolff (1991) implements the previous TFP catching-up equation with the capital/labor ratio growth rate and performs a regression to the G-7 countries. His results indicate a positive influence of capital accumulation on TFP catch-up. Dougherty and Jorgenson (1997) compute TFP levels across the G-7 countries and show a decrease of their coefficients of variation over time illustrating a significant process of convergence.

Empirical research on TFP growth is also available for developing or new industrialized countries. For instance, Young (1992, 1994, 1995), Kim and Lau (1994) study sources of development for the East Asian economies and find a limited role of the TFP growth. Interpreting the above results, Krugman (1994) concludes that East Asian growth has been mainly due to factor accumulation. In opposition to this view, Collins and Bosworth (1997) and Klenow and Rodriguez (1997) evaluate a more significant contribution of TFP growth for some East Asian economies such as Singapore. These last conclusions stress the role of assimilation of new technology to explain the growth of the East Asian countries and are in line with the interaction between technological adoption and capital accumulation leading to TFP growth.

However, most of these previous studies suffer from three weaknesses. First, they used catching-up variables that define the US as the technological leader. Needless to say, the US was the only technological leader at the end of World War II,but this advantage has gradually changed and technological leadership is now probably widespread among different developed countries. Second, the technology level is evaluated with a TFP index measured as a Solow-residual indicator with a particular functional form (Cobb–Douglas, CES, Translog…). Third,

[1] See Islam (2001) for a review on different approaches to international comparisons of TFP and the issue of convergence

TFP gaps may be in part due to the constant returns to scale assumption which does not take into account size heterogeneity across countries. These methodological choices may modify or bias the evaluation of the catching-up process.

More recently, Kumar and Russell (2002) re-examine the catching-up mechanism with a methodology which avoids the two first above mentioned drawbacks. This methodology requires no a priori functional form on the world production frontier, nor any assumption about market structure. In addition, it does not specify a particular nation as the world leader allowing for technical and/or allocative inefficiencies to arise from differences in the countries' ability to use available technology. They test for the catching-up hypothesis across 57 poor and rich nations, using labor productivity indexes calculated with a nonparametric method. To analyze the evolution of the cross-country distribution of labor productivity, they focus on differences in levels of technology, technological changes over time and how much of income convergence is due to technological diffusion or to convergence in capital/labor ratios. Their results conclude that there is evidence of technological catch-up, as countries have on the whole moved toward the world production frontier, non neutrality of technological change and a predominance of capital deepening as opposed to technological catch-up that contributes to both growth and income divergence of economies.

Christopoulos (2007) also considers a DEA approach to measure efficiency and examines the impact of human capital and openness on productive performance in a sample of 83 developed and less developed countries. His results support the view that movements towards openness increase a country's efficiency performance significantly, whereas human capital does not contribute to the efficiency. Nevertheless his analysis still relies on a restrictive constant returns to scale technology assumption.

Using a similar nonparametric approach, Färe et al. (1994) analyze productivity growth in 17 OECD countries over the period 1979-1988. Their productivity indexes are decomposed into two components namely, technical change and efficiency change interpreted as a catching-up effect. Relaxing constant returns to scale assumption for the technology, they further separate the catching-up effect into two terms: one representing a pure technical efficiency change and an other measuring changes in scale efficiency. The authors find that U.S. productivity growth is a little higher than average while Japan obtains the highest productivity growth rate.

Our research employs this above non-parametric programming method to focus both on input-ratio convergence and TFP catching-up among 15 European countries (EU) and the US over the period 1980-2004. Compared to previous studies on convergence, one contribution of our research is to separate country TFP differences into two components: a technology effect and a scale effect and to study the catching-up processes on each of them. The convergence test relies on the distance variations of the countries to an increasing and/or decreasing returns to scale production frontier over time. These movements previously corrected of the scale effect bias, reflect or not a pure technological diffusion process. A second contribution is to measure the variations in capital/labor mixes over time. These movements enable to reveal structural inefficiencies due to changes in input-ratio differences signaling the role of a capital deepening or expanding result on technological transfer. A third originality of our empirical study concerning macroeconomic data is to separate the information and communication technology from others capital-assets. As pointed by Timmer, Ypma and van Ark (2003) all European countries have been, and still are, seriously lagging behind the US in the share of IT investment in GDP. This specific technological lag may alter international TFP comparisons if they are computed from the usual production frontier only considering the two usual labor and capital inputs. To test for convergence, we use the Nahar and Hinder 's (2002) time series procedure which estimates a catching-up parameter and identifies particular countries or sub-sets of countries within the group, which might or not be converging. This paper is structured as follows. Using directional distance functions to conceptualize the west-wide production frontier, the next section recalls the measures of the three effects which may influence the convergence process between the US and European countries (respectively technical effect, scale effect and structural effect). Section 3 connects these three effects to the technological diffusion process by developing a time series test consistent with the definition of convergence of an individual economy or a sub-set of nations within a group of countries and then presents the sample and discusses the statistical results. Conclusions appear in the final section.

2. Analyzing convergence process with directional distance functions

The objectives of the model is both to gauge a catching-up effect between observed TFP levels of countries and their own maximal feasible level of productivity and to evaluate a convergence process of input mixes among countries. While the former depends on social capabilities to adopt available technology, the latter which encompasses the heterogeneity across countries relative to their input accumulations and can be viewed as a proxy for a capital deepening or expanding effect.

2.1. Definitions and concepts

2.1.1. Technological catching up process and TFP convergence.

Traditionally, the applied literature about technological adoption compares TFP levels across countries and tests an inverse relationship between growth TFP rates and their initial levels. Convergence in productivity levels turns out if countries with the lowest initial TFP have the highest growth rates: the followers catch up the leaders. This approach relies on an implicit assumption of constant returns to scale (CRS) since the optimal TFP, used as a benchmark for all countries, is the maximal observed productivity. However, if the CRS assumption does not hold and the production technology shows increasing and/or decreasing returns to scale (variable returns to scale, VRS), the maximal feasible level of TFP does not necessarily coincide with the maximal observed TFP and must be precisely gauged at the input level of each country. By assuming a CRS technology while a VRS technology prevails, some bias may be introduced in the analysis of technological diffusion. Indeed, a divergence in TFP levels can be observed while countries, reaching their production frontier, play a part in a technological catching up process as it is illustrated in Figure 1.

- Figure 1 about here -

In figure 1, three countries A, B and C produce one output (Y) from one input (X) under a variable returns to scale technology T_{VRS}. The observed levels of TFP for country B is easily computed as $\frac{0y_B}{0x_B}$ while the maximal productivity is observed for country A which characterizes the most productive scale size (mpss). If we consider this mpss as the benchmark for all other countries, we falsely assume a CRS technology. In that case, if countries B and C could come up to B^* and C^*, convergence TFP will arise since all countries achieve the same maximal TFP level.. However under the true VRS technology, countries will be able at best to reach B' and C'. Thus, while B and C will never be observed at B^* and C^*, one will conclude to a divergence of TFP levels between these two countries. Indeed TFP change is higher for country C than for country B even though the former was initially more productive than the latter, a contradiction to the TFP convergence hypothesis. By considering the true VRS technology of the example countries, we assume that the maximal feasible productivity levels evaluated at B' and C' onto the production frontier are their own respective optimal benchmarks rather than the mpss TFP level. Thus, a decrease with time in distances between countries and their respective benchmarks onto the production frontier denotes such a catching-up process to the maximal feasible productivity levels. One can note that traditional sigma or beta convergence tests on TFP levels are unable to point out this technological adoption effect. We will latter introduce the directional distance function to formally measure the distance of any production plan to the production frontier.

In our approach, the technological catching-up process is independent from the usual technical change definition since we compare the observed levels of TFP to their current technological benchmark. Comparisons are therefore done within the same period and not across time. While shifts of the production frontier modify productivity levels, they do not interfere with our technological catching-up measure since technical progress affect uniformly any country and its benchmark onto the frontier. This is illustrated by Figure 2. While there is technical progress over the two periods, distances to the frontiers have not changed implying no technological catching-up.

- Figure 2 about here -

2.1.2 Structural inefficiency and convergence of input-mixes.

We further illustrate the structural inefficiency effect in a multiple inputs case as a subtle source of inefficiency due to heterogeneity in factor accumulation among countries. Assume that two countries are technically efficient and also price efficient in the sense of Farrell (1957). Therefore no inefficiencies arise at the individual level. However, if countries face different price systems, it is clear that a kind of inefficiency prevails in the group of countries in line with the second welfare theorem. This market inefficiency is captured by a structural inefficiency component as shown in Figure 3. Let us consider two countries production plans (A and B) which are represented in the input space producing the same level of outputs. While countries A and B are both technically and price efficient, there is still inefficiency at the aggregate level. This structural inefficiency is coming from differences in relative input allocations among the two countries. Indeed, in a perfect competition market, only one input price vector has to coordinate the two countries and this structural effect computes the inefficient market allocation in the spirit of the Debreu (1951) coefficient of resource utilization.

- Figure 3 about here -

Moreover, it would be interesting to measure the respective contributions of countries A and B to this global structural inefficiency and thus to split it between them. This can be done thanks to the shadow price system defined at the aggregate technology and then apply it at each national production plan. As shown in Figure 4, structural inefficiency evaluated at aggregated level can be decomposed as the sum of individual shadow price inefficiencies.

- Figure 4 about here -

Before turning to a formal presentation of the model we use to gauge the technical, scale and structural effects defined above, we briefly highlight the implications of these concepts about the convergence process among countries. First, a decrease of technical inefficiency with time appears as a technological catching-up effect. Note, that we control for a potential countries' size bias by disentangling scale and technical effects. Second, the greater the structural inefficiency, the more heterogeneity we have in the input mixes between countries. Therefore, a decrease of structural inefficiency over time reveals a convergence towards a common expansion path linked to an input deepening effect.

2.2 Measuring technical, scale and structural inefficiencies

Formally, let $x \in R_+^N$ denote the vector of inputs and $y \in R_+^M$ the vector of outputs for a country. As we compare European nations and the US which have a rather similar degree of economic development, countries are assumed to face the same technology represented by its production set T:

$$T = \{(x, y) : x \text{ can produce } y\} \qquad (1)$$

The total group of countries (G) is composed of K countries $(k = 1, \ldots K)$. The aggregate technology at the group level inherits its properties from the country technology. Formally, we define the group technology T^G as the sum of the countries technologies:

$$T^G = \sum_{k=1}^{K} T \qquad (2)$$

It is possible to prove that the aggregate CRS technology is equal to the individual CRS technology (Li, 1995):

$$T_{CRS}^G = \sum_{k=1}^{K} T_{CRS} = T_{CRS} \qquad (3)$$

Li (1995) also showed that, if convexity holds then the VRS aggregate technology is equal to K times the individual technology:

$$T_{VRS}^G = \sum_{k=1}^{K} T_{VRS} = K \times T_{VRS} \qquad (4)$$

We now turn to the definition of the directional distance function which measures distances between observed production plans and the boundary of the technology. These distances are interpreted as gaps between observed TFP levels and their maximal feasible or desired levels of TFP. The function $D_T : (R_+^M \times R_+^N) \times (-R_+^M) \times R_+^N \longrightarrow R_+$ defined by:

$$\vec{D}_T(x, y; g_x; g_y) = \sup_{\lambda} \{ \lambda \in \Re_+ : (x - \lambda \cdot g_x, y + \lambda \cdot g_y) \in T \}, \qquad (5)$$

is called the directional distance function where $(g_x; g_y)$ is a nonzero vector that determines the direction in which $\vec{D}_T(\cdot)$ is defined. An analysis of the properties of directional distance functions can be found in Chambers et al. (1996). Note that $(x, y) \in T \Longleftrightarrow \vec{D}_T(x, y; g_x; g_y) \geq 0$. Thus, it is possible to characterize the production set from the directional distance function.

For estimation purposes, we follow the literature on non-parametric frontier estimation by specifying an operational definition of T based on a set of observed countries and a set of axioms which add some structure to the definition of T in (1). As motivated above, we consider here a convex production set satisfying free disposability of inputs and outputs. We allow various returns to scale assumption in order to decompose the TFP gap between technical and scale components. Under constant returns to scale, T_{CRS} is defined as:

$$T_{CRS} = \Big\{ (x, y) : x \in R_+^N, y \in R_+^M, \sum_{k=1}^{K} y_m^k z_k \geq y^m, m = 1, \ldots, M, \sum_{k=1}^{K} x_n^k z_k \leq x^n, n = 1, \ldots, N, z_k \geq 0, k = 1, \ldots, K \Big\} \qquad (6)$$

Under variable returns to scale, T_{VRS} is defined as:

$$T_{VRS} = \left\{ (x,y) : x \in R_+^N, y \in R_+^M, \sum_{k=1}^{K} y_m^k z_k \geq y^m, m = 1,\ldots,M, \right.$$
$$\left. \sum_{k=1}^{K} x_n^k z_k \leq x^n, n = 1,\ldots,N, \sum_{k=1}^{K} z_k = 1, z_k \geq 0, k = 1,\ldots,K \right\} \quad (7)$$

Concerning the directional distance function, we use the group output vector to construct the direction of translation; i.e. $(g_x, g_y) = \left(0, \sum_{k \in G} y^k \right)$. Therefore, technical and scale inefficiencies are computed as percentages of the aggregated GDP of the total group of countries (Dervaux et al., 2004).

For a specific country $(x^{k'}, y^{k'})$, the productivity gap is defined on a CRS technology by $\vec{D}_{T_{CRS}}(x^{k'}, y^{k'}; 0, \sum_{k \in G} y^k)$ and next can be decomposed between a technical component and a scale component. Technical efficiency is defined relatively to a VRS technology by $\vec{D}_{T_{VRS}}(x^{k'}, y^{k'}; 0, \sum_{k \in G} y^k)$. The scale component is computed as a residual between the two latter's measures. These two distance functions are computed by the following linear programs (LPs):

Directional distance function under CRS

$$\vec{D}_{T_{CRS}}(x^{k'}, y^{k'}; 0; \sum_{k=1}^{K} y^k) = \max_{z,\lambda} \ \lambda$$
$$s.t. \ \sum_{k=1}^{K} z_k y_m^k \geq y_m^{k'} + \lambda \sum_{k=1}^{K} y_m^k \quad \forall m = 1,\cdots,M \qquad \text{(LP1)}$$
$$\sum_{k=1}^{K} z_k x_n^k \leq x_n^{k'} \quad \forall n = 1,\cdots,N$$
$$z_k \geq 0 \quad \forall k = 1,\ldots,K$$

Directional distance function under VRS

$$\vec{D}_{T_{VRS}}(x^{k'}, y^{k'}; 0; \sum_{k=1}^{K} y^k) = \max_{z,\lambda} \ \lambda$$
$$s.t. \ \sum_{k=1}^{K} z_k y_m^k \geq y_m^{k'} + \lambda \sum_{k=1}^{K} y_m^k \quad \forall m = 1,\cdots,M$$
$$\sum_{k=1}^{K} z_k x_n^k \leq x_n^{k'} \quad \forall n = 1,\cdots,N \qquad \text{(LP2)}$$
$$\sum_{k=1}^{K} z_k = 1$$
$$z_k \geq 0 \quad \forall k = 1,\ldots,K$$

The structural efficiency part of the productivity gap is defined at the group level and is based on the difference between the technical inefficiency evaluated at the aggregated level and the sum of individual technical efficiencies defined by $\vec{D}_{T_{VRS}^G}(\sum_{k \in G} x^k, \sum_{k \in G} y^k; 0, \sum_{k \in G} y^k) - \sum_{k' \in G} \vec{D}_{T_{VRS}}(x^{k'}, y^{k'}; 0; \sum_{k=1}^{K} y^k)$ where the former component is computed by the following LP.

Next we determine the directional distance function under the VRS aggregate technology:

$$\vec{D}_{T_{VRS}^{G}}\Big(\sum_{k\in G} x^k, \sum_{k\in G} y^k \;;0; \sum_{k\in G} y^k\Big) = \max_{z,\lambda} \lambda$$

$$s.t.\ K\sum_{k=1}^{K} z_k y_m^k \geq (1+\lambda)\sum_{k\in G} y_m^k \quad \forall m = 1,\cdots,M$$

$$K\sum_{k=1}^{K} z_k x_n^k \leq \sum_{k\in G} x_n^k \;\; \forall n = 1,\cdots,N \qquad \text{(LP3)}$$

$$\sum_{k=1}^{K} z_k = 1$$

$$z_k \geq 0 \;\; \forall k = 1,\ldots,K$$

While technical and scale efficiencies are country-specific, structural efficiency is computed for the whole group. We can allocate structural inefficiency across countries by using the shadow prices derived in LP3. Indeed, it can be shown that structural inefficiency can be decomposed in individual effects as the countries' price inefficiency computed with the shadow prices derived from the aggregate technology (Briec and al., 2003).

3 Efficiency Convergence between the US and European countries

In this section, we investigate the process of efficiency convergence across leading countries at the macroeconomic level thanks to the following procedure. In a first step, directional distance functions $\vec{D}_{T_{CRS}}, \vec{D}_{T_{VRS}}, \vec{D}_{T_{VRS}^{G}}$ are used to measure rates of change of the three components of efficiency (technical, scale and structural). Hence, for each year and each country of the sample, efficiency gaps are then defined as the distances between each nation and the west-wide frontier. In a second step, following Nahar and Inder (2002), we develop a time series test estimating catching-up effects based on a statistical procedure which is consistent with the definition of convergence. This test considers convergence as movements towards a group of leaders located on a production frontier. Our procedure is well adapted to check for technical and structural adoption of an individual economy or a sub-set of nations within a group of countries. Thereof we are able to differentiate the European zone from the US in the convergence process analysis.

3.1 A Time Series Test Procedure for Efficiency Catching-up Effects

The catching-up hypothesis between a country k and its benchmark involves that the long-run average of the efficiency gap or distance $\vec{D}_T^t(x_t^k, y_t^k)$ converges to zero with time:

$$\lim_{l\to\infty} E_t(\vec{D}_T^{t+l}(x_{t+l}^k, y_{t+l}^k)) = 0 \qquad (8)$$

If $\vec{D}_T^{t+l}(x_{t+l}^k, y_{t+l}^k)$ approaches zero its rate of change with respect to time *t* is negative

$$\frac{\partial(\vec{D}_T^t(x_t^k, y_t^k))}{\partial t} < 0 \qquad (9)$$

Therefore, the signs of slopes (9) allow us to evaluate the catching-up process of a particular economy *k*. Although the $\vec{D}_T^{t+l}(x_{t+l}^k, y_{t+l}^k)$ series may not decrease uniformly with time, the average of these slopes should be negative if the country tends to catch up its productive frontier:

$$\frac{1}{T}\sum_{t=1}^{T}\frac{\partial(\vec{D}_T^t(x_t^k, y_t^k))}{\partial t} < 0 \qquad (10)$$

One can estimate (10) with a function of time trend t as:

$$\vec{D}_T^t(x_t^k, y_t^k) = f(t) + \mu_t^k = \sum_{p=0}^{P} a_p.t^p + \mu_t^k \qquad (11)$$

where the a_p's are parameters and μ_t^k is an error term with zero mean.
From equation (11), the average slope function is:

$$\frac{1}{T}\sum_{t=1}^{T}\frac{\partial(\vec{D}_T^t(x_t^k, y_t^k))}{\partial t} = \sum_{p=1}^{P} a_p.\omega_p = \omega' a$$

where

$$\omega_p = \frac{p}{T}\sum_{t=1}^{T} t^{p-1}$$

$\omega' = [0, 1, \omega_2 \ldots \omega_{P-1}, \omega_P]$ and

$a' = [a_0, a_1 \ldots a_{P-1}, a_P]$

The catching-up process can be tested under the two alternative following hypotheses:

$$H_0 : \omega' a \geq 0$$

$$H_1 : \omega' a < 0$$

Equation (11) is estimated by ordinary least squares to complete a *t*-test of this restriction on the a vector.

3.2 Data

Data come from the GGDC Total Economy Growth Accounting Database (Timmer, Ypma and van Ark, 2003). We use series for the US and the following 15 European countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Italy, Ireland, Luxembourg, the Netherlands, Portugal, Spain, Sweden, the United Kingdom (UK) over the period 1980-2004. To specify the west-wide technology we retain one output and three inputs: added value expressed in international prices (base year 2000), total worked hours as labor, information and communication equipments (ICT) and other equipments (non ICT), expressed in international prices (base year 2000). Over the whole period, one can note that the European average annual growth rates for GDP as well for worked hours are lower than the American ones. Except for Luxembourg, which is a very specific economy, only Ireland does better than the US with a GDP growth rate of 5.9%. The large European countries as UK, Germany and France are clearly in lower part of the US. On the other hand, both for ICT and non ICT equipments, rates of growth are similar between the two zones although there is a rather great heterogeneity within Europe. For ICT equipment, the US, Ireland and Finland experience the strongest rates of growth. For the other types of capital, the fastest evolutions are for Spain, Ireland, Portugal and France.

- Table 1 about here –

As a first exploratory analysis, the evolutions of partial labor productivity at an aggregated level for Europe and the US are plotted in Figure 5. This ratio was initially higher for the US but the differential rate of growth favors of Europe (respectively 1.7% and 2.1%) aims at similar levels until the middle of nineties. Then US labor productivity has again risen above Europe's leading to a divergence effect which has become more significant since 2000.

Concerning capital deepening effects, ratios of nonICT and ICT over labor are presented in Figures 6 and 7. For nonICT ratio, Europe has a significant higher growth rate than the US over the whole period and a convergence process clearly appears until the beginning of the nineties. However, this was followed by an increasing divergence effect along the nineties during which Europe has become more capital intensive than the US. A different picture arises for ICT ratio. A slow but regular convergence is observed over the past twenty five years. However, the US have still an upper ratio of IT/Labor.

- Figure 5, 6 and 7 about here -

Beyond these preliminary observations, more formal analyses, presented above in the methodological section, are required to encompass all individual countries and take simultaneously into account all inputs in productivity and capital deepening global measures.

3.3 Results and discussion

Annual production frontiers are calculated by linear programs LP1, LP2 and LP3 associated to their respective directional distance functions permitting the evaluation of technical, scale and structural efficiency scores for each individual country or group of countries. For each year of the period the US, UK, France and Luxembourg are located on the production frontier. This result points out that while there may be statistical evidence that the US are still a technological leader at the aggregate level (Taskin and Zaim, 1997), several countries are also high productive performances and constitute referents for the west-wide benchmark.

Before embarking in the results interpretation we recall that the directional distance function is based on the group output vector. Therefore, technical and scale inefficiencies are computed as percentages of the aggregated GDP of the total group of countries. Hence an inefficiency score of 1% means that the country could improve its output by 1% of the output sum of all countries which represents for example 10% to 20% of its own output. We chose this directional distance function instead of a usual radial one to enable aggregation of country scores and thus to perform a meaningful catching-up analysis. of total factor productivity.

On average, technical inefficiency is about 2.9% for the total aggregation of countries meaning that if all nations adopted the best productive practices and aligned onto the VRS benchmark, TFP of the aggregated zone could improve from nearly 3%. A great part of this technical inefficiency comes from Germany which, although being the greatest European economy, underwent the shock of the ex GDR integration during the beginning of the nineties.

Scale inefficiency exceeds 9% and is equally shared between Europe and the US. The high level of this component illustrates clearly the difficulty for countries to improve their TFP level by converging to a mpss evaluated under a hypothetical constant returns to scale production frontier. Macroeconomic data regroup countries so different in size as the US and Luxembourg or Ireland that TFP comparisons should obviously take into account this scale bias. Indeed individual countries will never reach such a supposed mediate mpss by drastically increasing or reducing their own economic size.

Structural inefficiency is nearly 4.6%, meaning that if all countries adopted a common input-mix, the TFP level of the aggregated group would improve of the same amount. Structural inefficiency predominates technical effect showing that the capital deepening effect is still playing a major role in the convergence debate. This conclusion can be related to the IT/Labor ratio for which most of developed countries have not even now caught up the US accumulation level. This inefficiency component is distributed between Europe and the US for respectively 70% and 30%.

The aggregated inefficiency scores are plotted in Figure 8. While scale inefficiency increases with time, there is evidence in favor of a convergence process for both technical and structural efficiencies. In fact, as we said before, studies about TFP catching-up among countries should eliminate the bias due to the scale effect. The structural component seems to converge faster than the technical one. Actually, these results are strongly influenced by the specific behavior of the US which differs from that of the European zone. Located on the VRS benchmark throughout the period, this country does not take part within the movement of technological catching-up. On the other hand, decreasing its structural inefficiency quickly, it explains a great part of structural convergence. As for Europe, two convergence processes can be observed over the whole period. From the beginning of the eighties to the end of the nineties, the European zone has steadily improved its level of efficiency and has caught up the US. However, since the year 2000, its technical inefficiency has been increasing and diverging from the American one. The European structural convergence has been effective until the beginning of the nineties, then it roughly stopped between 1994 and 1996, starting again for the nine last years.

The simple observation of these irregular and specific evolutions does not enable to clearly conclude on the convergence hypothesis for technical as well for structural inefficiencies. Therefore, the time series test exposed in 3.1 must be performed on these two effects.

The significant negative estimates of average slopes (Table 3) reinforce and precise our first conclusions based on the previous chart analysis. First at the aggregated level, the estimator of average slopes for structural inefficiency is twice higher than one for the technical component estimated under a VRS technology. According to Figure 8 it clearly indicates a faster catching-up process for that structural component. This differential of variation rates can be explained as following: the US who are on their technical frontier throughout the period do not take any part in technological adoption among countries whereas being given its great economic influence it strongly weighs within the structural efficiency convergence. Second, the non significant slopes for the technical inefficiency measured under a CRS technology hide the technological catching-up effect across European countries and the US. This result illustrates plainly the scale bias introduced into technological diffusion evaluation established on traditional comparisons of TFP levels. Third, one can note that the absolute value of the average slope for the American structural component is three time greater than the European one; although the latter is also significantly negative in spite of a clear rupture of tendency in 1996. Fourth, technical efficiency divergence between Europe and the US, noted at the beginning of the years 2000, do not erase the catching-up effect which took place during the previous twenty years. Therefore, over the whole time period of our sample, the technical efficiency average slope remained significantly negative. This European evolution is primarily due to the German productivity convergence, while the UK and France are located on the border not taking part in this catching-up process.

- Table 2 about here -

- Figure 8 about here -

- Table 3 about here -

- Figure 9 and 10 about here -

These results mean that the finding by Bernard and Durlauf (1995) generally rejected the convergence hypothesis of OECD countries using standard time series techniques on productivity indexes does not hold anymore when using technical gaps calculated by a nonparametric VRS distance function method and when the US are not a priori considered as the solely technology leader. Our conclusions are rather close to those found by Evans and Karras (1996) and Nahar and Inder (2002), who criticized the above time series approach, in favor of strong convergence for the developed countries. Moreover, we find a significant effect of input-mix convergence across economies to a common west-wide price structure. Therefore, as regards to the catching-up process at the macroeconomic level, there is evidence of simultaneous transmission of technological knowledge and input-mixes among Europe and the US.

4. Conclusion

We re-examined the convergence hypothesis at the macroeconomic level across the most developed European countries and the US using directional distance functions. In comparison with other studies, the substantial differences of our analysis are that we use a productivity change component which impose no a priori constants returns to scale assumption, nor any functional form on technology, and any restrictive assumptions on input price to evaluate both technological gaps and input-mix differences between nations or subset of countries and the west-wide production frontier.

Our results definitely demonstrate that analyses of technological adoption derived from statistical tests on TFP levels are biased since they rely on an implicit constant returns to scale assumption. This assumption appears too restrictive if productivity comparisons are established among countries with dissimilar sizes. Moreover, while the US are on the production frontier during the whole period, they are not the only benchmark for other countries. Under variable returns to scale, some small nations such as Luxembourg or Ireland and some medium size economies as France and UK also serve as benchmarks for countries.

We also find that structural inefficiency predominates technical effect. Therefore, we can conclude that regarding the convergence issue, the capital deepening effect still plays a major role especially when IT equipments is split from the traditional capital assets.

Thanks to a time series procedure studying convergence processes among nations, we can highlight statistical evidence of technological diffusion as well as structural convergence between European countries and the US. Furthermore, statistically significant structural catching-up effects for both Europe and the US are established but geographic differences in the rate of diffusion of technology are also found.

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Figure 1. TFP measure and its decomposition into technical and scale effects

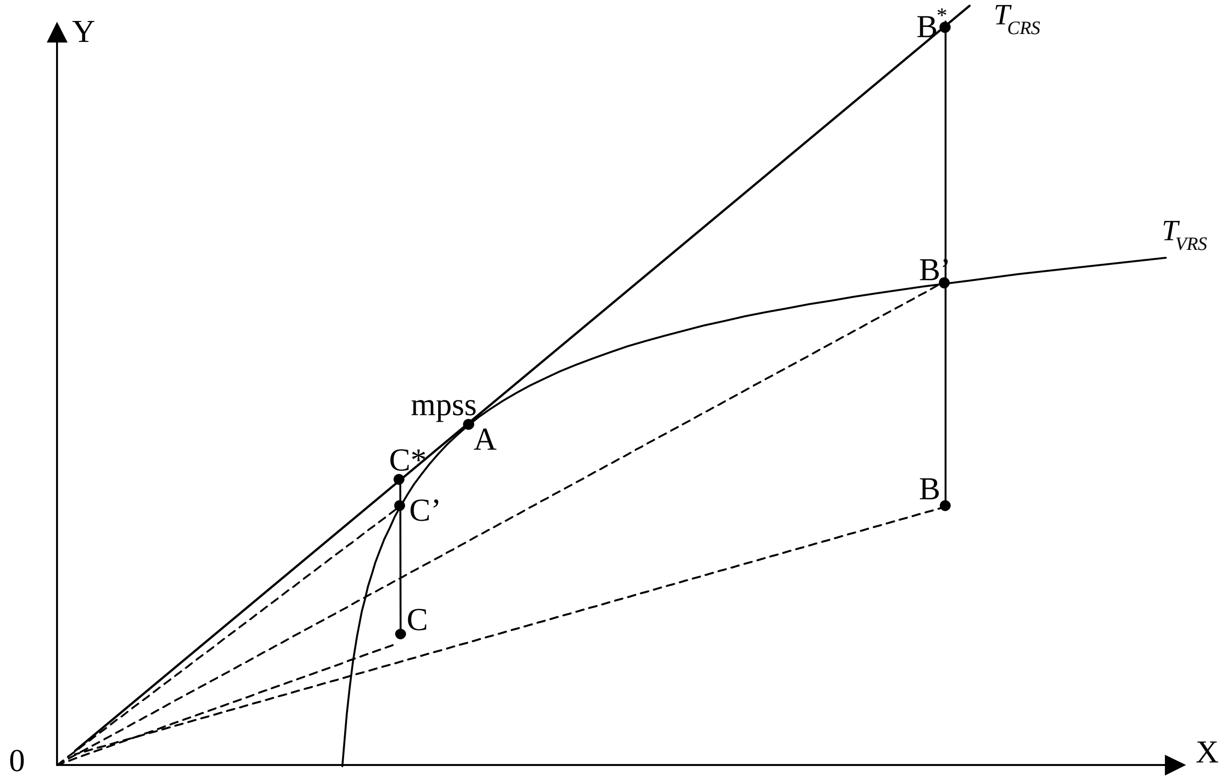

Figure 2. Technical progress and technological catching-up

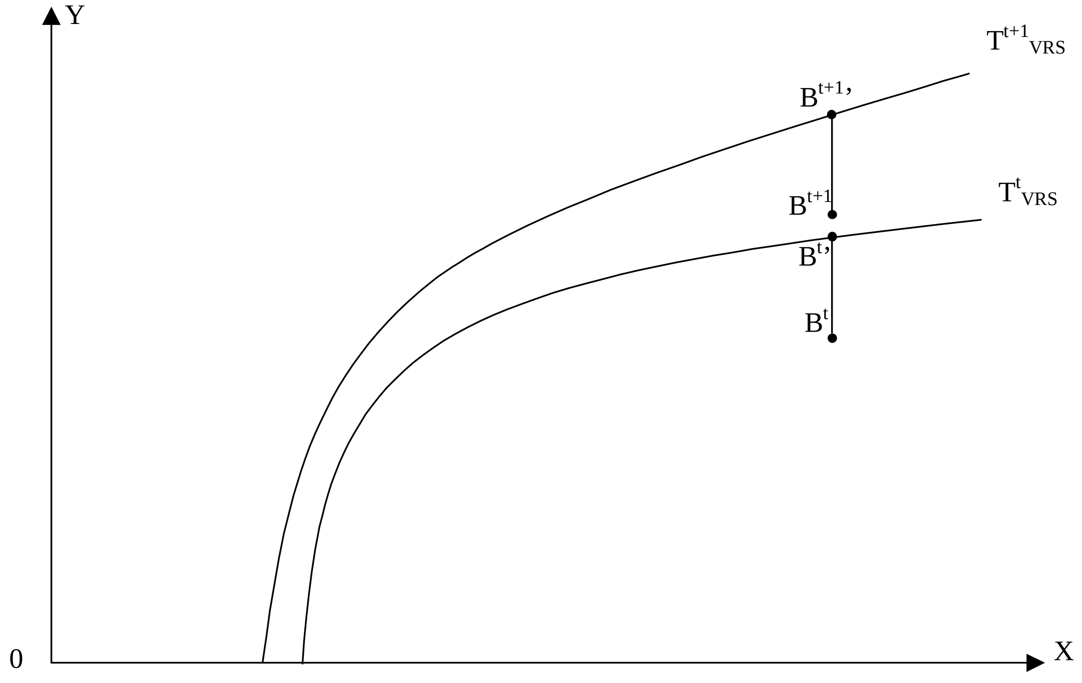

Figure 3. Illustration of structural efficiency

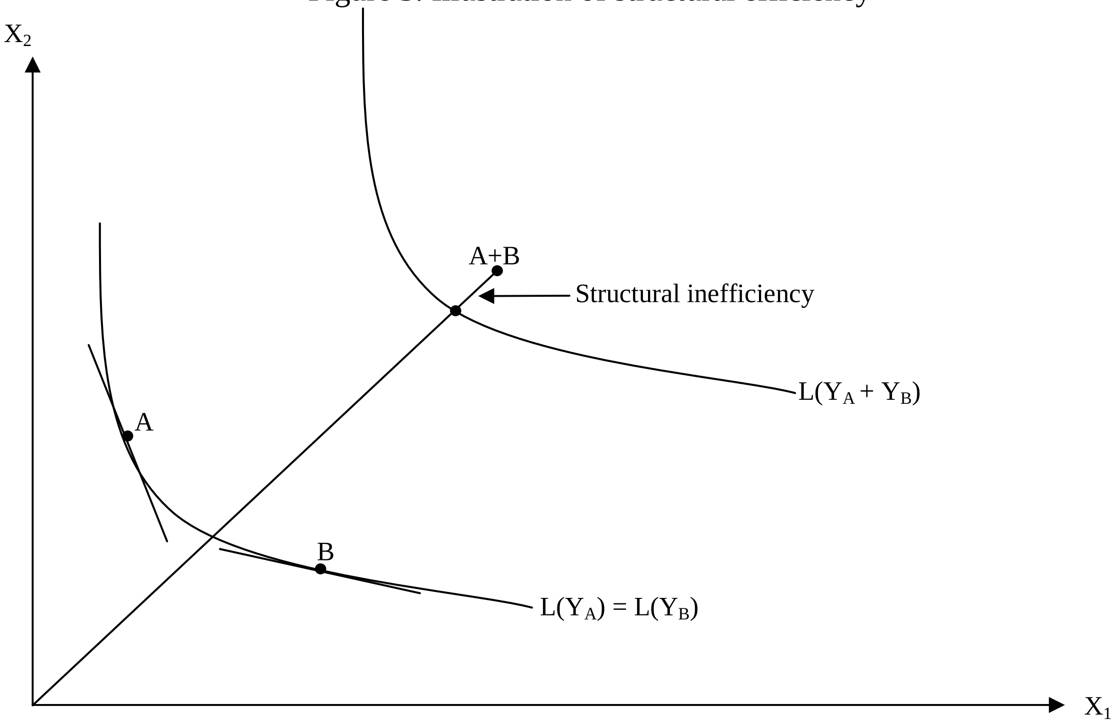

Figure 4. The measurement of structural efficiency

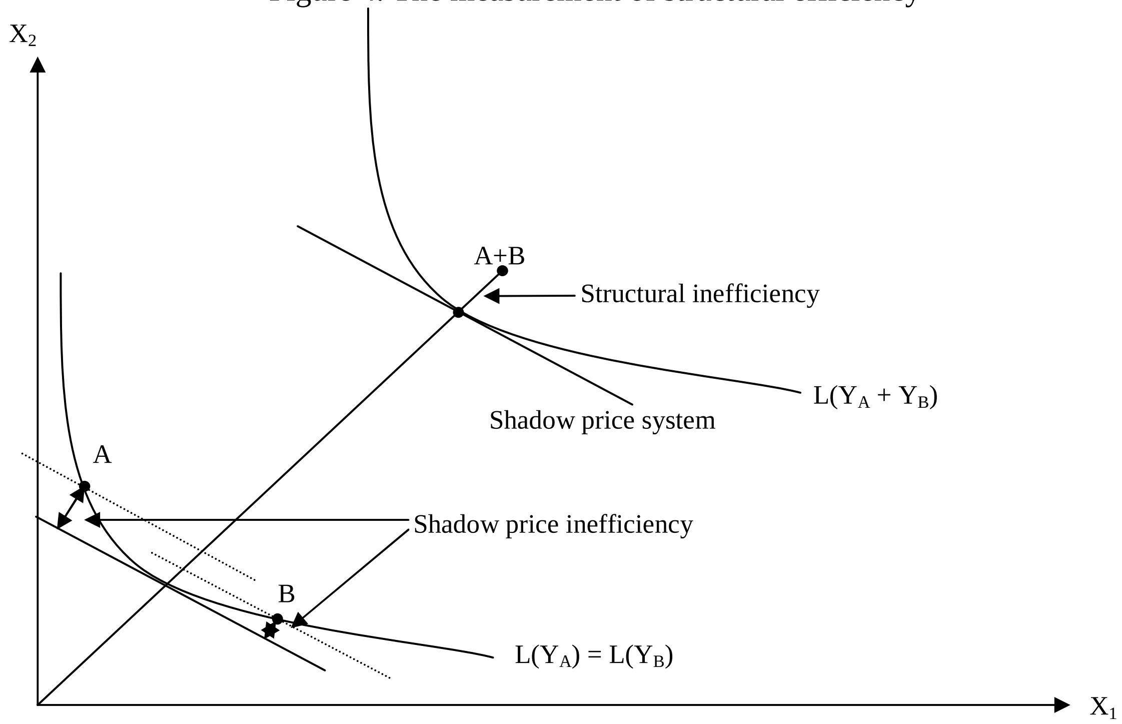

Figure 5. Log of Labor Productivity for Europe and the US

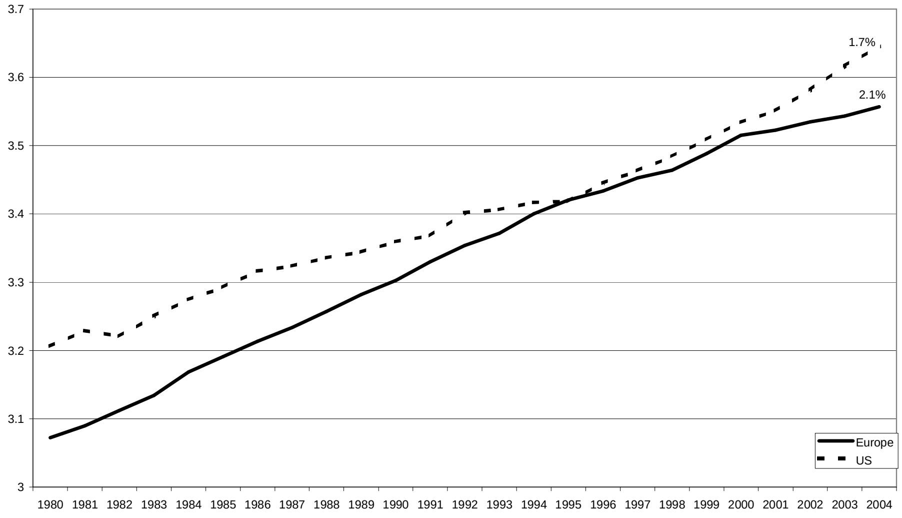

Figure 6. Log of nonICT/Labor for Europe and the US

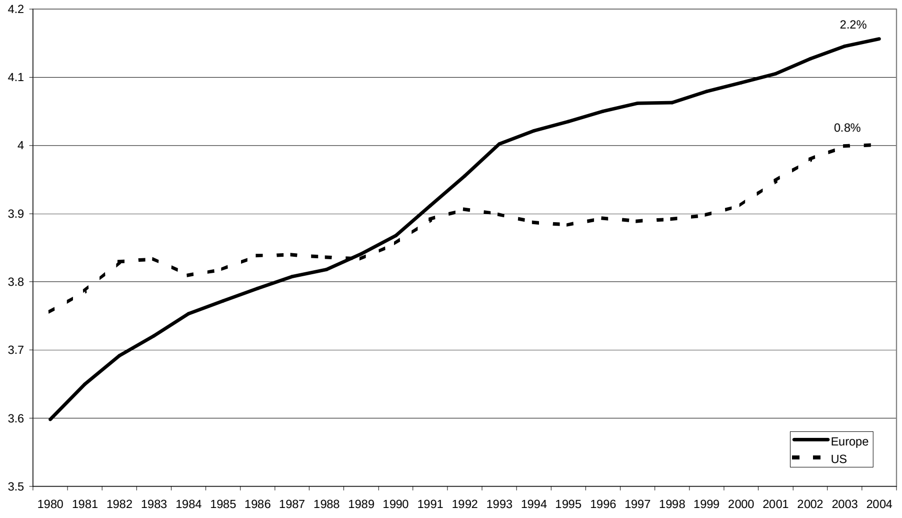

Figure 7. Log of ICT/Labor for Europe and the US

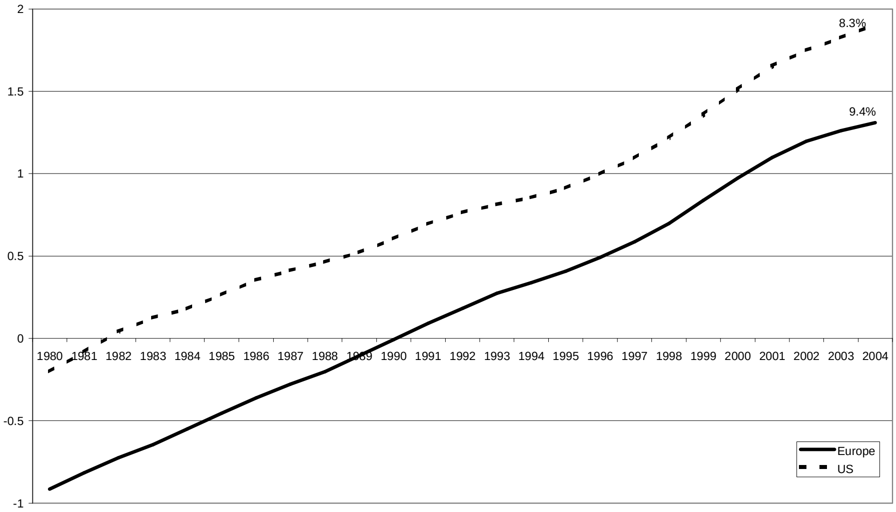

Figure 8. Comparing different inefficiency score variations
(total country aggregation)

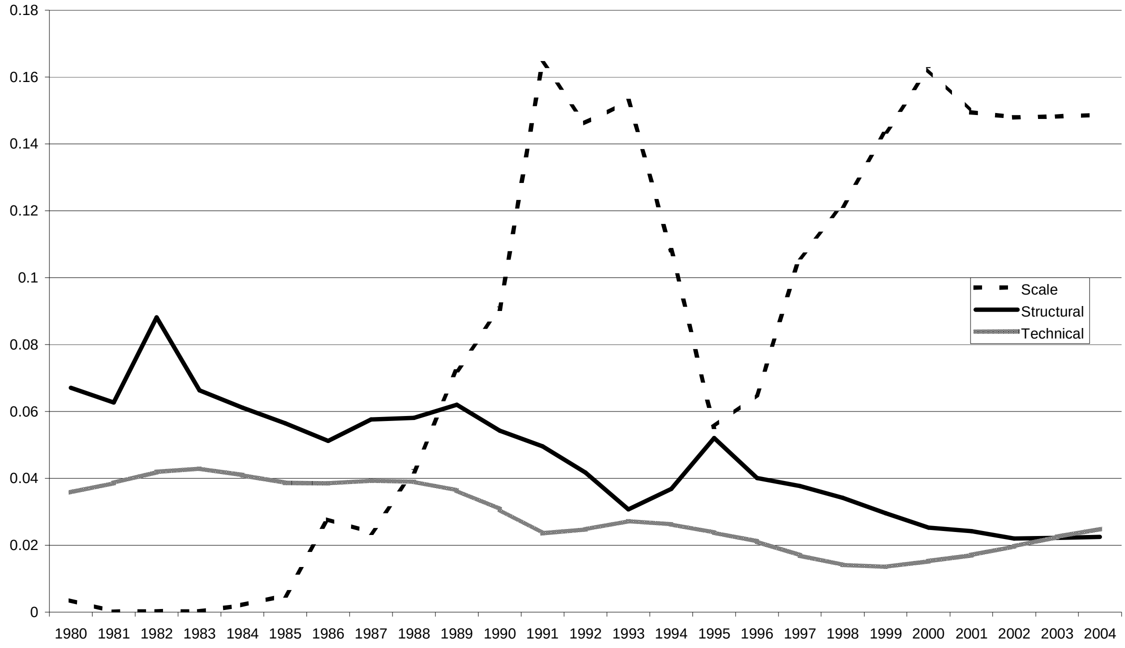

Figure 9. Comparing Structural Efficiency for Europe with the US

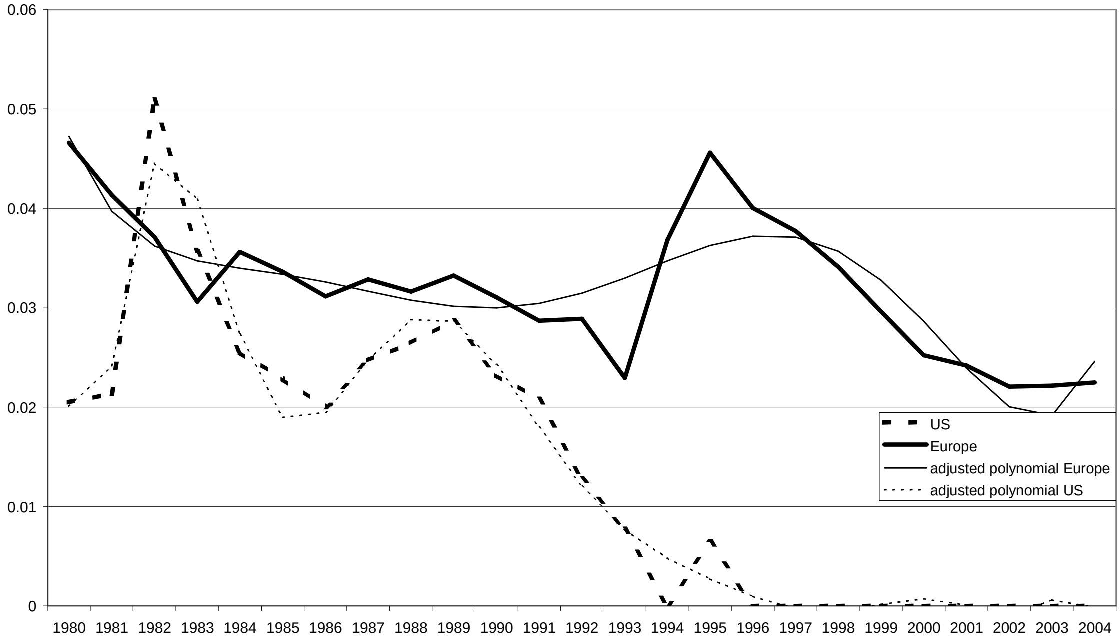

Figure 10. Technical Efficiency for Europe

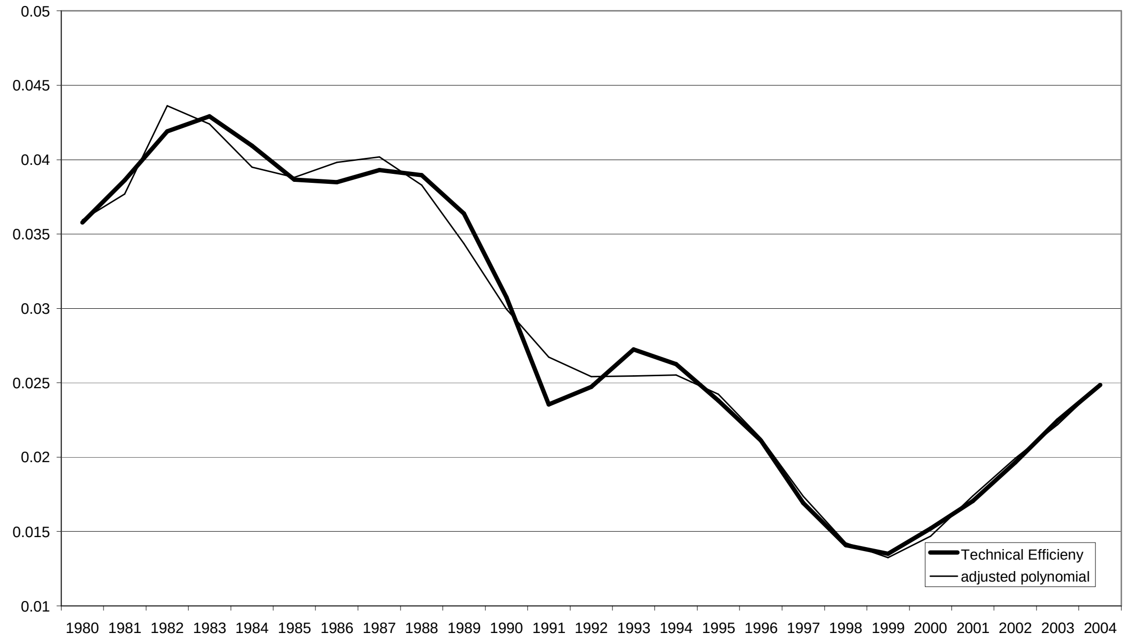

Table 1. Average Annual Growth Rates (1980-2004)

Country	GDP	Worked Hours	Total Capital	ICT equipment	non ICT equipment
Austria	2.36%	0.20%	2.90%	8.01%	2.74%
Belgium	2.18%	0.05%	1.66%	12.63%	1.39%
Denmark	2.07%	-0.03%	2.75%	12.24%	2.52%
Finland	2.08%	-0.58%	1.77%	13.29%	1.48%
France	2.07%	-0.05%	3.21%	10.45%	3.08%
Germany	2.10%	-0.60%	1.85%	7.20%	1.70%
Greece	1.94%	0.68%	2.60%	9.63%	2.44%
Ireland	5.92%	1.43%	3.80%	13.94%	3.63%
Italy	1.86%	0.19%	2.63%	9.98%	2.40%
Luxembourg	5.32%	2.54%	4.92%	10.37%	4.77%
Netherlands	2.67%	1.23%	1.95%	11.10%	1.79%
Portugal	2.94%	0.49%	3.64%	10.59%	3.44%
Spain	3.03%	1.36%	4.56%	11.48%	4.42%
Sweden	2.17%	0.20%	2.24%	10.28%	1.96%
UK	2.69%	0.37%	2.91%	13.61%	2.59%
US	3.29%	1.56%	2.74%	10.34%	2.36%
Europe	2.32%	0.19%	2.69%	10.01%	2.50%

Table 2. Inefficiency scores (Average 1980-2004)

Country	Technical	Scale	Structural
Austria	0.11%	0.13%	0.03%
Belgium	0.09%	0.10%	0.13%
Denmark	0.07%	0.05%	0.04%
Finland	0.19%	0.04%	0.06%
France	0.00%	0.13%	0.19%
Germany	1.25%	1.87%	0.63%
Greece	0.31%	0.14%	0.20%
Ireland	0.00%	0.00%	0.07%
Italy	0.04%	0.61%	0.00%
Luxembourg	0.00%	0.00%	0.02%
Netherlands	0.04%	0.05%	0.23%
Portugal	0.02%	0.03%	0.42%
Spain	0.46%	0.56%	0.49%
Sweden	0.27%	0.09%	0.01%
UK	0.00%	0.44%	0.70%
US	0.00%	4.90%	1.39%
Europe	2.85%	4.26%	3.22%
Total	2.85%	9.16%	4.61%

Table 3. Estimates of average slopes and t-ratios for testing efficiency convergence

VRS Technical Efficiency	Polynomial order	Average Slope	Test statistic	Structural Efficiency	Polynomial order	Average Slope	Test statistic
US				US	11	-29.3E-04	-3.12
Europe	11	-9.9E-04	-2.38	Europe	6	-9.0E-04	-2.93
Total	11	-9.9E-04	-2.38	Total	10	-23.0E-04	-2.72

Scale Efficiency	Polynomial order	Average Slope	Test statistic	CRS Technical Efficiency	Polynomial order	Average Slope	Test statistic
US	12	-8.83E-04	-0.50	US	12	-8.83.0E-04	-0.50
Europe	12	8.86E-04	0.81	Europe	12	-1.02E-04	-0.09
Total	12	0.04E-04	0.14	Total	12	-9.85E-04	-0.44