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April 2007

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Total Factor Productivity Growth in the G7 Countries: Different or Alike?*

João Amador[†] Carlos Coimbra[‡]

April 2007

Abstract

The paper compares the contribution of total factor productivity (TFP) to economic growth in the G7 countries, from 1960 until 2005. A dynamic world translog stochastic production frontier is computed through Bayesian statistical methods using panel data on 21 OECD economies. The real GDP growth rate is decomposed in TFP and input accumulation contributions', the former being divided in two components: efficiency developments (the distance to the world production function) and technological progress (the expansion of the world production function). The paper adopts the methodology suggested by Koop, Osiewalsky and Steel (1999), though it covers a much larger period, allowing for the identification of intertemporal growth patters. The growth accounting exercise requires a Gibbs Sampling iteration algorithm and it is carried out for eight periods, each one covering ten yearly growth rates, with overlapping sub periods of five years. The results obtained show that the contribution of technological progress to total TFP is typically stronger than efficiency improvements. The US and Canada recorded a TFP acceleration after the mid 1980s, following declines in the previous decades. In addition, the inputs accumulation gave a relatively stable contribution for GDP growth throughout the sample period. Italy and France present a continuous declining trend in TFP contribution, though more marked in the latter case. Germany and the UK seem to have moved to a new lower floor of TFP contribution in the last decades. Japan, presents a downward trend in TFP contribution that is even more pronounced than in Italy. However, some reversal was seen in the Japanese TFP in the last decade considered. The shape of the stochastic production function changed along the period considered, benefiting more capital intensive input-combinations. In addition, there is some evidence of increasing returns to scale in the G7 countries, though it may be related with the non consideration of quality aspects in the measurement of inputs.

Keywords: Growth Accounting, Productivity, G7 Countries, Stochastic Frontiers, Bayesian Methods.
JEL Classification: C11, O47, O5.

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1 Introduction

The analysis of the composition of economic growth in the G7 countries has been motivated by the possible identification of regularities that contribute to explain economic success. Such analysis must be carried out in a long term perspective and the relevant production function must describe the existing world technology and not just domestic conditions. Moreover, in order to assess the relative performance of each country, economic growth should be disentangled in a way that total factor productivity (TFP) is not determined as a mere residual.

The seminal papers in modern economic growth literature are those of Solow (1956), Romer (1986, 1990) and Lucas (1988). The empirical research literature in this area followed two different strands. One strand reports to Solow (1957), which decomposes economic growth in a given economy on factor accumulation and total factor productivity. The other strand of literature bases on cross-country regressions, with a multitude of explanatory variables. Important contributions in this area are those of Baumol (1986), Barro (1991) and Sala-Martin (1997).

In the last years the continuing progress on computation methods generalized the utilization of Bayesian statistical methods in economic research. In the empirical growth literature this has allowed for the computation of dynamic stochastic production frontiers. Nevertheless, apart from the initial contributions of Koop, Osiewalski and Steel (1999, 2000), the utilization of Bayesian inference techniques to growth accounting is still very limited. Throughout this paper we heavily rely on these contributions.

In this paper we use Bayesian stochastic production frontiers to describe the main characteristics of the G7 countries from the 1960's until 2005. The growth accounting exercise was carried out taking eight separate periods of 11 years each and assuming a dynamic translog stochastic production frontier. The computation of the stochastic production frontier bases on information for 21 OECD economies and the results are presented in terms of annual averages for each period considered. The growth accounting exercise carried out here provides results for the contribution of inputs to GDP growth, for the capital and labour elasticities and for total factor productivity contribution, which is disentangled into technological progress and degree of efficiency. Intuitively, these components represent two different aspects to be considered in TFP developments. Technological progress corresponds to more *efficient* production techniques. Improvements in efficiency correspond to better institutional and organizational arrangements, i.e. the more *efficient* use of the current level of inputs and technology. However, in practice, it is often difficult to establish a clear distinction between the two concepts as technological progress and efficiency interact. Thus, although the statistical method used provides contributions for both components, the degree of precision is smaller than the one associated with the computation of total TFP .

In addition, it should be noted that, although using less conventional methods, this paper is still a growth accounting exercise, thus it is not able to reveal economic causation channels between the variables under observation or to identify any underlying fundamental causes for the economic growth.

The paper is organized as follows. In the next section we discuss some methodological issues and present the details of the model that is used for sampling. In addition, we describe the database that is used and point some information shortcomings. In the third section we present the results obtained for the growth accounting exercises and compare the growth experiences of the G7 countries. Especial emphasis is put on the TFP performance of the G7 countries and on its two components. In addition, we argue that there is some evidence of changes in the shape of the world production frontier, probably associated with the development of the information and communications technology sectors (ICT). Finally, section four presents some concluding remarks.

2 The Stochastic Frontier Approach

Prior to the presentation of the details of the model used for sampling it is important to discuss some methodological issues. Firstly, contrary to what is done in most the traditional empirical growth accounting exercises, the GDP growth decomposition should be jointly and simultaneously computed for several economies. The underlying assumption is that there is an international production frontier, which can be statistically identified because there are countries lying in its different segments. On conceptual grounds it means that all countries have equal access to the same technology, implying that if two countries have equal labour and capital endowments the one with higher GDP is more efficient, i.e. stands closer to the stochastic production frontier.

The speed of international dissemination of technological progress and its implications in terms of growth theory are discussed by Basu and Weil (1998). These authors argue that the dissemination of technological progress in the actual production system occurs at a slower pace than the diffusion of knowledge. In the OECD countries, knowledge diffusion should occur at a very fast pace, meaning the existence of a common set of potentially available production technologies for all member countries. Therefore, the time that elapses until a country effectively adopts the technological innovations in the production systems becomes reflected in its relative production efficiency. In addition, if there is a gradual technological progress potentially available for all, the international production frontier expands in time in some way. We simply assume that the technological progress evolves according to a linear trend during each period considered.[1] This implicitly assumes that there is an average speed in adopting new technologies and each country specific lag or lead is captured by the efficiency component.

The analysis focuses on eight 11 year periods (10 annual growth rates), for which stochastic production frontiers are computed. It is important to notice that the non-synchronization of economic cycles can affect the results obtained in the sampling. In this case different growth performances and the form of the computed stochastic production frontiers may reflect cyclical developments and not the effect of structural factors. However, the length of the periods considered in the analysis is enough to encompass the average duration of the economic cycles, thus averaging out cyclical effects on the macroeconomic variables considered. All results of the growth accounting exercise are presented in terms of 10 year average growth rates or contributions.[2] The partition of the sample in sub-periods is also necessary because of the assumption on the dynamics of technological progress. In fact, it does not seem reasonable to assume that technology evolves linearly throughout several decades.

Regarding the specification of the production function, a translog formulation is used. This formulation comprehends as a special case the log transformation of the Cobb-Douglas production function, though it is much more flexible than the latter. In fact, a major limitation of the Cobb-Douglas production function is the absence of cross effects between labour and capital. Temple (2006) argues that the assumption of a Cobb-Douglas specification may lead to spurious results in economical and statistical terms. The problem is magnified because traditional growth accounting exercises treat TFP as unobservable (omitted variable), limiting specification testing. In fact, if the researcher had identified a good proxy for TFP and the data were actually generated by a translog, a suitably specified regression would accurately recover the parameters of that translog production function, and reject the Cobb-Douglas specification.

Classical econometrics allows for the estimation of stochastic production functions, namely through maximum likelihood methods.[3] However, the Bayesian methods employed here are suitable when samples are small, as it is the case, allowing inferences without relying on asymptotic approximations. Bayesian methods allow to rationally

[1] Koop, Osiewalski and Steel (1999) tested other formulations for the dynamics of the production function, namely a time specific model, where frontiers are totally independent in time, a quadratic trend model and a linear trend model imposing constant returns to scale. They concluded that the linear trend model is the best performer in terms of in-sample fit, ability to distinguish the components of TFP and number os parameters to compute.

[2] The decades defined are 1960-70, 1965-75, 1970-80, 1975-85, 1980-90, 1985-95, 1990-2000 and 1995-2005.

[3] For references on non-bayesian estimation methods of stochastic production functions see for example Aigner, Lovell and Schmidt (1977), Meeusen and der Broeck (1977) and Kumbhakar and Lovell (2004).

combine observed data with economically meaningful priors. In practical terms, for each variable, observed data and initial assumptions (priors) generate a posterior distribution function. The posterior distribution functions of all parameters in the model are derived simultaneously, leading to the posterior distribution function of GDP growth components.

The prior for the posterior distribution function of the efficiency parameter is an asymmetric positive distribution. The rational behind this assumption is twofold. Firstly, this parameter measures the distance to the production frontier so it should be positive. Secondly, there is a smaller probability of finding observations as we move further inner the production frontier. This assumption is common in stochastic frontier functions' literature, remaining the concrete nature of the asymmetric distribution an open question. We opted for the use of a normal-gamma model (normal distribution of the residual component and gamma distribution for the efficiency component). Its relative advantages to the usual alternatives, normal-half normal and normal-exponential models are discussed in Greene (2000) and Tsionas (2000).

2.1 The Model

The model considered for the growth accounting exercise follows Koop et al. (1999). The GDP is defines by:

$$Y_{ti} = f_t\left(K_{ti}, L_{ti}\right)\tau_{ti}w_{ti} \tag{1}$$

where Y_{ti}, K_{ti} and L_{ti} denote the real output, the capital stock and labour in period t $(t = 1, ..., T)$ in country i $(i = 1, ..., N)$, respectively. Furthermore, τ_{ti} $(0 < \tau_{ti} \leqslant 1)$ is the efficiency parameter and w_{ti} represents the measurement error in the identification of the frontier or the stochastic nature of the frontier itself. As mentioned above, the basic model assumes a flexible translog production function:

$$y_{ti} = x_{ti}^{'}\beta_t + v_{ti} - u_{ti} \tag{2}$$

where:

$$x_{ti}^{'} = \left(1, k_{ti}, l_{ti}, k_{ti}l_{ti}, k_{ti}^2, l_{ti}^2\right) \tag{3}$$

$$\beta_t = (\beta_{t1}, ..., \beta_{t6})' \tag{4}$$

and lower case letters indicate natural logs of upper case letters. The logarithm of the measurement error v_{ti} is *iid* $N(0, \sigma_t^2)$ and the logarithm of the efficiency parameter is one sided to ensure that $\tau_{ti} = \exp\left(-u_{ti}\right)$ lies between zero and one. The prior for u_{ti} is taken to be a gamma function with a time specific mean λ_t.

The contribution of input endowment, technology change and efficiency change to GDP growth is defined in a fairly simple way. The GDP growth rate in country i in period $t+1$ can be written as:

$$y_{t+1,i} - y_{t,i} = \left(x'_{t+1,i}\beta_{t+1} - x'_{t,i}\beta_t \right) + (u_{t,i} - u_{t+1,i}) \qquad (5)$$

where the first term includes technical progress and factor accumulation and the second term represents efficiency change. The first term can be further decomposed as:

$$\frac{1}{2}\left(x_{t+1,i} + x_{ti}\right)'\left(\beta_{t+1} - \beta_t\right) + \frac{1}{2}\left(\beta_{t+1} + \beta_t\right)'\left(x_{t+1,i} - x_{ti}\right) \qquad (6)$$

The technical change for a given level of inputs results from the first term of the previous equation and is defined as:

$$TC_{t+1,i} = \exp\left[\frac{1}{2}\left(x_{t+1,i} + x_{ti}\right)'\left(\beta_{t+1} - \beta_t\right)\right] \qquad (7)$$

and the input change defined as the geometric average of two pure input change effects, relatively to the frontiers successive periods:

$$IC_{t+1,i} = \exp\left[\frac{1}{2}\left(\beta_{t+1} + \beta_t\right)'\left(x_{t+1,i} - x_{ti}\right)\right] \qquad (8)$$

The efficiency change is defined as:

$$EC_{t+1,i} = \exp(u_{ti} - u_{t+1,i}) = \frac{\tau_{t+1,i}}{\tau_{t,i}} \qquad (9)$$

For each of these growth components 10-year geometric averages are computed. Koop et al. (1999) suggest different models for the structure of technology change. It can be assumed that the parameters for the technology are different in each of the T time periods (*time specific model*) or a more structured assumption where technology in a decade evolves in a linear (*linear trend model*) or a quadratic (*quadratic trend model*) way. Finally, the authors refer a linear trend model constrained to a constant returns to scale technology.[4] Each of these alternatives presents advantages and potential limitations. The time specific model is very flexible but implies the sampling of numerous parameters, which is computationally heavy. The linear and quadratic trend models are less demanding in terms of parameters but force a more rigid dynamics for technical progress. The quadratic trend is obviously more flexible than the linear one, which makes it preferable if long periods are considered. The linear trend constrained to a constant returns technology probably imposes to much structure. These different alternatives were tested by Koop et al. (1999) and the *linear trend model* offered the

[4]Other more restrictive formulations consider technological progress to be exclusively captured by changes in the first term of β_t. For instance Cornwell, Schmidt and Sickles (1990) consider a quadratic trend on β_t and Perelman and Pestieau (1994) a linear trend.

best results in terms of the in-sample fit and the ability to separate the components of TFP. Therefore we adopt such a formulation:

$$\beta_t = \beta^* + t\beta^{**} \tag{10}$$

and

$$\sigma_t^2 = ... = \sigma_T^2 = \sigma^2 \tag{11}$$

Thus the model can be written as:

$$y = X^*\beta - u + v \tag{12}$$

with

$$y = \left(y_1^{'}...y_T^{'}\right), u = \left(u_1^{'}...u_T^{'}\right), v = \left(v_1...v_T\right)', \beta = \left(\beta^{*'}\beta^{**'}\right)' \tag{13}$$

where β is a 12×1 vector and:

$$X^* = \begin{bmatrix} X_1 & X_1 \\ . & . \\ X_t & tX_t \\ . & . \\ X_T & TX_T \end{bmatrix} \tag{14}$$

where X_t is a 21×6 vector.[5] At this stage the full likelihood function of the model can be written as:

$$f_N^{TN}\left(y\left|X^*\beta - u, \sigma^2 I_{TN}\right.\right) p\left(\sigma^{-2}\right) p\left(\lambda^{-1}\right) \prod_{t=1}^{T} \prod_{i=1}^{N} f_G\left(u_{ti}\left|1, \lambda^{-1}\right.\right) \tag{15}$$

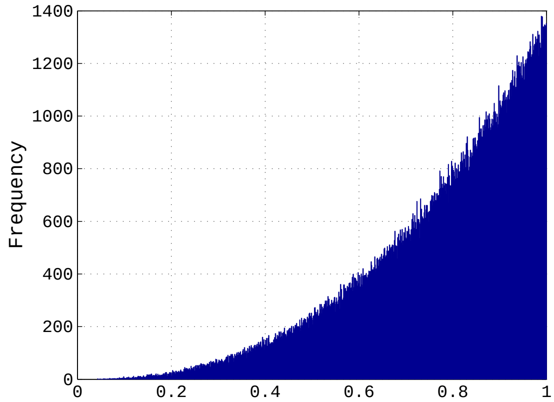
where f_N^{TN} stands for a multivariate $T \times N$ normal probability distribution function, f_G stands for a gamma probability distribution function and:

$$\begin{aligned} p\left(\lambda^{-1}\right) &= f_G\left(\lambda^{-1}\left|1, -\ln\left(\tau^*\right)\right.\right) \\ p\left(\sigma^{-2}\right) &= \sigma^2 \exp - \frac{10^{-6}}{2\sigma^2} \end{aligned}$$

Note that the prior for λ^{-1} assumes a gamma distribution with the first parameter equal to 1, meaning a very flat prior and second parameter such that $(-ln(\tau^*))^{-1}$ is the prior median efficiency. We assume $\tau^* = 0.03$ so that the median of the efficiency distribution is 0.75. The robustness of results to this prior was confirmed taking different initial values for τ^*. In Figure 1 we simulate the prior distribution of the efficiency parameter. As for σ^{-2} we assume the usual flat prior.

[5] Given this matricial formulation, the generic element is: $y_{ti} = (\beta_1^* + t\beta_7^{**}) + (\beta_2^* + t\beta_8^{**})k_{ti} + (\beta_3^* + t\beta_9^{**})l_{ti} + (\beta_4^* + t\beta_{10}^{**})k_{ti}l_{ti} + (\beta_5^* + t\beta_{11}^{**})k_{ti}^2 + (\beta_6^* + t\beta_{12}^{**})l_{ti}^2$. Therefore, the formulas for capital and labour elasticities are given by $EK_{ti} = (\beta_2^* + t\beta_8^{**}) + (\beta_4^* + t\beta_{10}^{**})l_{ti} + 2(\beta_5^* + t\beta_{11}^{**})k_{ti}$ and $EL_{ti} = (\beta_3^* + t\beta_9^{**}) + (\beta_4^* + t\beta_{10}^{**})k_{ti} + 2(\beta_6^{**} + t\beta_{12}^{**})l_{ti}$, respectively.

Figure 1: Prior distribution for the efficiency parameter
Simulation with 420.000 iterations and $\tau^* = 0.03$



Given this prior structure the posterior marginal distributions that compose the Gibbs sampler are easily derived (see Appendix A). The conditional for β is:

$$p\left(\beta \,\middle|\, Data, u, \sigma^{-2}, \lambda^{-1}\right) \propto f_N^{2J}\left(\beta \,\middle|\, \widehat{\beta},\ \sigma^2\left(X^{*\prime}X^*\right)^{-1}\right) \tag{16}$$

where

$$\widehat{\beta} = \left(X^{*\prime}X^*\right)^{-1}X^{*\prime}\left(y+u\right) \tag{17}$$

The conditional for σ^{-2} to be used in the Gibbs sampler is:

$$p\left(\sigma^{-2} \,\middle|\, Data, \beta, u, \lambda^{-1}\right) \propto f_G \left(\sigma^{-2} \,\middle|\, \frac{n_0 + TN}{2}, \frac{1}{2}\left[a_0 + \left(y - X^*\beta + u\right)'\left(y - X^*\beta + u\right)\right]\right) \tag{18}$$

Next, the conditional for u is:

$$p\left(u \,\middle|\, Data, \beta, \sigma^{-2}, \lambda^{-1}\right) \propto f_N^{TN}\left(u \,\middle|\, X^*\beta - y - \frac{\sigma^2}{\lambda}i, \sigma^2 I_{NT}\right) \tag{19}$$

Finally the marginal posterior distribution for the λ^{-1} is:

$$p\left(\lambda^{-1} \,\middle|\, Data, \beta, u, \sigma^{-2}\right) = f_G\left(\lambda^{-1} \,\middle|\, 1 + TN, -\ln\left(\tau^*\right) + \sum_{t=1}^{T}\sum_{i=1}^{N} u_{it}\right) \tag{20}$$

The sequential Gibbs sampling algorithm defined by equations 16 to 20 was run with 420.000 iterations for each separate decade, with a burn-in of the first 20.000 iterations to eliminate possible start-up effects (see Casella and George (1992)). The computational burden of running such a large number of iterations is high. Nevertheless, given the somewhat limited sample information content and the measurement problems intrinsic to macroeconomic variables, such high number of iterations is necessary to obtain an adequate degree of convergence of the algorithm. For the period 1995-2005 we ran 620.000 iterations in order to test improvements in the accuracy of the results. The gains resulting from the increased iterations were marginal. The traditional algorithm convergence criteria were computed and the posterior distributions were analyzed (see Geweke (1992)).

2.2 Database

The data used for employment and GDP from 1960 until 2005 was obtained from the European Commission AMECO database (December 2005 version). The data for the total capital stock typically poses some problems. For the first period in the sample, the stock of capital in each country was obtained from King and Levine (Penn World Tables). These levels were updated using the capital real growth rates existing in the AMECO database. The reasons for this procedure are twofold. On the one hand, we did not adopt the initial capital stock of AMECO because, as an assumption, it simply corresponds to 3 times the GDP at 1960, which is an obvious limitation. On the other hand, it is not possible to use only data from King and Levine (1994) because it ends in 1994. Other alternatives for the construction of the series of capital stock were tested but the results do not change qualitatively.

It should be noted that, in spite of the international conventions governing national accounts compilation, there are important country specific practices that tend to blur international comparisons. For example, the separation of nominal variations in price and volume is not uniformly computed by the national statistical authorities (see Berndt and Triplett (1990)). The compilation of value added for some services, namely those associated to general government activities, also poses difficulties in international comparisons. These problems may affect the results obtained, though, we hope, not dramatically.[6]

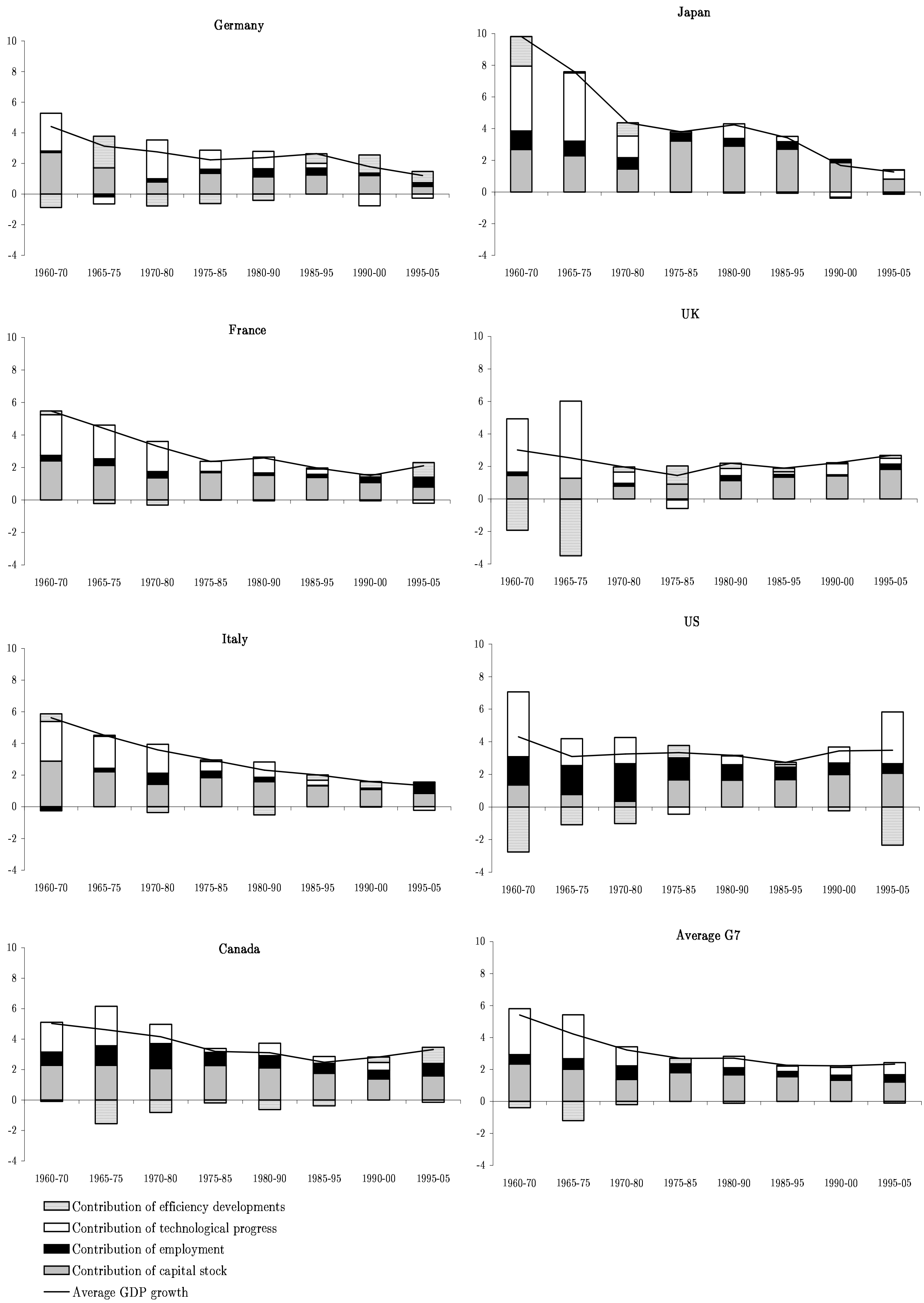
3 TFP in the G7: Different or Alike?

3.1 Growth Accounting for the G7 Countries

Figure 2 plots the contributions of factor endowments and TFP to the average real GDP growth rates of the G7 countries. The contribution of inputs is separated into labour and capital, using the respective computed elasticities. As previously mentioned, the contribution of TFP is disentangled into technology progress and efficiency

[6] The methodology adopted here can be extended to capture some of these effects, as suggested in Koop, Osiewalski and Steel (2000), which base on a bilinear production function and take explicitly into consideration variables that reflect the quality of inputs.

Figure 2: Growth accounting in the G7 countries



developments. The numeric results of the growth accounting exercise are presented in Appendix A. Next we briefly analyze the results for each country.

The US economy presents a growth pattern that is relatively stable along the time. Firstly, it presents average growth rates around three and four per cent in the decades considered. Secondly, it shows a significant contribution of labour to GDP growth during all the periods considered. This contribution is higher than in other G7 countries and it is particularly strong in the period 1960-1985. Thirdly, the contribution of capital is close to the G7 average, showing some increase in the last decades. As for technological progress, there were positive but decreasing contributions to GDP growth in the beginning of the sample, reaching a negative value in the decade 1975-85, the period when the effect of oil shocks was mostly felt. After that period the contributions increased, reaching more than 3 per cent in the decade 1995-05. As a matter of fact, the contribution of technology to GDP growth is strong in the 1960-70 and 1995-2005 decades. Nevertheless, in these periods the contribution of efficiency was negative, partly offsetting the contribution of technology. We discuss the interpretation of such result in the next subsection.

The growth pattern of Canada resembles that of the US in some points. The contribution of employment to GDP growth is also significant. In fact, both countries have received important immigration throughout the period of analysis. Furthermore, the entrance of baby boomers in the US labour market during the 1960's and the 1970's was quite significant. The contribution of capital is also important and stable. Nevertheless, the contribution of technological progress in the last two decades considered is smaller than in the US and there is a considerable contribution of efficiency in the period 1995-2005.

As regards the G7 countries that are euro area members - Germany, France and Italy - some differences in the growth patterns are identified. Germany recorded a trend decrease in the average GDP growth rates mostly attributable to a lower TFP contribution. The labour contribution has been low with the exception of the 1980-1995 period and the contribution of capital accumulation was lower than in the US and Canada with the exception of the 1960-70 decade. As for TFP performance the contribution of technological progress decreased since the 1970's being negative in the period 1990-2000. This latter result is probably capturing the consequences of the German reunification. Conversely, in the period 1990-2005 the efficiency contributed positively to GDP growth, meaning that, although the existing input combination penalized growth, the economy became closer the computed production frontier.

The French economy shows a qualitative behaviour that is close to the Italian case, and, to a lesser extent with Germany. In fact, comparing with Germany two major exceptions are worth mentioning. Firstly, the contribution of technology to GDP growth in the decade 1990-2000 is not negative. Nevertheless, it is close to zero and it has shown a significant decrease since the 1960's. Secondly, there is a large contribution of labour input to growth in the period 1990-2005.

The Italian economy recorded a continuing decrease in the 10-year average real GDP growth rate since the 1960's. This story of decline is mainly attributable to the decreasing contribution of technological progress. This is similar to what was identified for France and Germany, but unlike these countries it has not benefited from increased efficiency in the last decade considered. Though, like France, it recorded a positive contribution of employment in the 1995-2005 period.

The UK shows a poor growth pattern in the period considered, though with some revival in the last decade. Is has not recorded high real GDP growth rates during the 1960's and 1970's and the recent performance is only slightly better than that of the G7 countries that are euro area members. The contribution to GDP growth is shared by all factors, with a predominant role for capital. In the period 1960-1975 the contribution of technical progress was very high, partly offset by efficiency losses. Such TFP pattern has been attributed to underinvestment and restructuring in some industries, driving to a shift of resources to services (see Kitson and Michie (1996)). The improved performance recorded in the last decade may reveal some payback of these structural changes.

The Japanese economy recorded a golden economic growth period in the 1960-1975. The contributions of inputs and mostly of technology gains were strong. From the 1970's until the 1990's the growth pattern changed with real GDP growth benefiting mostly from capital accumulation, labour input and some technological gains. In the 1990s the asset bubble crisis translated into a negative contribution of TFP (both technology and efficiency) to GDP growth. In the 1995-2005 period the average GDP growth was low, relying on the contribution of capital and technology.

3.2 The behaviour of TFP

In this subsection we further analyze the behaviour and the components of TFP in the G7. It is a well established fact that a large part of economic growth is attributable to TFP. In fact, Figure 3 points to a positive relation between average GDP growth and TFP contribution. Nevertheless, this relation seems not to hold for the case of the UK economy in the most recent decades.

When looking at the contribution of technology and efficiency to the overall TFP per-

Figure 3: GDP Growth and TFP contribution in the G7 countries

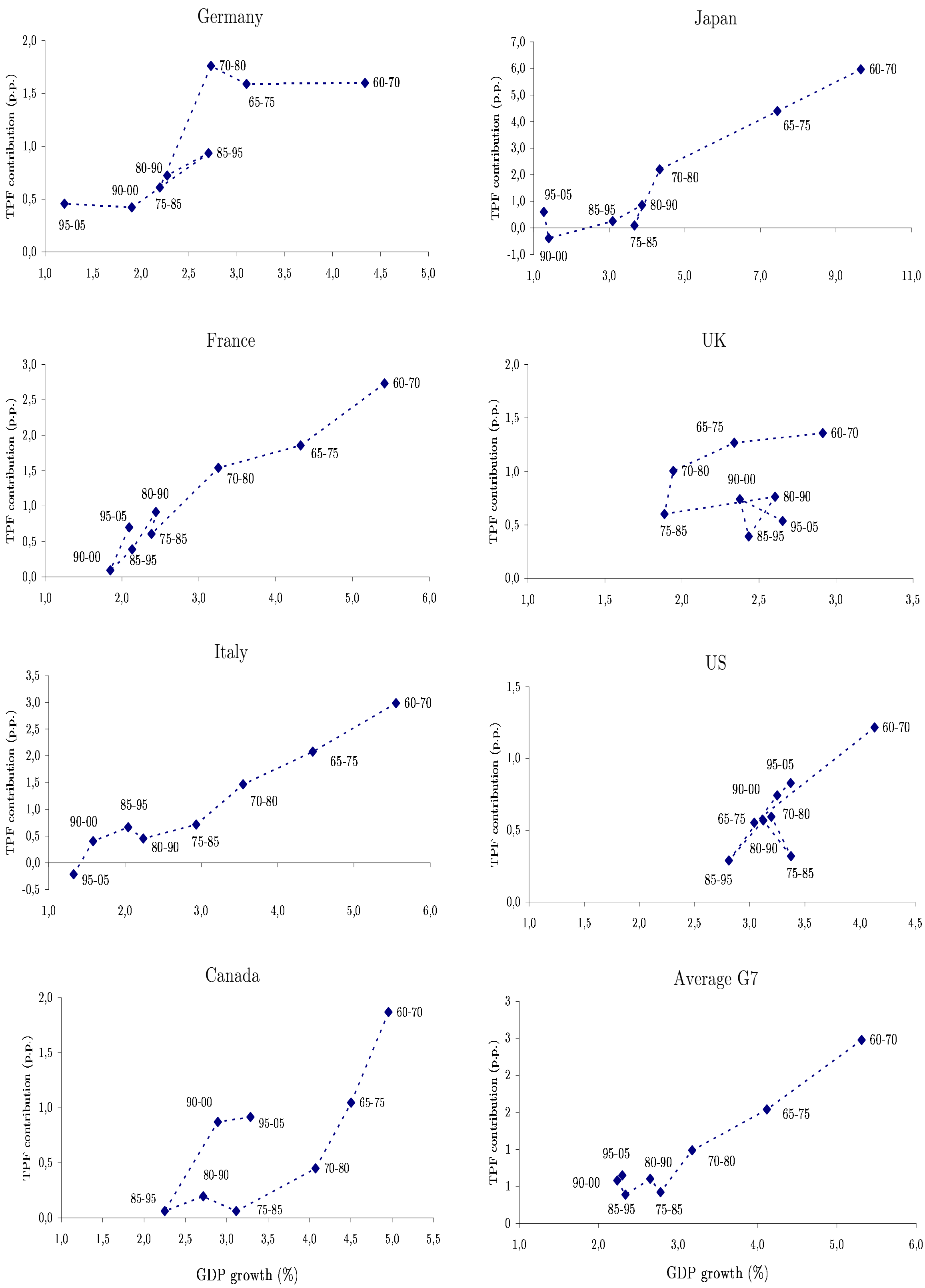
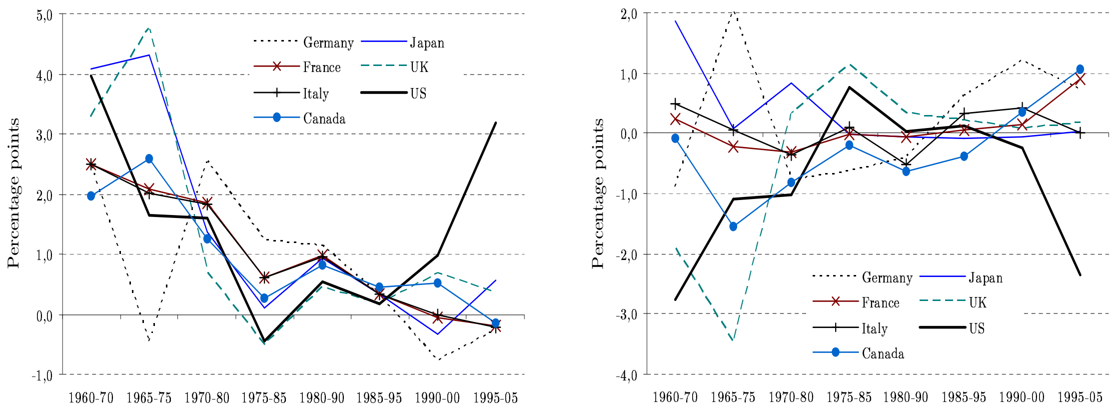


Figure 4: TFP decomposition



(a) Contribution of Technology

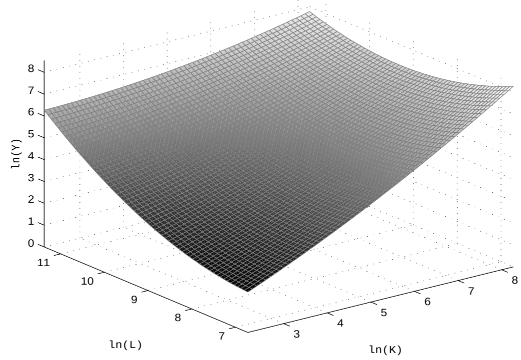
(b) Contribution of Efficiency

formance some results are worth mentioning (figure 4). Firstly, the contribution of technological progress is stronger than efficiency improvements. Secondly, the periods of high technology gain are frequently associated with negative contributions of efficiency (for example the US in the period 1995-2005 and UK and Germany in the period 1965-75). A possible explanation may argue along the following lines. When new technologies appear and countries move some resources to such sectors, the technology effect is beneficial but, given the slow adjustment of input mix and the expansion of the frontier, efficiency is reduced. In addition, it is also true that periods of strong technology change imply high adjustment costs that, in our model, would be captured in the efficiency component. Bessen (2002) and Pakko (2002) discuss this issue in relation with the information technology revolution. Annex B reports the distributions of the efficiency parameter in each country for each decade.

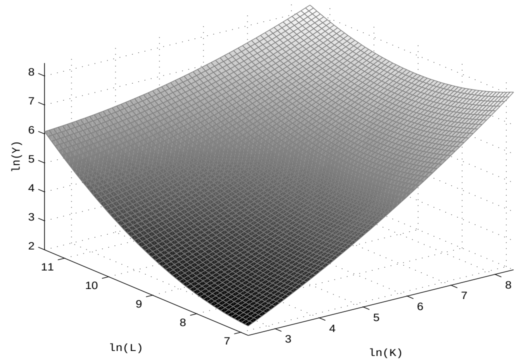
3.3 The Changing World Production Frontier

In this section the shape and the dynamics of the computed world translog production function is analyzed. Figure 5 plots the frontiers in the beginning of each decade considered, revealing substantial changes in its shape. The changes seem to indicate that that new technologies favor higher capital-labour ratios, meaning that the technological progress and potential TFP gains are centered in sectors with higher capital content. Such finding is consistent with the idea that technology and productivity gains are essentially associated with manufacturing and capital intensive services. The strong contribution of ICT industries to the G7 countries GDP growth in the last decade is a good illustration of this phenomenon (for a discussion see Jorgenson (2005)).

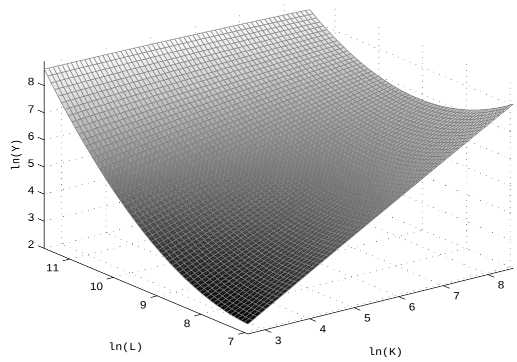
Figure 5: 3D stochastic production frontiers



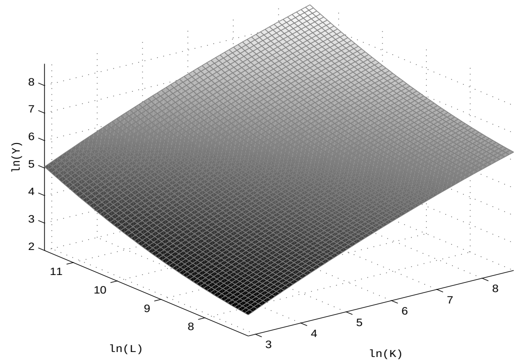
(a) 1960



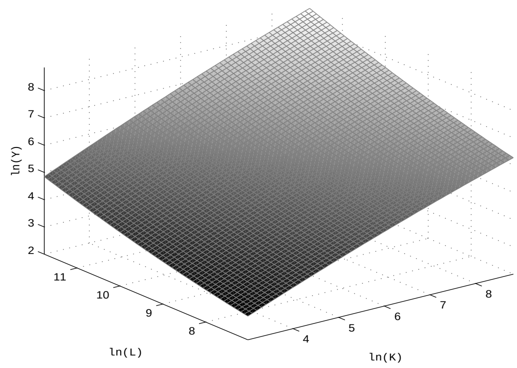
(b) 1965



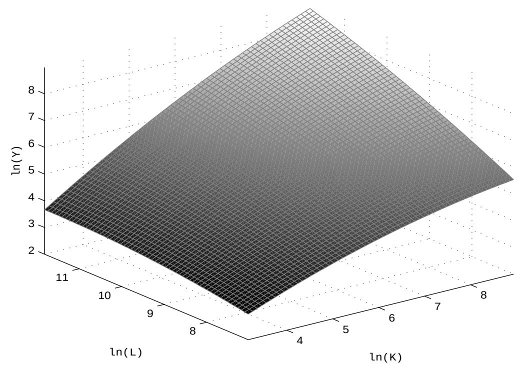
(c) 1970



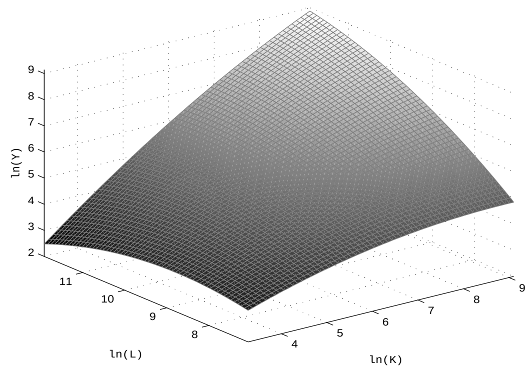
(d) 1975



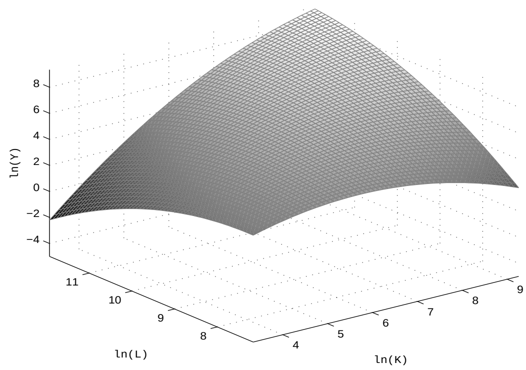
(e) 1980



(f) 1985

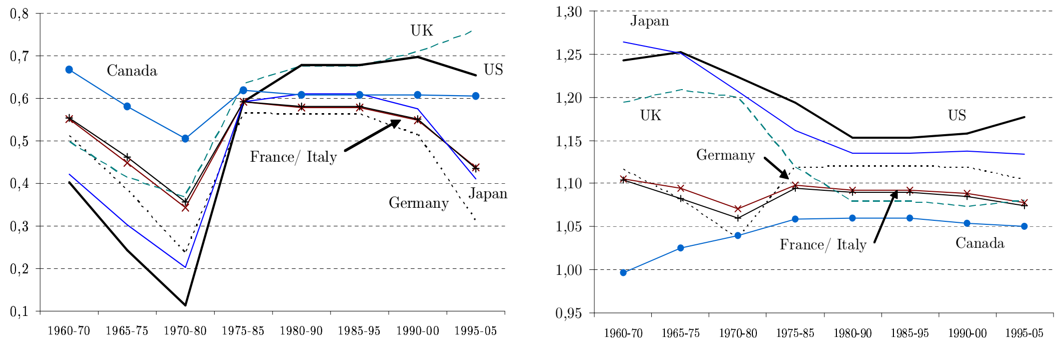


(g) 1990



(h) 1995

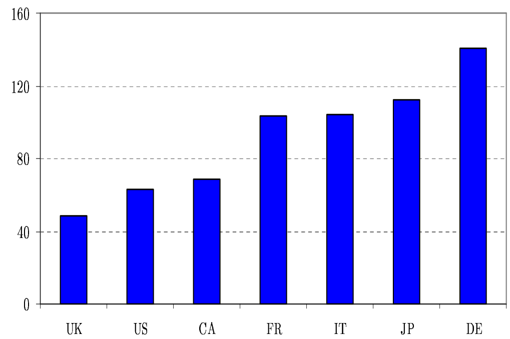
Figure 6: Capital elasticity and returns to scale in the G7 countries



(a) Capital elasticity (b) Returns to scale

The changes in the shape of the stochastic international production frontier have consequences in the elasticities computed for capital and labour in each country (see figure 6(a)). The path of the computed elasticities for capital in the G7 countries was quite similar until the period 1995-2005. It is noticeable the sharp decrease in the capital elasticity in the 1970-1980 period, where severe supply shocks occurred. However, this is not recorded in case of economies of smaller size in terms of employment. In the recent periods the surface of the stochastic production function seems to have became more convex, setting higher computed elasticities of capital for large economies with lower capital-labour ratios like the UK, US and Canada (see figure 7).

Figure 7: Capital-labour ratio in the G7 countries
OECD21 average=100 (1995-2004)



Source: AMECO, King and Levine (1994) and authors' calculations

Finally, a related debate concerns the type of returns to scale implicit in the stochastic production function for the G7 countries. The neoclassical view bases on the principle that capital presents diminishing returns at some point, leaving productivity gains to be explained by technological progress. However, the new growth theory, based on endogenous growth models, deviated from this result either based on the existence of spillovers (Romer (1986)) or on issues of measurement and quality of the production factors (for a discussion see Stiroh (2001)). Departing from a simple growth accounting perspective, our analysis provides some results in this area. In fact, the sum of the capital and labour elasticities for the periods considered seems to point to the existence of increasing returns to scale in the G7 countries, which were particularly strong in Japan, US and UK in the sixties and seventies (see figure 6(b)). More recently, the US and, at a lower level, the UK show some increase in the level of returns to scale, while the G7 euro area countries record slight decreases. It would be interesting to note weather these results change in a framework where the quality of the production factors is explicitly taken into account in the computation of the dynamic stochastic production frontier as in Koop et al. (2000).

4 Final Remarks

The paper compares the contribution of total factor productivity to economic growth in the G7 countries, from 1960 until 2005. A dynamic world translog stochastic production frontier is computed through Bayesian statistical methods, where the real GDP growth rate is decomposed in the contributions of TFP and input accumulation, the former being divided into efficiency and technological progress. Special emphasis is put on the comparison of TFP developments amongst G7 countries.

The results obtained show that the contribution of technological progress to total TFP contribution is typically stronger than efficiency improvements. As for individual countries, the US and Canada present a behaviour different from other G7 countries both in terms of TFP and inputs accumulation. In those two countries, after the mid 1980s, TFP started to accelerate following declines in the previous decades. In addition, inputs' accumulation gave a relatively stable contribution for GDP growth, particularly in the case of the US. Italy and France present a continuous declining trend in TFP contribution, though more marked in the latter case. Germany and the UK seem to have moved to a new lower floor of TFP contribution. Nevertheless, in the UK there was a small acceleration of inputs' contribution in the last two decades. Japan, presents a downward trend in TFP contribution that is even more pronounced than in Italy. However, some reversal was seen in the Japanese TFP in the last decade considered, though accompanied by a noticeable reduction in the contribution of inputs' accumulation.

The shape of the stochastic production function changed along the period considered, benefitting more capital intensive input-combinations. Contrary to what was seen in the past decades, this pattern is clearly marked for larger economies. Furthermore, although the results are less precise in disentangling technological progress and efficiency in TFP, there is some evidence of episodes of technological progress being accompanied by negative efficiency developments, which may be related with a slow adjustment of the input mix and adjustment costs. In addition, there is some evidence of increasing returns to scale in the G7 countries, though it may be related with the non consideration of quality aspects in the measurement of inputs.

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Appendices

A Growth accounting in the G7 countries

Table 1: Economic growth in the G7 countries

Germany

Decade starting in	Observed GDP growth	Expected GDP growth	Input growth			Total factor productivity		
			Total	Contrib. of capital	Contrib. of labour	Technological growth	Efficiency growth	Total
60	4,34	4,41	2,81	2,71	0,10	2,48	-0,88	1,60
		0,05	*0,23*			*0,46*	*0,56*	*0,23*
65	3,10	3,13	1,54	1,72	-0,17	-0,47	2,06	1,59
		0,05	*0,19*			*0,94*	*0,87*	*0,19*
70	2,73	2,76	1,00	0,78	0,21	2,54	-0,78	1,84
		0,12	*0,26*			*1,87*	*1,85*	*0,29*
75	2,20	2,24	1,63	1,35	0,27	1,24	-0,63	0,62
		1,24	*0,26*			*2,03*	*2,27*	*1,29*
80	2,27	2,38	1,65	1,13	0,53	1,13	-0,41	0,73
		1,74	*0,15*			*1,70*	*2,22*	*1,76*
85	2,70	2,63	1,70	1,25	0,45	0,31	0,62	0,96
		1,80	*0,16*			*1,47*	*2,23*	*1,79*
90	1,91	1,79	1,37	1,22	0,15	-0,77	1,19	0,45
		1,48	*0,17*			*1,14*	*1,81*	*1,49*
95	1,20	1,21	0,74	0,50	0,25	-0,29	0,76	0,46
		0,04	*0,04*			*0,38*	*0,38*	*0,07*

Note: Values in italics stand for inter quartile ranges

Japan

Decade starting in	Observed GDP growth	Expected GDP growth	Input growth			Total factor productivity		
			Total	Contrib. of capital	Contrib. of labour	Technological growth	Efficiency growth	Total
60	9,66	9,82	3,85	2,68	1,17	4,09	1,87	5,98
		0,04	*0,27*			*0,38*	*0,32*	*0,29*
65	7,45	7,60	3,20	2,28	0,92	4,31	0,08	4,39
		0,05	*0,28*			*0,57*	*0,55*	*0,29*
70	4,34	4,36	2,16	1,44	0,72	1,37	0,84	2,25
		0,09	*0,62*			*1,04*	*0,72*	*0,64*
75	3,67	3,80	3,71	3,22	0,49	0,10	-0,01	0,07
		0,88	*0,65*			*0,98*	*0,61*	*1,06*
80	3,87	4,24	3,38	2,90	0,48	0,93	-0,07	0,86
		1,11	*0,44*			*1,03*	*0,63*	*1,15*
85	3,09	3,42	3,17	2,70	0,47	0,33	-0,08	0,25
		1,19	*0,35*			*1,12*	*0,77*	*1,26*
90	1,40	1,67	2,06	1,85	0,20	-0,32	-0,06	-0,40
		1,00	*0,22*			*0,98*	*0,59*	*1,04*
95	1,27	1,27	0,67	0,81	-0,14	0,57	0,03	0,60
		0,04	*0,07*			*0,20*	*0,17*	*0,09*

Note: Values in italics stand for inter quartile ranges

Table 1 (cont): Economic growth in the G7 countries

France

Decade starting in	Observed GDP growth	Expected GDP growth	Input growth			Total factor productivity		
			Total	Contrib. of capital	Contrib. of labour	Technological growth	Efficiency growth	Total
60	5,42	5,48	2,75	2,40	0,34	2,50	0,23	2,73
		0,04	*0,14*			*0,22*	*0,21*	*0,15*
65	4,32	4,39	2,54	2,12	0,41	2,07	-0,22	1,85
		0,05	*0,13*			*0,26*	*0,19*	*0,15*
70	3,26	3,29	1,75	1,36	0,40	1,85	-0,31	1,57
		0,09	*0,24*			*0,55*	*0,64*	*0,26*
75	2,39	2,37	1,76	1,69	0,07	0,62	-0,01	0,61
		0,95	*0,26*			*0,90*	*0,94*	*1,00*
80	2,44	2,59	1,67	1,52	0,15	0,97	-0,05	0,92
		1,10	*0,19*			*0,87*	*0,85*	*1,13*
85	2,13	1,97	1,58	1,39	0,19	0,32	0,06	0,39
		1,11	*0,14*			*0,83*	*0,89*	*1,13*
90	1,85	1,51	1,42	1,07	0,35	-0,05	0,14	0,09
		0,91	*0,09*			*0,71*	*0,73*	*0,92*
95	2,10	2,10	1,40	0,80	0,60	-0,21	0,91	0,71
		0,04	*0,02*			*0,31*	*0,31*	*0,05*

Note: Values in italics stand for inter quartile ranges

UK

Decade starting in	Observed GDP growth	Expected GDP growth	Input growth			Total factor productivity		
			Total	Contrib. of capital	Contrib. of labour	Technological growth	Efficiency growth	Total
60	2,91	3,01	1,65	1,45	0,21	3,28	-1,92	1,36
		0,05	*0,11*			*0,38*	*0,29*	*0,13*
65	2,34	2,52	1,26	1,27	-0,02	4,75	-3,48	1,26
		0,07	*0,10*			*0,55*	*0,55*	*0,11*
70	1,94	1,97	0,96	0,78	0,18	0,69	0,32	1,02
		0,10	*0,11*			*1,81*	*1,78*	*0,17*
75	1,89	1,45	0,85	0,91	-0,06	-0,52	1,12	0,65
		1,15	*0,16*			*1,24*	*1,52*	*1,17*
80	2,60	2,19	1,43	1,13	0,30	0,44	0,32	0,77
		1,42	*0,11*			*1,24*	*1,25*	*1,39*
85	2,43	1,90	1,50	1,34	0,17	0,17	0,23	0,40
		1,33	*0,11*			*1,21*	*0,98*	*1,35*
90	2,38	2,23	1,49	1,42	0,07	0,67	0,07	0,74
		1,09	*0,14*			*0,98*	*0,76*	*1,06*
95	2,65	2,68	2,14	1,82	0,32	0,36	0,17	0,53
		0,04	*0,03*			*0,39*	*0,39*	*0,06*

Note: Values in italics stand for inter quartile ranges

Table 1 (cont): Economic growth in the G7 countries

Italy

Decade starting in	Observed GDP growth	Expected GDP growth	Input growth: Total	Input growth: Contrib. of capital	Input growth: Contrib. of labour	Total factor productivity: Technological growth	Total factor productivity: Efficiency growth	Total factor productivity: Total
60	5,55	5,62	2,63	2,88	-0,25	2,50	0,48	2,98
		0,04	*0,18*			*0,22*	*0,20*	*0,20*
65	4,46	4,51	2,43	2,21	0,23	2,02	0,06	2,08
		0,04	*0,14*			*0,25*	*0,20*	*0,15*
70	3,55	3,59	2,12	1,42	0,70	1,83	-0,36	1,50
		0,09	*0,19*			*0,57*	*0,65*	*0,22*
75	2,93	2,96	2,25	1,85	0,40	0,61	0,10	0,71
		1,25	*0,22*			*0,88*	*1,53*	*1,28*
80	2,24	2,31	1,86	1,58	0,28	0,96	-0,51	0,45
		1,77	*0,18*			*0,84*	*1,92*	*1,78*
85	2,04	2,02	1,35	1,32	0,03	0,33	0,34	0,67
		1,83	*0,15*			*0,80*	*1,98*	*1,84*
90	1,58	1,58	1,17	1,09	0,08	-0,01	0,42	0,41
		1,52	*0,10*			*0,70*	*1,67*	*1,52*
95	1,33	1,34	1,55	0,84	0,71	-0,23	0,01	-0,22
		0,04	*0,02*			*0,32*	*0,32*	*0,05*

Note: Values in italics stand for inter quartile ranges

US

Decade starting in	Observed GDP growth	Expected GDP growth	Input growth: Total	Input growth: Contrib. of capital	Input growth: Contrib. of labour	Total factor productivity: Technological growth	Total factor productivity: Efficiency growth	Total factor productivity: Total
60	4,13	4,30	3,08	1,35	1,73	3,97	-2,76	1,22
		0,06	*0,10*			*0,48*	*0,54*	*0,10*
65	3,04	3,09	2,54	0,76	1,78	1,65	-1,09	0,55
		0,05	*0,11*			*0,82*	*0,76*	*0,13*
70	3,20	3,25	2,66	0,35	2,31	1,61	-1,01	0,62
		0,09	*0,13*			*1,15*	*1,10*	*0,17*
75	3,37	3,33	3,01	1,66	1,35	-0,44	0,76	0,34
		1,19	*0,15*			*1,57*	*1,85*	*1,20*
80	3,12	3,16	2,60	1,65	0,95	0,54	0,03	0,58
		1,57	*0,14*			*1,57*	*1,69*	*1,56*
85	2,81	2,73	2,45	1,67	0,77	0,16	0,13	0,30
		1,55	*0,11*			*1,55*	*1,53*	*1,56*
90	3,25	3,44	2,70	1,99	0,71	0,98	-0,24	0,75
		1,31	*0,12*			*1,40*	*1,41*	*1,30*
95	3,37	3,50	2,66	2,07	0,58	3,31	-2,47	0,83
		0,08	*0,06*			*1,07*	*1,01*	*0,11*

Note: Values in italics stand for inter quartile ranges

Table 1 (cont): Economic growth in the G7 countries

Canada

Decade starting in	Observed GDP growth	Expected GDP growth	Input growth			Total factor productivity		
			Total	Contrib. of capital	Contrib. of labour	Technological growth	Efficiency growth	Total
60	4,95	5,02	3,15	2,28	0,88	1,95	-0,08	1,87
		0,04	*0,03*			*0,24*	*0,23*	*0,05*
65	4,50	4,61	3,57	2,28	1,29	2,59	-1,55	1,05
		0,04	*0,03*			*0,20*	*0,20*	*0,05*
70	4,07	4,16	3,71	2,07	1,64	1,26	-0,81	0,46
		0,09	*0,05*			*0,67*	*0,69*	*0,11*
75	3,11	3,19	3,13	2,26	0,87	0,25	-0,19	0,05
		1,11	*0,10*			*0,71*	*1,29*	*1,12*
80	2,72	3,11	2,91	2,11	0,80	0,82	-0,63	0,20
		1,49	*0,09*			*0,76*	*1,57*	*1,50*
85	2,25	2,48	2,42	1,75	0,66	0,44	-0,38	0,06
		1,53	*0,06*			*0,78*	*1,59*	*1,53*
90	2,89	2,82	1,95	1,39	0,56	0,51	0,36	0,88
		1,38	*0,05*			*0,73*	*1,50*	*1,38*
95	3,29	3,32	2,40	1,58	0,82	-0,15	1,06	0,91
		0,05	*0,02*			*0,32*	*0,33*	*0,05*

Note: Values in italics stand for inter quartile ranges

Average G7 (non-weighted)

Decade starting in	Observed GDP growth	Expected GDP growth	Input growth			Total factor productivity		
			Total	Contrib. of capital	Contrib. of labour	Technological growth	Efficiency growth	Total
60	5,28	5,38	2,85	2,25	0,60	2,97	-0,44	2,53
		0,05	0,15			0,34	0,34	0,16
65	4,17	4,27	2,44	1,81	0,63	2,42	-0,59	1,82
		0,05	0,14			0,51	0,47	0,15
70	3,30	3,34	2,05	1,17	0,88	1,59	-0,30	1,32
		0,09	0,23			1,09	1,06	0,27
75	2,79	2,76	2,33	1,85	0,48	0,27	0,16	0,44
		1,11	0,26			1,19	1,43	1,16
80	2,75	2,85	2,21	1,72	0,50	0,83	-0,19	0,64
		1,46	0,19			1,14	1,45	1,47
85	2,50	2,45	2,02	1,63	0,39	0,30	0,13	0,43
		1,48	0,15			1,11	1,42	1,50
90	2,18	2,15	1,74	1,43	0,30	0,14	0,27	0,42
		1,24	0,13			0,95	1,21	1,25
95	2,17	2,20	1,65	1,20	0,45	0,48	0,07	0,55
		0,05	0,04			0,43	0,42	0,07

Note: Values in italics stand for the non-weighted averages of the inter quartile ranges in G7 countries

B Posterior Distribution of the Efficiency Parameter

Figure 8: Posterior distribution of the efficiency parameter - Germany

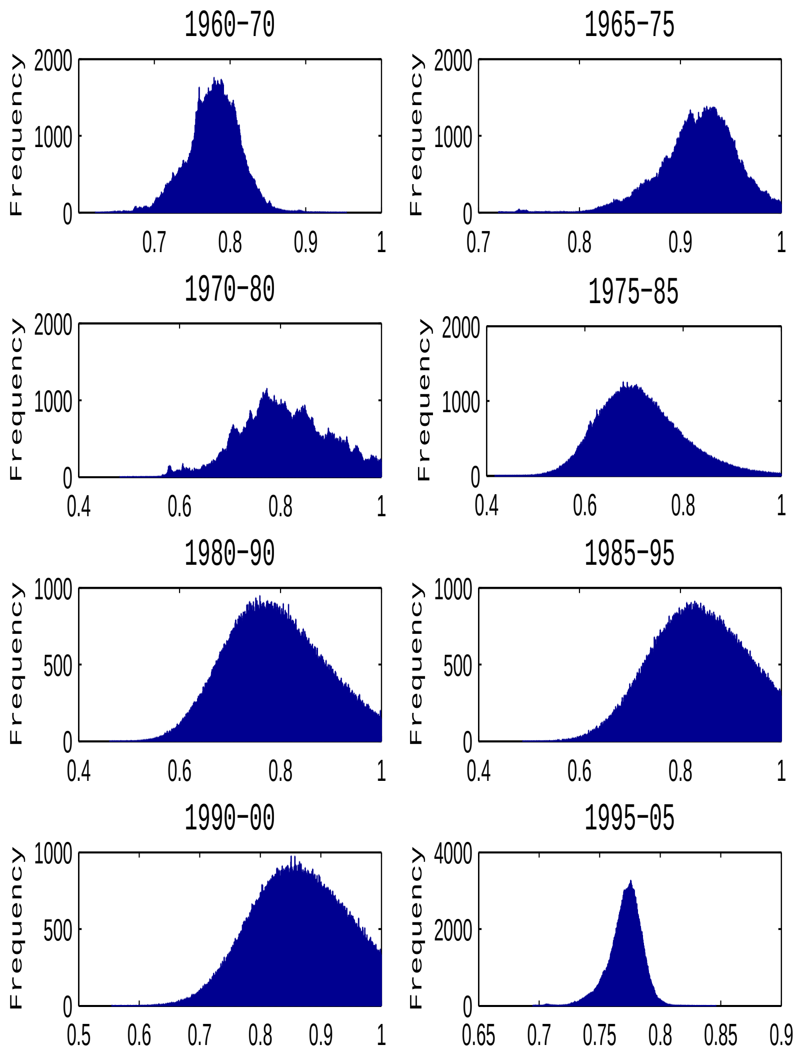


Figure 9: Posterior distribution of the efficiency parameter - France

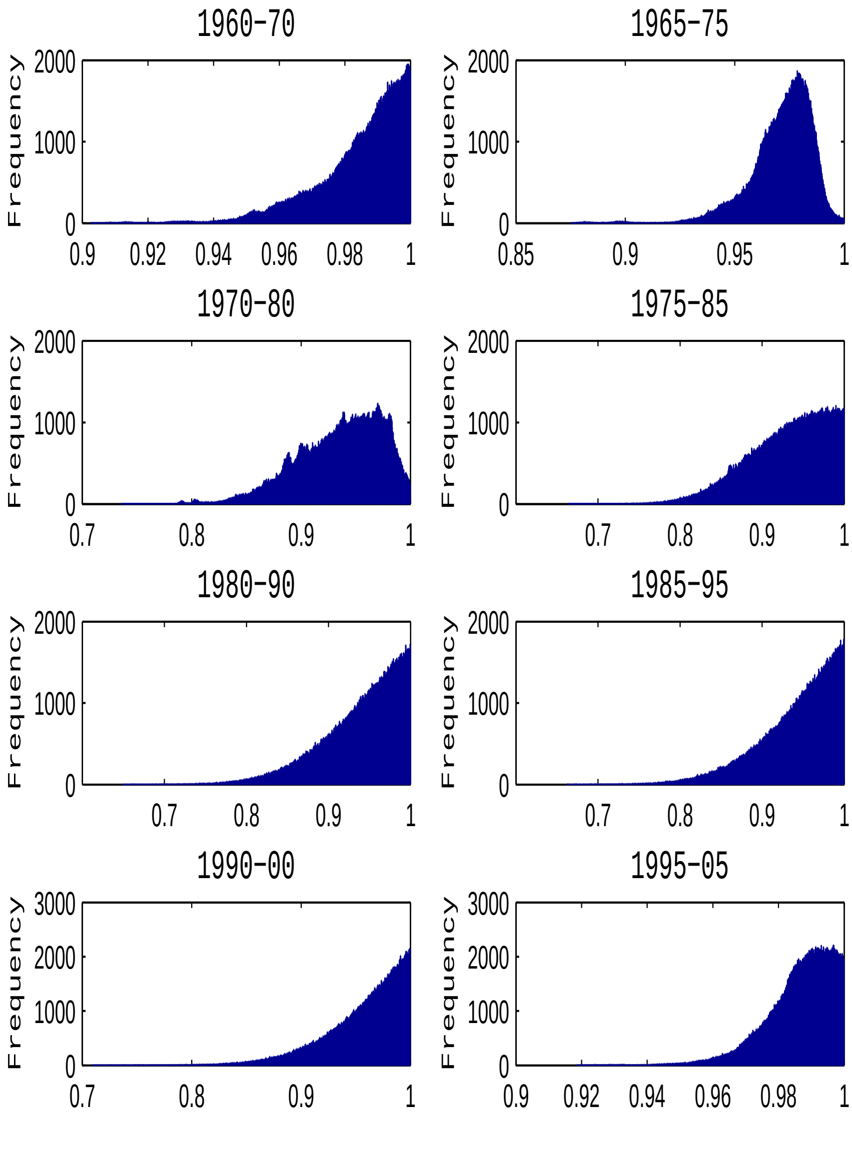


Figure 10: Posterior distribution of the efficiency parameter - Italy

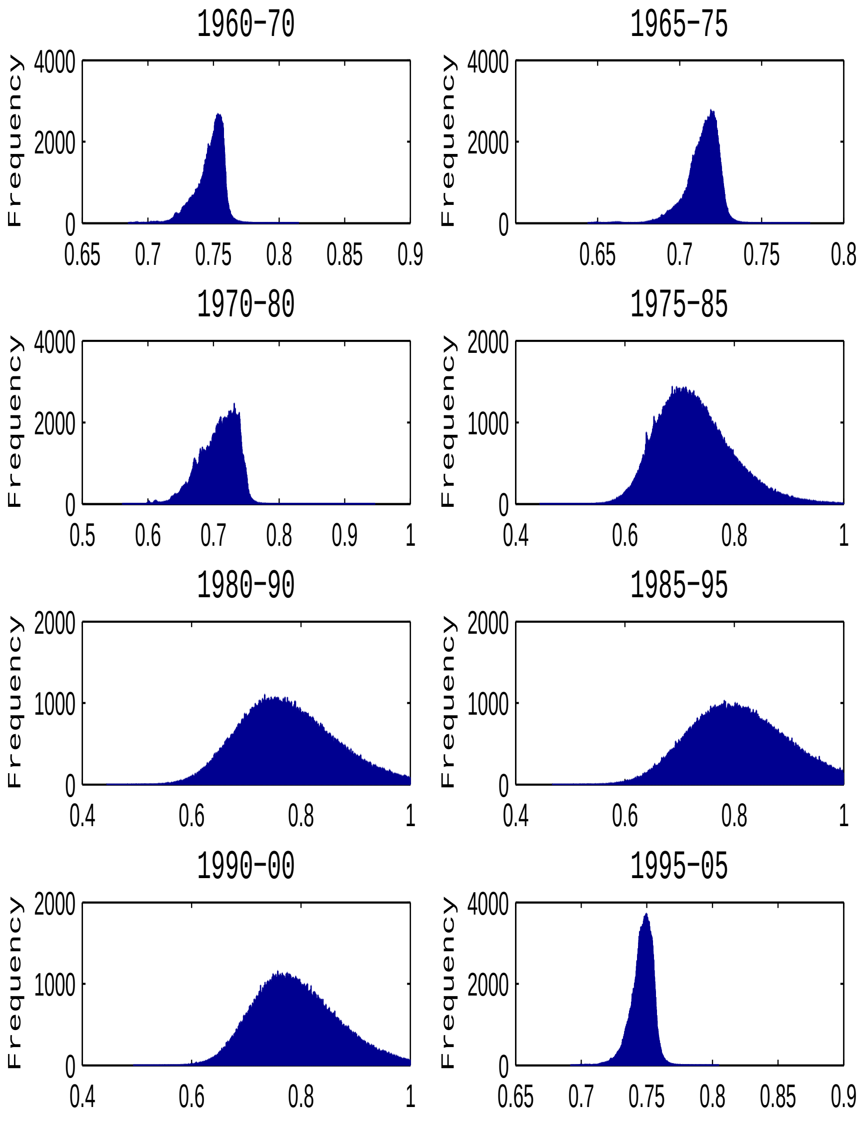


Figure 11: Posterior distribution of the efficiency parameter - UK

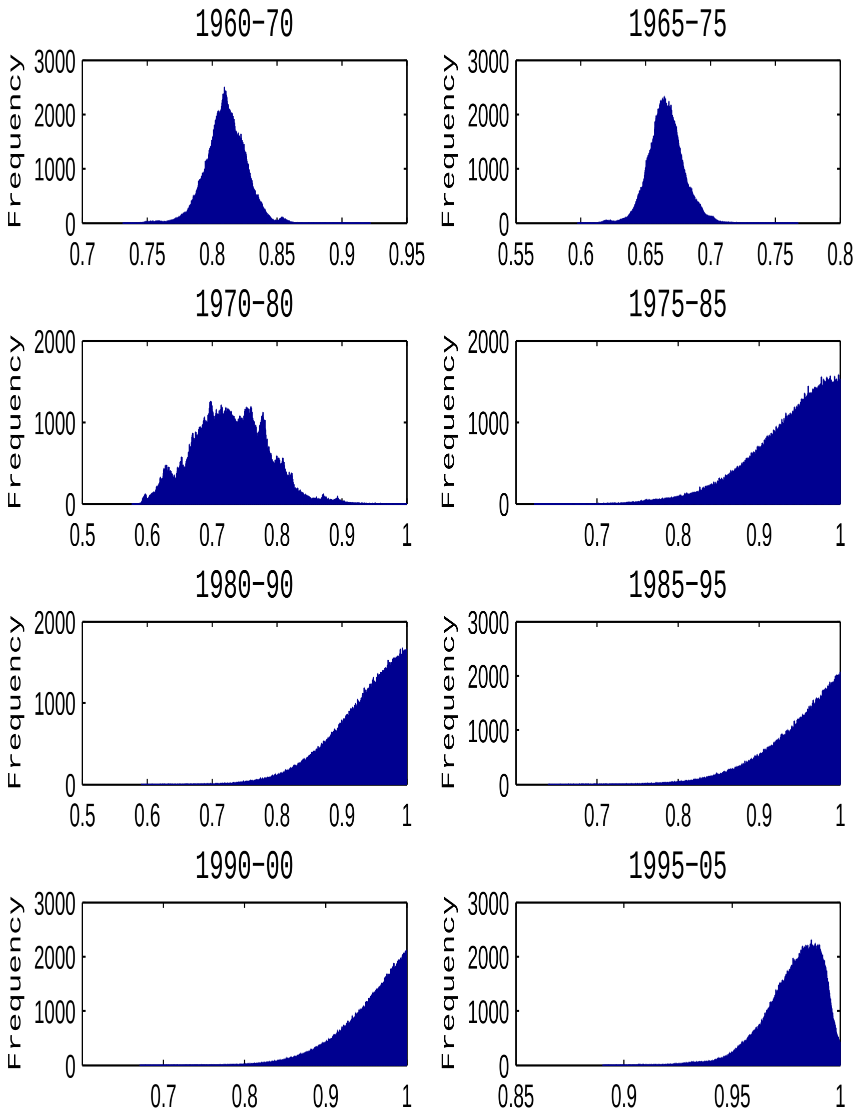


Figure 12: Posterior distribution of the efficiency parameter - Japan

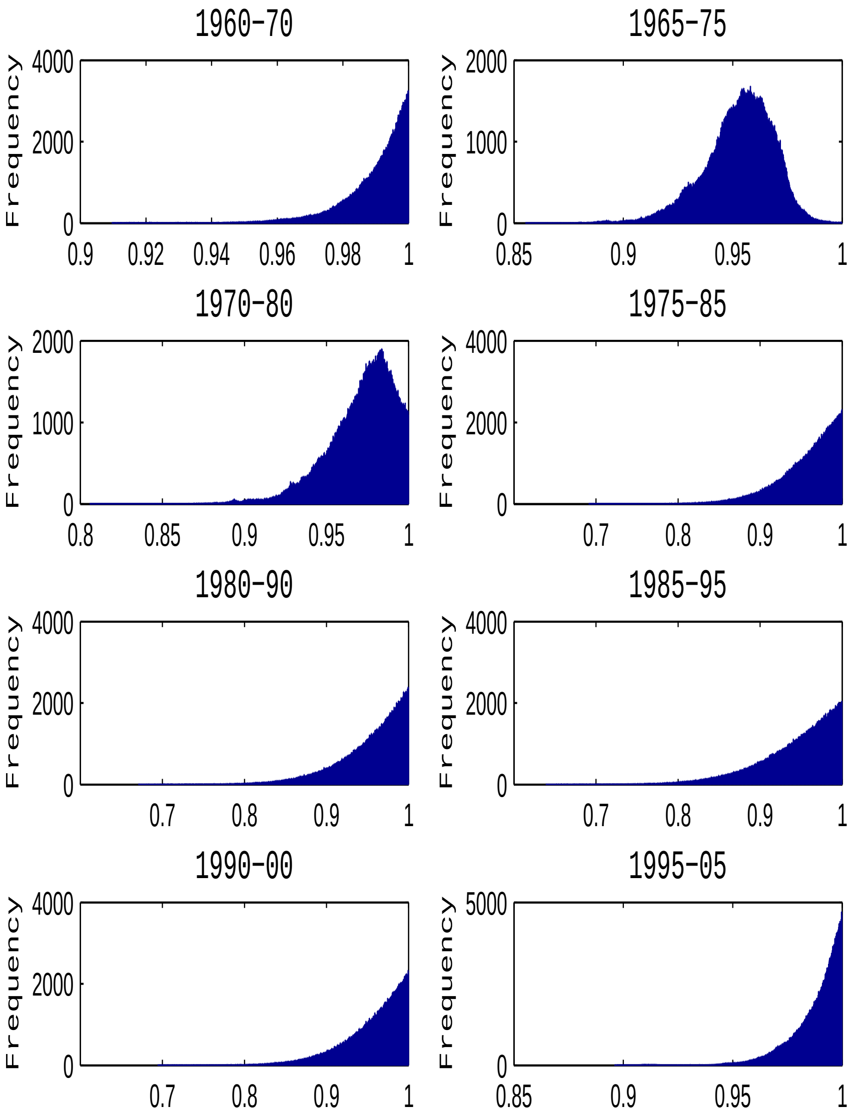


Figure 13: Posterior distribution of the efficiency parameter - Canada

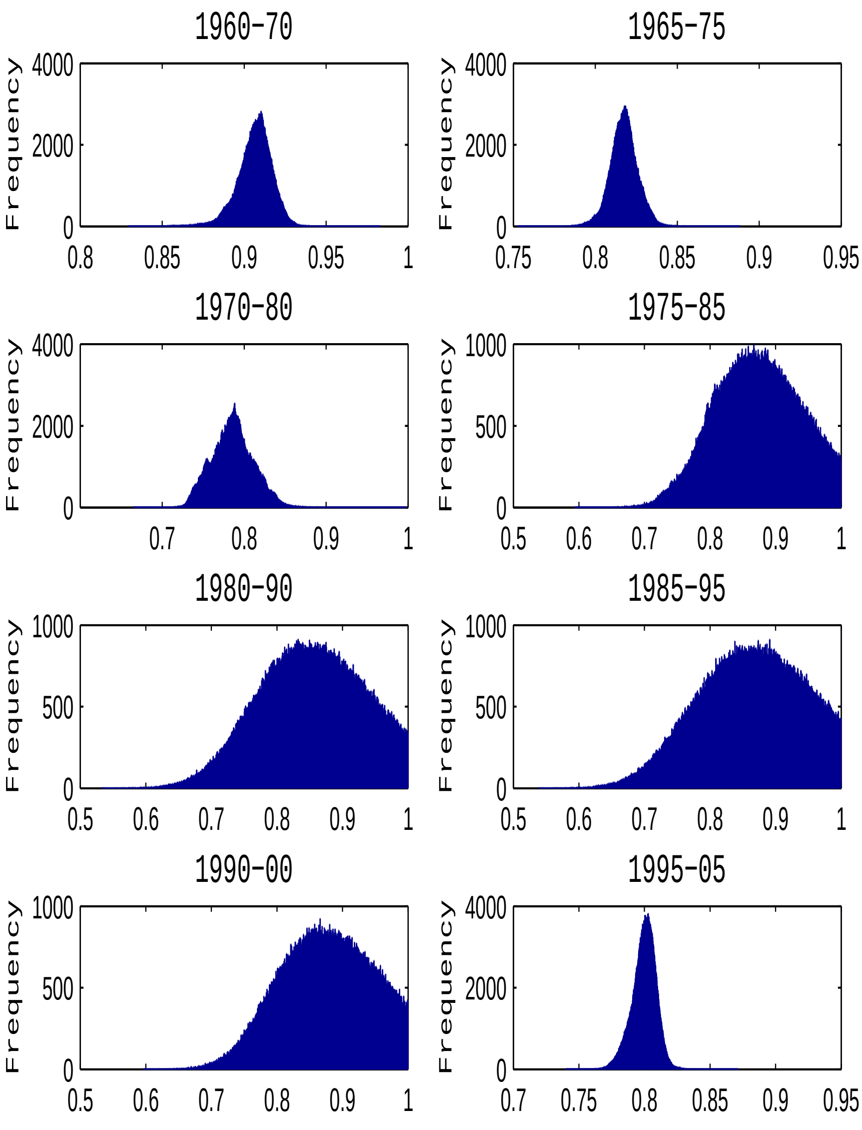
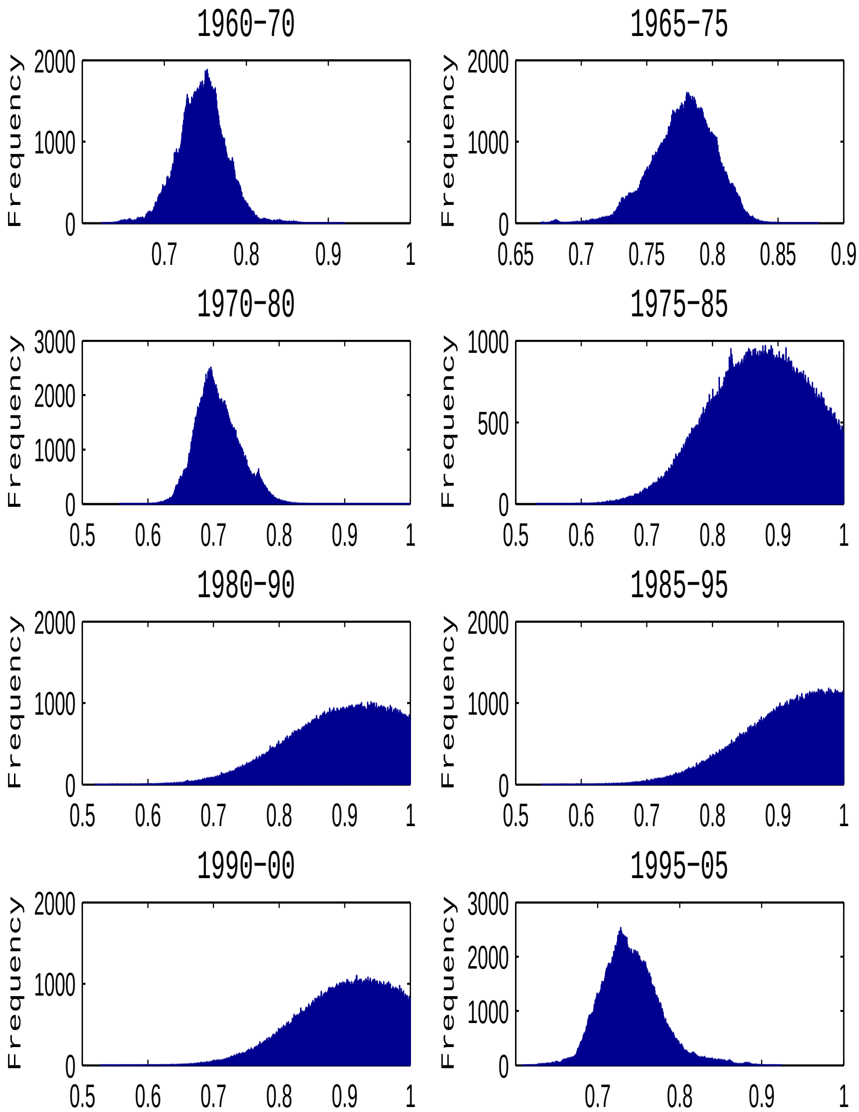


Figure 14: Posterior distribution of the efficiency parameter - US



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