INTERNATIONAL AND INTERTEMPORAL COMPARISON OF PRODUCTIVE EFFICIENCY: AN APPLICATION OF THE META-PRODUCTION FUNCTION APPROACH TO THE GROUP-OF-FIVE (G-5) COUNTRIES*

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1. Introduction

The objective of this study is to apply the inter-country aggregate meta-production function estimated by Boskin and Lau (1990) with annual data for the post-war period drawn from the Group-of-Five (G-5) countries: France, West Germany, Japan, United Kingdom and United States, in an international and intertemporal comparison of the levels and rates of growth of productive efficiencies. There have been many studies comparing the rates of growth of productivity across nations. However, there are very few that compare the levels of technology across different countries. The latter is a considerably more difficult undertaking as it requires the comparison of the entire production function rather than just its values at the actual observed quantities of inputs. Moreover, it is necessary to standardize the measurement of both the outputs and the inputs of different countries so that they are internationally comparable. Only then is it meaningful to compare the technologies.

The Lau and Yotopoulos (1989) implementation of the meta-production function approach, introduced by Hayami and Ruttan (1970, 1985), through the use of time-varying, country- and

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commodity-specific augmentation factors provides an ideal solution to the problem of the international comparison of the levels of the production technologies. The basic assumptions for the Lau and Yotopoulos (1989) implementation of the meta-production function approach are:

(1) All countries have the same underlying production function $F(\cdot)$ but may operate on different parts of it. The production function, however, applies to “efficiency”-equivalent quantities of outputs and inputs, that is:

$$Y_{it}^* = F(X_{ilt}^*, \ldots, X_{imt}^*), \quad i = 1, \ldots, n;$$

where $Y_{it}^*$ and $X_{ijt}^*$'s are the “efficiency”-equivalent quantities of output and inputs respectively of the $i$th country at time $t$, $m$ is the number of inputs, and $n$ is the number of countries. The assumption of a meta-production function implies that $F(\cdot)$ does not depend on $i$ (but may depend on $t$).

(2) The “efficiency”-equivalent quantities of output and inputs of each country are not directly observable. They are, however, assumed to be linked to the measured quantities of outputs, $Y_{it}$'s, and inputs, $X_{ijt}$'s, through the multiplication of time-varying, country- and commodity-specific augmentation factors $A_{ij}(t)$'s, $i = 1, \ldots, n; j = 0, \ldots, m$:

$$Y_{it}^* = A_{i0}(t)Y_{it}; \quad X_{ijt}^* = A_{ij}(t)X_{ijt}, \quad j = 1, \ldots, m.$$ We note that in terms of the measured quantities of outputs, the production function may be rewritten as:

$$Y_{it} = \frac{1}{A_{i0}(t)}F(X_{ilt}^*, \ldots, X_{imt}^*), \quad i = 1, \ldots, n,$$

so that the reciprocal of the output-augmentation factor $A_{i0}(t)$ has the interpretation of the possibly time-varying level of the technical efficiency of production, also referred to as output efficiency, in the $i$th country at time $t$.

There are many reasons why these commodity augmentation factors are not likely to be identical across countries. Differences in climate, topography and infrastructure, differences in definitions and measurements; differences in quality; differences in the composition of outputs; and differences in the technical efficiencies of production are some examples. The commodity augmentation factors are introduced precisely to capture these differences across countries. In Boskin and Lau (1990), the commodity augmentation factors are assumed to have the exponential form with respect to time. Thus:

$$Y_{it}^* = A_{i0}(t) \exp(c_{i0}(t))Y_{it}; \quad X_{ijt}^* = A_{ij}(t)X_{ijt}, \quad j = 1, \ldots, m, \quad i = 1, \ldots, n;$$

where the $A_{i0}$'s, $A_{ij}$'s, $c_{i0}$'s, and $c_{ij}$'s are constants. We shall refer to the $A_{i0}$'s and $A_{ij}$'s as augmentation level parameters and $c_{i0}$'s and $c_{ij}$'s as augmentation rate parameters. Without loss of generality we take the $A_{i0}$ and $A_{ij}$'s for the United States to be identically unity.

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1) In this study, it is assumed that $F(\cdot)$ depends on $t$ only through the commodity-augmentation factors.
2) Constancy of the $c_{i0}$'s and $c_{ij}$'s is a maintained assumption in Boskin and Lau (1990). These parameters may be interpreted as the average rate of augmentation of a commodity in a country over the sample period. It is in principle possible to test whether these augmentation rate parameters remain the same over time.
3) For at least one country, say the $i$th, the constants $A_{i0}$ and $A_{ij}$'s can be set identically at unity (or some other arbitrary constants), reflecting the fact that “efficiency”-equivalent outputs and inputs can be measured only relative to some standard.
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this normalization, it turns out that the augmentation level and rate parameters of all countries are all potentially estimable simultaneously with the parameters of the aggregate meta-production function—there is thus no need to rely on arbitrary assumptions or extraneous information.

The assumption of a single aggregate meta-production function in terms of “efficiency”-equivalent units of outputs and inputs and the possibility of estimating the country and commodity-specific augmentation level and rate parameters directly from the empirical data provide the basis for an international as well as intertemporal comparison of productive efficiencies.

The wide ranges of variation of the inputs resulting from the use of inter-country data necessitate the use of a flexible functional form for \( F(\cdot) \) above. In addition, a flexible functional form is needed to allow the possibility of identifying the biases, if any, in returns to scale and technical progress.\(^4\) In Boskin and Lau (1990), the aggregate metaproduction function is specified to be the transcendental logarithmic (translog) functional form introduced by Christensen, Jorgenson and Lau (1973). For a production function with two inputs, capital \((K)\) and labor \((L)\), the translog function, in terms of “efficiency”-equivalent outputs and inputs, takes the form:

\[
(1.5) \quad \ln Y_{it} = \ln Y_0 + a_K \ln K_{it}^* + a_L \ln L_{it}^* + B_{KK}(\ln K_{it}^*)^2/2 + B_{LL}(\ln L_{it}^*)^2/2 + B_{KL}(\ln K_{it}^*)(\ln L_{it}^*), \quad i = 1, \ldots, n.
\]

An additional advantage of our approach is that it is not necessary to make the assumptions of constant returns to scale, neutral technical progress and profit maximization with competitive output and input markets, assumptions which are traditionally maintained in almost all studies of productivity. Instead, all these hypotheses can be directly tested.

2. The Empirical Model and Results

The Transcendental Logarithmic Production Function Model

We employ the transcendental logarithmic production function in equation (1.5), without imposing the restrictions of constant returns to scale\(^5\) or neutral technical progress.\(^6\) We also do not assume instantaneous profit maximization with respect to capital or labor. Equation (1.5) is written in terms of the “efficiency”-equivalent quantities of outputs and inputs. By substituting equations (1.4) into equation (1.5), we obtain the translog production function in terms of measured quantities of output and inputs:

\[^4\] For example, if the meta-production function \( F(\cdot) \) is chosen to be the Cobb-Douglas form, then the returns to scale will be neutral with respect to the inputs. Moreover, the commodity augmentation factors cannot be separately identified and thus the technology will be indistinguishable from one with neutral technical progress. For this last point, see, for example, Lau (1980).

\[^5\] Most measurements of technical progress (or total factor productivity) assume constant returns to scale. However, it is an arbitrary assumption and the resulting estimate of technical progress is sensitive to the assumed degree of returns to scale. In general, the higher the degree of returns to scale assumed, the lower the estimate of technical progress.

\[^6\] Most measurements of technical progress (or total factor productivity) assume neutrality implicitly. Otherwise, such measurements of technical progress cannot be simply cumulated over time. Under non-neutral technical progress, the magnitude of technical progress depends on the quantities of the inputs.
(2.1) \[
\ln Y_{it} = \ln Y_0 + \ln A^*_i + (a_K + B_{KK} \ln A_{ik} + B_{KL} \ln A_{il})(\ln K_{it}) \\
+ (a_L + B_{KL} \ln A_{ik} + B_{LL} \ln A_{il})(\ln L_{it}) \\
+ B_{KK}(\ln K_{it})^2/2 + B_{LL}(\ln L_{it})^2/2 + B_{KL}(\ln K_{it})(\ln L_{it}) + c_{it}^o t \\
+ (B_{KK}c_{ik} + B_{KL}c_{il})(\ln K_{it})t + (B_{KL}c_{ik} + B_{LL}c_{il})(\ln L_{it})t \\
+ (B_{KK}(c_{ik})^2 + 2B_{KL}(c_{ik})(c_{il}) + B_{LL}(c_{il})^2)t^2/2,
\]

where \(A^*_i\) and \(c_{it}^o\) are country-specific constants. Equation (2.1) may be simplified into:

(2.2) \[
\ln Y_{it} = \ln Y_0 + \ln A^*_i + a_K^i \ln K_{it} + a_L^i \ln L_{it} \\
+ B_{KK}(\ln K_{it})^2/2 + B_{LL}(\ln L_{it})^2/2 + B_{KL}(\ln K_{it})(\ln L_{it}) + c_{it}^o t \\
+ (B_{KK}c_{ik} + B_{KL}c_{il})(\ln K_{it})t + (B_{KL}c_{ik} + B_{LL}c_{il})(\ln L_{it})t \\
+ (B_{KK}(c_{ik})^2 + 2B_{KL}(c_{ik})(c_{il}) + B_{LL}(c_{il})^2)t^2/2,
\]

where \(A^*_i\), \(c_{it}^o\), \(a_K^i\) and \(a_L^i\) are also country-specific constants. Note that the only parameters that are independent of \(i\), that is, of the particular individual country, are \(B_{KK}, B_{LL}\) and \(B_{KL}\). They must be identical across countries. Note also that the parameter corresponding to the \(t^2/2\) term for each country is not independent but is completely determined given \(B_{KK}, B_{KL}, B_{LL}, c_{ik}\) and \(c_{il}\).

Equation (2.2) is the most general specification possible under our maintained assumptions. We shall refer to this model as our “Base Model.” The country- and commodity-specific augmentation factors can all be identified from equation (2.2), subject to the normalization. In addition to the aggregate production function, we also consider the behavior of the share of labor costs in the value of output: \(w_{it}L_{it}/p_{it}Y_{it}\), where \(w_{it}\) is the nominal wage rate and \(p_{it}\) is the price of output in the \(i\)th country at time \(t\), as a function of measured capital and labor inputs:

(2.3) \[
\frac{w_{it}L_{it}}{p_{it}Y_{it}} = a_{li}^* + B_{KLi} \ln K_{it} + B_{LLi} \ln L_{it} + B_{li}^* t.
\]

Equation (2.2) and (2.3) constitute the estimating equations for this study.

The Stochastic Specification

We introduce stochastic disturbance terms \(\varepsilon_{1i}\)'s and \(\varepsilon_{2i}\)'s into the natural logarithm of the first-differences of the aggregate meta-production function and the labor share equation, respectively. We assume

(2.4) \[
E\begin{bmatrix} \varepsilon_{1i} \\ \varepsilon_{2i} \end{bmatrix} = 0, \forall i, t; \\
V\begin{bmatrix} \varepsilon_{1i} \\ \varepsilon_{2i} \end{bmatrix} = \Sigma, \text{ a constant, nonsingular matrix, } \forall i, t;
\]

and the stochastic disturbance terms are uncorrelated across countries and over time. In this form, the influence of the stochastic disturbance terms is permanent—they raise or lower the (natural logarithm of the) meta-production function and the labor share permanently until further changes caused by future stochastic disturbance terms.

Under the further assumption of joint normality of the stochastic disturbance terms, we can estimate the system of two equations consisting of the meta-production function and the labor share equation and its various specializations by the method of nonlinear instrumental
variables. The list of instruments used consists of first differences of the natural logarithms of real output lagged one and two periods; lagged capital stock; lagged labor force; world population; female life expectancy; male life expectancy; female population; male population; arable land; land under permanent crops; world prices of cotton, oil and iron ore relative to the world price of wheat; lagged relative prices of cotton, oil and iron ore; time; and country dummy variables.

The Data

We use data from the Group-of-Five (G-5) countries: France, Federal Republic of Germany, Japan, United Kingdom, and United States. The period covered is from 1957 to 1985 except for West Germany and the United States, data for which begin in 1960 and 1948 respectively. A detailed description of the variables and the data sources is available in Boskin and Lau (1990).

Empirical Results

First of all, Boskin and Lau (1990) find that the maintained hypotheses of the meta-production function approach namely: (1) The aggregate production functions of all countries are identical in terms of "efficiency"-equivalent units of outputs and inputs; and (2) Technical progress in all countries can be represented in the commodity-augmentation form; cannot be rejected. Second, conditional on the maintained hypotheses of the meta-production function approach, they find that the traditionally maintained hypotheses of productivity analysis, namely: (1) Constant returns to scale; (2) Neutrality of technical progress; and (3) Profit maximization; can all be rejected.

Most importantly, the results of the hypothesis testing and estimation of Boskin and Lau (1990) indicate that (1) technical progress may be represented as purely capital-augmenting, that is, the aggregate production function may be written in the form:

\[ Y_{it} = A^{-1}_{i0}F(A_{ik}(t)K_{it}, L_{it}), \quad i = 1, \ldots, n, \]

and (2) Significant differences in both the levels and the rates of growth of commodity-augmentation factors across countries exist. In particular, the level of output augmentation and the rate of capital augmentation differ significantly across countries. The level of output augmentation indicates the level of overall productive efficiency relative to the United States in the base year, 1970. In 1970, the United States had the highest level of output efficiency, followed by France, West Germany, and Japan, all with approximately 60 percent of U.S. efficiency; and the United Kingdom had the lowest level of output efficiency, equivalent to approximately 40 percent of U.S. efficiency. The estimated capital augmentation rates are statistically significant and positive for all countries. The rates of capital augmentation of France, W. Germany and Japan were found to be significantly higher than those of the U.K. and the U.S.

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7) See, e.g., Gallant and Jorgenson (1979).
8) It is important to observe that capital-augmenting technical progress does not necessarily mean that the quality of capital per se has improved or that labor per se has not improved. (For example: an increase in the computer literacy of workers may be represented as an increase in the effective number of computers.)

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The parameter estimates of the final specification are presented in Table 2.1. Overall, the model of capital-augmenting technical progress seems to fit quite well.

Boskin and Lau (1990) also find that there are locally decreasing returns to scale for the aggregate economy as a whole in all countries. At the 1970 values of the independent variables of each country, statistically significant decreasing returns to scale are exhibited for all countries. The estimated degrees of local returns to scale range approximately between 0.7 and 0.8. This finding may possibly be attributed to omitted factors of production such as land, public capital stock (in the case of Japan and the United States), human capital, R&D capital stock, and the environment.

9) The elements of the gradient and the Hessian matrix of the production function for the five countries in 1970. The first partial derivatives are all positive. The own second-partial derivatives are all negative and the determinants of the Hessian matrices are all positive. Thus the estimated translog meta-production function is monotonically increasing and concave at least within a convex neighborhood of the 1970 values of the independent variables.

10) The t-ratios for the null hypothesis that the degree of returns to scale is equal to unity, that is, the null hypothesis of constant returns to scale, are 2.373 for France, 3.648 for West Germany, 2.508 for Japan, 3.207 for the United Kingdom and 2.892 for the United States. The critical values are 2.58, 2.81 and 3.29 for levels of significance equal to 0.01, 0.005 and 0.001 respectively.

11) For definitions of the degree of local returns to scale and the rate of local technical progress, see Lau (1987).

<table>
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<tr>
<th>Direct Estimates</th>
<th>Estimate</th>
<th>T-ratio</th>
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<tbody>
<tr>
<td>$a_K$</td>
<td>0.199</td>
<td>4.685</td>
</tr>
<tr>
<td>$a_L$</td>
<td>0.622</td>
<td>2.479</td>
</tr>
<tr>
<td>$B_{KK}$</td>
<td>-0.047</td>
<td>-4.085</td>
</tr>
<tr>
<td>$B_{LL}$</td>
<td>-0.034</td>
<td>-0.289</td>
</tr>
<tr>
<td>$B_{KL}$</td>
<td>0.015</td>
<td>0.893</td>
</tr>
<tr>
<td>$c_{FK}$</td>
<td>0.128</td>
<td>5.471</td>
</tr>
<tr>
<td>$c_{GK}$</td>
<td>0.146</td>
<td>6.169</td>
</tr>
<tr>
<td>$c_{JK}$</td>
<td>0.149</td>
<td>4.664</td>
</tr>
<tr>
<td>$c_{UK}$</td>
<td>0.089</td>
<td>5.246</td>
</tr>
<tr>
<td>$c_{US}$</td>
<td>0.074</td>
<td>5.474</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.838</td>
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<tr>
<td>$D.W.$</td>
<td></td>
<td>2.018</td>
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<table>
<thead>
<tr>
<th>Implied Estimates</th>
<th>Estimate</th>
<th>T-ratio</th>
</tr>
</thead>
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<tr>
<td>$A_{F0}^{2}$</td>
<td>0.613</td>
<td>147.13</td>
</tr>
<tr>
<td>$A_{G0}^{2}$</td>
<td>0.577</td>
<td>157.23</td>
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<tr>
<td>$A_{J0}^{2}$</td>
<td>0.561</td>
<td>147.99</td>
</tr>
<tr>
<td>$A_{UK0}^{2}$</td>
<td>0.432</td>
<td>346.16</td>
</tr>
<tr>
<td>$A_{US0}^{2}$</td>
<td>1.000</td>
<td>N.A.</td>
</tr>
</tbody>
</table>
3. International and Intertemporal Comparison

International and Intertemporal Comparison

As an application of the estimated meta-production function we use it to compare the evolution of the technologies of the different countries over time. In Table 3.1, we present the average annual rates of growth of real GDP, Capital, and Labor in the five countries over the periods under study. In Figure 3.1, we plot the real output per measured labor-hour of each of the five countries against time. The United States had the highest real output per labor-hour until it was overtaken by France and West Germany in the late 1970’s. The United Kingdom fell behind France and West Germany in the early 1960’s. Japan started in the last place at a very low level but by 1985 had narrowed the gap considerably. However, real output per labor-hour may differ across countries because of differences in capital intensity (capital stock per unit labor) and scale, as well as in efficiency and technical progress, not to mention the exchange rates used in convert-

<table>
<thead>
<tr>
<th>Period</th>
<th>GDP</th>
<th>Capital Stock</th>
<th>Utilized Capital</th>
<th>Labor Force</th>
<th>Employment</th>
<th>Labor Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>France</td>
<td>57–85</td>
<td>0.039</td>
<td>0.045</td>
<td>0.007</td>
<td>0.004</td>
<td>-0.003</td>
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<tr>
<td>W. Germany</td>
<td>60–85</td>
<td>0.029</td>
<td>0.041</td>
<td>0.001</td>
<td>-0.002</td>
<td>-0.005</td>
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<tr>
<td>Japan</td>
<td>57–85</td>
<td>0.068</td>
<td>0.092</td>
<td>0.011</td>
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<td>0.007</td>
</tr>
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<td>U.K.</td>
<td>57–85</td>
<td>0.024</td>
<td>0.031</td>
<td>0.005</td>
<td>0.001</td>
<td>-0.002</td>
</tr>
<tr>
<td>U.S.</td>
<td>48–85</td>
<td>0.031</td>
<td>0.032</td>
<td>0.018</td>
<td>0.017</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Figure 3.1 Real Output Per Labor-Hour

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ing the real outputs to a comparable basis. In Figure 3.2, we plot the quantity of the real capital stock per worker in the labor force of each of the five countries, adjusted for coverage, against time.\(^{12}\) We note that the U.S. had the highest level of capital stock per worker until around 1970, when it was overtaken by the European countries, due in part to the higher rate of growth of the labor force in the United States. However, the measured capital stock per worker of the United States was still significantly higher than that of Japan as of 1985 even though the rate of growth of the Japanese capital stock was almost three times that of the United States. As of 1985, West Germany had the highest measured capital stock per worker, followed by France and the U.K.

In Figure 3.3 we plot the quantity of real output per unit of the measured capital stock of each of the five countries, again adjusted for coverage, against time. We note that capital productivity showed a generally declining trend. What this implies is that the capital-output ratio, the reciprocal of capital productivity, must have been rising over time.

In order to compare overall productive efficiencies across countries, we must net out the effects of differing quantities of inputs (capital intensity and scale). Within our framework, the production functions of the different countries are, by definition, identical in terms of "efficiency"-equivalent quantities of output and inputs. However, they are not identical in terms of the measured quantities of output and inputs. We may therefore pose the hypothetical question: if all countries have the same quantities of measured inputs of capital and labor as the United States,

\(^{12}\) In Figure 3.2, the capital stock data include only private non-residential capital.
but their own augmentation factors (that is, efficiencies), what would have been the quantities of their real outputs and how would they evolve over time? In other words, we compare their abilities to produce real output, that is, their productive efficiencies, holding measured inputs constant.

To answer this question we project the time-series of hypothetical real outputs for each country by the formula:

\[
(3.1) \quad \ln \bar{Y}_{it} = \ln Y_0 - \ln A_{i0} + a_K \ln K_{USi} + a_L \ln L_{USi} \\
+ B_{KK}(\ln K_{US})^2/2 \\
+ B_{LL}(\ln L_{US})^2/2 \\
+ B_{KL}(\ln K_{US})(\ln L_{US}) \\
+ (a_K \epsilon_{IK})t \\
+ (B_{KK}\epsilon_{IK})(\ln K_{US})t \\
+ (B_{KL}\epsilon_{IK})(\ln L_{US})t \\
+ (B_{KK}(\epsilon_{IK})^2)t^2/2, \quad i = 1, \ldots, n,
\]

substituting in the estimated values of the parameters. In order to implement equation (3.1), we need to estimate \( \ln Y_0 \) and \(-\ln A_{i0} \) for all of the countries except the United States. Since the aggregate meta-production function is estimated in the first-differenced form, \( \ln Y_0 \) and the \(-\ln A_{i0} \)'s are not directly estimated. It is therefore necessary to compute the implied estimates of \( \ln Y_0 \) and the \(-\ln A_{i0} \)'s by the following formulae:
(3.2) \[ \ln \tilde{Y}_0 = \left[ \sum_{t=0}^{T} \ln Y_{UST} - \hat{\alpha}_K \sum_{t=0}^{T} \ln K_{UST} - \hat{\alpha}_L \sum_{t=0}^{T} \ln L_{UST} - \hat{B}_{KK} \sum_{t=0}^{T} \frac{(\ln K_{UST})^2}{2} - \hat{B}_{LL} \sum_{t=0}^{T} \frac{(\ln L_{UST})^2}{2} - \hat{B}_{KL} \sum_{t=0}^{T} (\ln K_{UST})(\ln L_{UST}) - \hat{\alpha}_K \hat{c}_{USK} \sum_{t=0}^{T} t - \hat{B}_{KK} \hat{c}_{USK} \sum_{t=0}^{T} t - \hat{B}_{KL} \hat{c}_{USK} \sum_{t=0}^{T} t - (\hat{B}_{KK}(\hat{c}_{USK})^2) \sum_{t=0}^{T} t^2/2 \right]/(T + 1); \]

Figure 3.4 Hypothetical Output Levels of Countries with Measured Inputs of U.S.
The implied estimates of $A_i^{-1}$'s have been presented in Table 2.1.

Given the estimated values of $\ln Y_0$, $-\ln A_i$'s and the parameters of the aggregate meta-production function, equation (3.1) is used to project the level of real output that would have been produced by each country in each period if it had the measured inputs of the United States in that period. The results are plotted for each country in Figure 3.4.

Figure 3.4 shows that in 1949 the United States had the highest level of overall productive efficiency, France the second highest (but considerably lower than the United States), and Japan the lowest. By the late 1950's West Germany and Japan had overtaken the United Kingdom. As of 1985, the United States remained in the first place as the most productive economy (in terms of having the highest output given the same measured inputs) and the United Kingdom in last place, with France, West Germany and Japan closely clustered together. However, U.S. productivity has not been growing as fast as those of some of the other countries and thus its "advantage" has been declining. With the same measured inputs, Japan could produce less than 40 percent of United States aggregate real output in 1949, but almost 70 percent of United States aggregate real output in 1985. The same is true of France and W. Germany. The gap between the United Kingdom and the United States only narrowed very slightly during this period.

In Figure 3.5 we plot the relative productive efficiency of each of the four countries against time, using the United States level as the reference (that is, with U.S. productive efficiency normalized at unity). Figure 3.5 provides the same picture as Figure 3.4, namely, that France, West Germany and Japan have closed the gap significantly but not the United Kingdom. The two interesting questions that emerge are: What accounts for the initial and still considerable U.S. edge (size, land input, natural resources, human capital, greater degree of economic competition, economic and social mobility, etc.)? And why is the U.S. losing ground (relatively) to France, West Germany and Japan (declining educational standards, falling ratio of public to private investment)? These questions await further study.

13) In the context of the framework here, this is equivalent to asking why the augmentation rate for capital is so much lower in the United States compared to France, West Germany and Japan.
Convergence in Technology

One natural definition of convergence across countries is based on their production technologies. Two countries may be said to have converged to each other in technology, if, given the same inputs, they produce approximately the same output. What this definition means is that if countries have the same measured inputs, they will eventually have the same measured outputs if there is convergence in their technologies. Of course, if their inputs differ, their outputs will differ.

If convergence in technology holds, one immediate implication is that the country with the lower level of productive efficiency should have a higher rate of technical progress (or, equivalently, growth of total factor productivity). Convergence in technology implies that the technology of production becomes more and more similar across countries over time, which is certainly a plausible hypothesis, at least for the industrialized countries. Other definitions of convergence, such as those used by Baumol (1986) and Durlauf and Bernard (1991) do not apply to technology per se but to the rate of growth of real output (or real output per capita). Even if two countries converge in technology, they do not necessarily converge in the rate of growth of output because the rates of growth of inputs may differ for whatever other reasons. Thus, convergence in technology does not imply convergence in the rate of growth of output. The converse is also not true, it is in principle possible for two countries to converge in the rate of growth of output but have different technologies of production, and different rates of growth in inputs. A simple example is that of the steady-state growth model analyzed by Solow (1956). There the rate of growth of output is equal to the rate of growth of the labor, regardless of the

Figure 3.5 Productive Efficiency Relative to the United States

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technology and the saving rate, so that two economies with the same rate of growth of labor will converge in the rate of growth of output but they may well have vastly different production technologies.

Figure 3.5, which shows the differences in productive efficiency narrowing among nations over time, provides empirical evidence in support of the hypothesis of convergence in technology, that is, given the same measured inputs, different countries tend to produce increasingly similar quantities of outputs over time.

4. Concluding Remarks

We have compared the overall productive efficiencies of the Group-of-Five (G-5) countries—France, West Germany, Japan, United Kingdom and United States—for the post-war period, using the inter-country aggregate meta-production function estimated by Boskin and Lau (1990). It is found that the United States had the highest level of overall productive efficiency for the entire period under study (1949–1985). However, the productive efficiencies of France, West Germany and Japan rose rapidly from less than 40 percent of the U.S. level in 1949 to approximately two-thirds of the U.S. level in 1985. There is thus some evidence of convergence in technology.

Technical progress (specifically the rates of commodity augmentation) is taken as exogenous in this study. Moreover, the rates of augmentation are assumed to be constant over time. It is, however, remarkable that the rates of augmentation of capital turn out to be almost identical for France, West Germany and Japan—the hypothesis of equal rates of capital augmentation among these countries cannot be rejected—indicating that the three countries have nearly the same access to advances in technology. It will be interesting to explore why the equality hypothesis does not seem to apply to the U.K. and the U.S. and more generally to investigate the determinants of the observed international variations in the augmentation level and rate parameters (can it be satisfactorily explained by capital accumulation, education, R&D expenditures, the ratio of public to private investment, or other factors?).

The international differences in the levels of overall productive efficiency do not in themselves determine international competitiveness. The latter depends on, in addition to relative productive efficiencies, relative prices of the factors of production—capital and labor—and the exchange rate. If relative prices of the factors and the exchange rate have been unchanged, then clearly the United States has lost competitiveness in the post-war period. However, both the German Mark and the Japanese Yen have appreciated considerably, in fact, more than doubled in value, during this period, which would have offset their gains in relative productive efficiency. Moreover, the costs of capital and wage rates in the different countries have evolved at different rates. Further research on the relative movements of factor prices and exchange rates among the G-5 countries are required before a definite conclusion can be reached on the changes in international competitiveness.

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14) The actual technical progress realized, in the sense of the rate of growth of real output, holding inputs constant, is endogenous, as it depends on the quantities of capital and labor in addition to time.
REFERENCES


