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INTERNATIONAL COMPARISON OF TOTAL FACTOR PRODUCTIVITY: A REVIEW

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Several different approaches to international comparison of Total Factor Productivity (TFP) have now emerged. Among these are the time-series approach, the panel approach, and the cross-section approach. This paper compares methodologies of these different approaches and results that have been obtained from their application. The comparison of results is conducted in the context of two samples, namely the sample of G7 countries and a large sample that includes developing nations. It is found that while there are broad agreements in results, there exist considerable differences too. The analysis shows how these differences can be related, in part, to differences in methodology. The paper also shows how these different approaches to international TFP-comparison can play a complementary role in enhancing our understanding of such important phenomena as technological diffusion and TFP-convergence.

1. INTRODUCTION

Neoclassical economic theory has generally emphasized differences in factor endowments across countries and has devoted less attention to the possibility and actuality of differences in productivity and technology. However, empirical researchers have noticed that countries differ persistently in terms of productivity. For a long time, international differences in total factor productivity (TFP) were studied following the time-series growth accounting approach. This methodology has reached a high level of sophistication thanks to efforts by researchers such as Kendrick, Denison, and Jorgenson. However, because of data constraints mainly, application of this methodology has remained limited to small samples of developed countries. Yet, from the viewpoint of technological diffusion and TFP-convergence, extent and evolution of TFP differences across wider samples of countries is of particular interest. This has given rise to two new approaches to international TFP comparison. These are: (i) the cross-section growth-accounting approach suggested by Hall and Jones (1996) and (ii) the panel regression approach presented in Islam (1995). In this paper, we present a comparison of these three approaches and of results that have been obtained on the basis of their use.

The time-series growth accounting approach has been implemented in two forms, namely the *absolute form* and the *relative form*. The main limitation of the absolute form is that it can provide TFP comparison only in terms of TFP *growth rates* and not in terms of TFP *levels*. The relative form of time-series approach

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overcomes this limitation. It produces TFP levels *and* growth rates for all years of the sample period. The more sophisticated form of the time-series approach, such as that of Jorgenson and his associates, distinguishes growth in quality and quantity of inputs. This requires disaggregated data on different *types* of capital and labor and their respective compensation. It is difficult to find this kind of data for wider samples of countries. Hence, it is likely that the application of the sophisticated version of time-series approach to large sample of countries will remain limited for some time to come.

Both cross-section growth accounting and panel regression approaches have their methodological strengths and weaknesses. The advantages of the cross-section growth accounting approach are that it does not impose a specific form on the aggregate production function and does not require econometric estimation of parameters. It also allows factor share parameters to vary across countries. However, this approach requires prior ordering of countries and is sensitive to inclusion/exclusion of countries. Also, it has to rely on some controversial assumptions in order to compute country specific factor shares. The panel regression approach, on the other hand, does not require prior ordering and is not sensitive to the inclusion/exclusion issue. However, it imposes homogeneity of share parameters across countries and requires econometric estimation based on specified functional form.

The paper compares results in two formats. One is for the G-7 countries, and the other is for a wider sample of 96 countries. A comparison of results for G-7 countries by Dougherty and Jorgenson (1998), on the one hand, and Wolff (1991), on the other, shows that they agree more with regard to the initial TFP-*level* distribution of countries than regarding the subsequent distribution. This implies difference in results regarding TFP *growth*. These differences arise in part from difference in data used and in part from difference in production function used in these two studies.

The comparison for 96 countries is between relative TFP level indices produced by Hall and Jones on the one hand and Islam on the other. This comparison shows that there is more agreement with regard to the bottom end of the distribution than regarding the top. The Hall and Jones index places some rather surprising candidates at the apex of the TFP distribution. Also, the distribution as a whole is more uniform according to the Hall and Jones index than according to the Islam index. The latter yields a more bottom-heavy distribution. These differences can, again, be attributed to differences in data and methodology. With regard to these two indices, there is also a difference in the precise focus of measurement. While the Hall and Jones index is for relative levels in 1988, the Islam index pertains to the 1960–85 period as a whole.

Instead of being discouraging, these differences in results can be stimulating for further research. For example, the difference in the shape of distributions obtained from the Hall and Jones and the Islam indices helps to pose the question of TFP convergence. This question has already been investigated in the context of small samples of developed countries using the time-series growth accounting approach. However, similar analysis is yet to be done for larger samples of countries. Moreover, before conclusions can be drawn regarding technological diffusion from results on TFP, it is necessary to decompose TFP into its different components. This is again something that has not yet been done for a large cross-section of countries.

Both cross-section growth accounting and panel regression approaches can prove fruitful in undertaking these tasks that remain ahead. In fact, with each year, time-series for *all* countries are getting lengthier. Hence, it is increasingly becoming feasible to implement even the time-series growth accounting approach—if not its sophisticated version then, at least, its cruder versions—for wider samples of countries. Hence, all three approaches to international TFP comparison discussed in this paper can play a complementary role in enhancing our understanding of important issues of productivity, technology, and growth. Since cross-section and panel approaches rely on crude aggregate data, productivity indices produced by them are useful mainly for inter-country comparison. On the other hand, productivity indices produced by a sophisticated and data-intensive time-series growth-accounting procedure give a more accurate picture of productivity dynamics within individual countries. However, all three approaches accept the restrictions implied by the concepts of production function and competitive equilibrium.

The paper is organized as follows. In Section 2, we provide some broad perspective to research on international TFP comparison. Methodologies of three different approaches to TFP comparison are discussed in Section 3. In Section 4, we compare results obtained by use of these different approaches. The issue of decomposition of TFP is discussed in Section 5, and in Section 6, we discuss the issue of TFP convergence. Section 7 presents concluding observations.

2. Renewed Interest in TFP Differences Across Countries

In recent years, renewed interest is observed in international comparison of total factor productivity (TFP). To the extent that differences in TFP are related to differences in technology, this indicates a certain departure from the standard neoclassical paradigm. One of the main distinctions between Ricardian and neoclassical trade theories concerns the assumption regarding technology. While the Ricardian theory allows for long-term differences in technology/productivity across countries, the neoclassical trade theory assumes that identical technology is available to all countries, and the difference lies in factor endowment.[1] Similarly, discussion of neoclassical growth theory has proceeded generally on the basis of the assumption of identical production technologies. A central issue around which recent discussion of growth has evolved is that of "convergence", which is the hypothesis that poorer countries grow faster than richer countries and eventually catch up with the latter. Convergence is an implication that has been ascribed to neoclassical growth theory (NCGT) because of its property of diminishing returns

[1]This distinction is not that straightforward, however. It may be said that the Ricardian trade theory is based on differences in labor productivity, and that it did not delve into the causes of these differences. Hence, it may as well be that, instead of, or in addition to, differences in technology, the labor productivity differences in the Ricardian theory arise from differences in factor endowment, in particular, from differences in the availability and quality of soil. However, the fact remains that technology differences are not ruled out in the Ricardian model in the same way as in the standard neoclassical model. For a similar discussion of the difference between neoclassical and Ricardian trade theories, see Kennen (1993, p. 46).

to capital. However, along the way, the assumption of identical production technology has crept in. This assumption, often not even recognized, has had considerable influence on results presented in many prominent works in the recent growth debate.

However, other researchers have not failed to notice that the assumption of identical technologies may not hold. Thus, for example, summarizing his results on inter-country comparison of productivity, Dale Jorgenson notes:

> "One of the critical assumptions of the Heckscher–Ohlin theory is that technologies are identical across countries. That is a very appealing assumption, since it has been difficult to find a rationale for failures of countries to achieve the same level of technical sophistication. However, data on relative productivity levels for German, Japanese, and U.S. industries... reveal that the assumption of identical technologies is untenable. There is no evidence for the emergence of a regime in which the Heckscher–Ohlin assumption of identical technologies would be appropriate. We conclude that the appropriate point of departure for econometric modeling of international competitiveness is a model with perfect competition, constant returns to scale, technologies that are not identical across countries and products of identical industries that are not perfect substitutes." (Jorgenson, 1995b, p. xxv.)

Similarly, Durlauf and Johnson in their analysis of convergence, come to the conclusion that the assumption of identical production technologies may not be appropriate and suggest that "the Solow growth model should be supplemented with a theory of aggregate production differences in order to fully explain international growth patterns." (Durlauf and Johnson, 1995, p. 365.) Fagerberg (1994) also addresses this issue in detail and provides a historical perspective.

In the light of the above, interest in cross-country TFP-differences is a welcome development. The recent debate regarding sources of growth in the East Asian countries has reaffirmed the importance of correct estimation and comparison of TFP.[2] Of course, TFP-differences are not identical to technology-differences. There are many other factors, besides differences in technology, which contribute to computed TFP-differences. However, it is certain that technology-difference leads to TFP-difference, and in order to study the former, one has to start from the latter.

The convergence discussion has shown that there are two processes required for income-convergence to happen. These are (a) reaching similar levels of capital intensity and (b) attaining similar levels of technology. Just as capital accumulation in a capital-shallow country can benefit from capital inflows from capital-rich countries, technological progress in a less-developed country can also benefit from technology-diffusion/transfer from technologically developed countries. Although these two processes are interrelated, it is the first that has received more attention. The standard trade theory devotes considerable attention to the issue of capital (factor) mobility but, because of the assumption of identical technology, says very little about technology diffusion. Similarly, neoclassical growth theory

[2]See for example Young (1995), Krugman (1994).

assumed that technological progress was exogenous, accessible to all, and free. This is an abstraction (necessary at that stage of development of growth theory) from the issue of both generation and diffusion of technology. Rise of new growth theories has been, in part, a response to this abstraction, and the emergence of new theories has brought the issue of generation and diffusion of technology to the forefront of mainstream economics research. Needless to say current interest in TFP-differences across countries is closely related to recent developments in growth theory, and analysis of TFP-differences across countries can be an important complement to research on growth theory in general.

3. Three Approaches to TFP Comparison

For a long time TFP computation has been associated with the time-series approach to growth accounting. However, recently two new approaches have emerged with regard to international comparison of TFP. Thus, broadly we now have three different approaches, namely:

(a) Time-series Growth Accounting Approach,
(b) Cross-section Growth Accounting Approach, and
(c) Panel Regression Approach.

Not all the international growth-accounting works fall neatly under one or the other of the above. There is some overlap in this regard, and it is possible to distinguish sub-variants within these approaches. Also, in addition to the above, there are other approaches to productivity analysis and efficiency comparison. Among these are, for example, the stochastic frontier production function (SFPF) approach and the frontier approach.[3] In most cases these approaches have been used for productivity comparison at the *industry* level. Also methodologically the frontier approach depends on linear programming and does not use parametric production functions. In this paper, therefore, we limit our comparison to the above listed three approaches that use parametric production functions. Extension of this comparison to other approaches is left as a task for the future.

3.1. *Time-series Approach to International TFP Comparison*

By time-series approach to international TFP comparison, we refer to that growth accounting tradition in which analysis is focused on the time-series dimension of data. This, in turn, has two variants, namely the *absolute* and the *relative*. In the absolute form, time-series data of individual countries are analyzed without relating these to time-series data of other countries. In this form, researchers obtain TFP *growth rates* within individual countries. These are then compared and analyzed. Implementation of the absolute form, therefore, does not require time-series data of different countries to be converted to a common currency. By the same token, the absolute form of time-series approach cannot give a comparison of TFP *levels*. The comparison has to be limited to that of TFP growth rates only.

[3]For a discussion of stochastic frontier production function approach, see Caves (1992). Important works on the frontier approach include Nishimizu and Page (1983) and Färe *et al.* (1994).

This limitation is overcome by the time-series approach in *relative form.* In this form, data for different countries are converted to a common currency, using either official exchange rates or exchange rates based on purchasing power parity (PPP). These converted data are then analyzed with reference to either a benchmark country or the mean of the sample. The relative form of time-series approach can, therefore, give not only TFP growth rates within each country but also relative TFP *levels* of these countries.

3.1.1. Time-series Approach in Absolute Form

So far as the absolute form is concerned, international TFP comparison is as old as the study of TFP itself. The latter goes back to Tinbergen (1942/1959) who extended Douglas's idea of production function to include a time trend representing the level of *efficiency.* Tinbergen used this framework to conduct a comparison of TFP growth in France, Germany, the U.K., and the U.S. for the period of 1870–1910. Solow's (1957) seminal article "Technical Change and Aggregate Production Function" put growth accounting on firm theoretical foundations and allowed (unlike in Tinbergen) the rate of TFP growth to vary from year to year. Initial research that followed Solow's paper focused on growth accounting for the U.S. However, soon, from the confinement of a single country, growth accounting spread to samples of countries. Denison (1967) presented a comparison of TFP growth rates among Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, the U.K., and the U.S.A. Other works in this tradition include Barger (1969), Bergson (1974), Domar *et al.* (1964), and Kuznets (1971). Sample sizes of these studies were limited to 9, 7, 5, and 5, respectively, and all countries included in these samples were OECD members.[4]

Jorgenson raised TFP computation to a high level of sophistication. He and his associates introduced the use of Divisia and translog indices to growth accounting, integrated income accounting with wealth accounting, and connected growth accounting with multi-sectoral general equilibrium analysis.[5] Having perfected the methodology on the basis of the U.S. data, Jorgenson and his associates proceded to use it for international TFP comparison. In Ezaki and Jorgenson (1973), the methodology is used to analyze the economic growth of Japan. In Christensen, Cummings, and Jorgenson (1980), the analysis is extended to a sample of nine countries that include the U.S. and its eight major trading partners, namely Canada, France, Germany, Italy, Japan, Korea, the Netherlands, and the U.K.

In the initial phase of growth accounting, the main focus was on the *proportion* issue. This concerns the question of how much of output growth can be explained by measured input growth and how much is left to be explained by TFP growth. The interest in the proportion-issue also carried over to international TFP comparison. In all studies mentioned above, researchers first show how countries compare with each other in terms of growth rate of input, output, and TFP. They then show how countries compare among themselves in terms of proportion of output growth that is explained by input growth and by TFP

[4]See also Maddison (1972) for a critical appraisal of Denison (1967).
[5]See Jorgenson (1995a) for a recent compilation of the important papers on this topic.

growth. Since the *absolute form* of time-series approach readily provided growth rates of input, output, and TFP, this approach was adequate for investigating the proportion-issue.

Studies using the absolute form of time-series growth accounting approach were reviewed earlier by Kravis (1976), Nadiri (1972), Norsworthy (1984), and others. Nadiri compiles results from a number of papers, some of which were TFP studies of single countries. He provides an insightful analysis of differences in TFP growth rates across countries and relates them to corresponding differences in input growth rates and other factors. Christensen, Cummings, and Jorgenson (1980) also provide, at the beginning of their paper, an excellent survey of previous works of the absolute form.

3.1.2. Time-series Approach in the Relative Form

Jorgenson and Nishimizu (1978) initiated the *relative form* of time-series approach to international TFP comparison. In this paper, the authors conduct growth accounting for the U.S. and Japan by considering their data in relative form. In Christensen, Cummings, and Jorgenson (1981), this method is extended to the same sample of nine countries that were studied earlier in Christensen, Cummings, and Jorgenson (1980). In order to consider data in relative form, Jorgenson and his associates use the following translog production function:

$$\begin{aligned} Y = \exp[&\alpha_0 + \alpha_K \ln K + \alpha_L \ln L + \alpha_T T + \textstyle\sum \alpha_C D_C \\ &+ \tfrac{1}{2}\beta_{KK}(\ln K)^2 + \beta_{KL}\ln K \ln L + \beta_{KT} T \ln K + \textstyle\sum \beta_{KC} D_C \ln K \\ &+ \tfrac{1}{2}\beta_{LL}(\ln L)^2 + \beta_{LT} T \ln L + \textstyle\sum \beta_{LC} D_C \ln L \\ &+ \tfrac{1}{2}\beta_{TT} T^2 + \tfrac{1}{2}\textstyle\sum \beta_{TC} T D_C + \tfrac{1}{2}\beta_{CC} D_C^2], \end{aligned} \tag{1}$$

where Y is output, K is capital, L is labor, T is time, and D_C is a dummy variable for country C. This is the same translog production function that these researchers used earlier for growth accounting in absolute form, except that it now includes country dummies. The U.S. is taken as the reference country, and hence the dummy for the U.S. is dropped. In this set-up, the rate of TFP growth *within* a country is given by

$$v_T = \frac{\partial \ln Y}{\partial T} = \alpha_T + \beta_{KT} \ln K + \beta_{LT} \ln L + \beta_{TT} T + \beta_{TC} D_C, \tag{2}$$

which is approximated by the following *translog index of productivity growth*:

$$\begin{aligned} \bar{v}_T = \ln Y(T) - \ln Y(T-1) - \bar{v}_K(\ln K(T) - \ln K(T-1)) \\ - \bar{v}_L(\ln L(T) - \ln L(T-1)) \end{aligned} \tag{3}$$

where $\bar{v}_K = \frac{1}{2}[v_K(T) + v_K(T-1)]$ with $v_K = \partial \ln Y / \partial \ln K$. Similar definitions apply for $\bar{v}_L$ and $\bar{v}_T$. The novelty of the approach is that this function now allows having an expression for difference in TFP *levels*. The TFP difference between any country C and the U.S. is expressed as follows:

$$(4) \qquad v_C = \frac{\partial \ln Y}{\partial D_C} = \alpha_C + \beta_{KC} \ln K + \beta_{LC} \ln L + \beta_{TC} T + \beta_{CC} D_C.$$

This is approximated by the following translog multilateral index of differences in productivity:

$$(5) \quad \hat{v}_C = \ln Y(C) - \ln Y(US) - \hat{v}_K(C)[\ln K(C) - \ln \bar{K}] + \hat{v}_K(US)[\ln K(US) - \ln \bar{K}] - \hat{v}_L(C)[\ln L(C) - \ln \bar{L}] + \hat{v}_L(US)[\ln L(US) - \ln \bar{L}],$$

where, $\hat{v}_K(C) = \frac{1}{2}[v_K(C) + \frac{1}{2}\sum v_K]$, $\hat{v}_L(C) = \frac{1}{2}[v_L(C) + \frac{1}{2}\sum v_L]$, and $\ln \bar{K}$ and $\ln \bar{L}$ denote averages of $\ln K$ and $\ln L$ over all countries in the sample. This index is based on Caves, Christensen, and Diewert (1982) and is transitive and base-country invariant. This framework allows Christensen, Cummings, and Jorgenson (1981) to conduct TFP comparison in terms of not only growth rates but also levels, using translog indices presented above. Dougherty and Jorgenson (1996, 1998) have updated this work and have presented relative TFP level indices for the G-7 countries and for all the years between 1960 and 1989.

Wolff (1991) and Dollar and Wolff (1994) also conduct international TFP comparison using the relative form of time-series growth accounting approach. Wolff's (1991) TFP measure is based on the following simple equation:

$$(7) \qquad TFP_i = Y_i/[\alpha_i K_i + (1 - \alpha_i) L_i],$$

where Y is output, L is labor measured by hours, and K is aggregate capital stock measured by non-residential fixed plant and equipment. The author uses Maddison (1982) data, which were already converted to U.S. dollars. This also allows him to take a long historical view. Wolff presents relative TFP indices for the G-7 countries for the period of 1870–1979 with intervals of roughly a decade. The set of TFP indices for the seven countries is complete from 1950 onwards.

Time-series growth accounting generally requires data for long periods of time. Also, in order to implement Jorgenson and his associates' methodology, one needs to distinguish between growth of quality and quantity of inputs. This, in turn, requires disaggregated data on different types of labor and capital and their respective compensations. This kind of data is available only for a small number of developed countries. Due to these data requirements, the time-series growth accounting approach to international TFP comparison has generally remained limited to the G-7 or the OECD countries. Yet, with regard to TFP-convergence and technology diffusion, the experience of wider sample of countries is of particular interest. The knowledge of what is happening to relative labor and total factor productivity in such wider samples, where the differences in technology and productivity are greater, should be of particular use for further development of growth theory. The cross-section and panel approaches to TFP comparison may be very helpful in this regard, because both these approaches can be applied to large samples of countries.

3.2. *Cross-section Approach to International TFP Comparison*

The cross-section growth accounting approach to TFP level comparison has been suggested recently by Hall and Jones (1996, 1997). The methodology is similar to that of time-series growth accounting, but it is now applied along the cross-section dimension. Hall and Jones proceed from a production function of the following general form:

$$Y_i = A_i \cdot F(K_i, H_i), \tag{8}$$

where Y is output, K is capital, H is human capital augmented labor, A is Hicks-neutral productivity, and i is the country index. H is related to L through the following relationship,

$$H_i = e^{\phi(S_i)} L_i, \tag{9}$$

where $e^{\phi(S_i)}$ shows the factor by which efficiency of raw labor gets multiplied because of S years of schooling. From (8), following Solow (1957), they arrive at the standard growth accounting equation:

$$\Delta \log y_i = \bar{\alpha}_i \Delta \log k_i + (1 - \bar{\alpha}_i)\Delta h_i + \Delta \log A_i. \tag{10}$$

The difference here is that while in Solow, differentiation, or what boils down in practice to differencing, is conducted in the direction of time t, Hall and Jones propose to apply the procedure in the cross-sectional direction, i.e. in the direction of i.

This, however, poses a problem. In time-series growth accounting, there is no ambiguity regarding the direction in which t moves. In the cross-sectional case, however, movement of i depends on the particular way the countries are ordered. Hall and Jones order the countries on the basis of an index that is a linear combination of the individual country's physical and human capital per unit of labor and its value of α the share of (physical) capital in income. However, in order to get country specific α the authors make the assumption that service price of capital (say, r) is the same across countries. They calibrate r so as to have $\alpha_{USA} = 1/3$. This value of r equals to 13.53 percent. The $\bar{\alpha}_i$ in equation (10) above is the average of α for two adjacent countries, i.e. $\bar{\alpha}_i = 0.5\ (\alpha_i + \alpha_{i-1})$. With regard to $\phi(S)$, Hall and Jones make the assumption that it is piece-wise linear with the value of ϕ being 13.4, 10.1, and 6.8 percent respectively for 0–4, 4–8, and more than 8 years of schooling.[6]

With this arrangement and parameter values, Hall and Jones compute TFP level indices for different countries by summing up TFP differences over relevant range of ordering, using the following equation:

$$\log A_i = \sum_{j=2}^{i} \Delta \log A_j + \log A_1, \tag{11}$$

where A_1, TFP value for the base country, is normalized to some arbitrary value. The authors implement this procedure for a very wide sample consisting of 133

[6]These values are taken mainly from studies by Psacharopoulos (1994) for different regions of the world.

countries. These TFP indices are presented in their Table 9, and we reproduce them here in Table A3.

There are several advantages to the cross-section growth accounting approach. First, it does not impose a specific form of aggregate production function. As the authors emphasize, only constant returns to scale and differentiability are required to arrive at growth accounting equation (10). Second, the approach allows factor income share parameters to be different across countries. This also means that econometric estimation is not required to obtain the share parameters.

However, the cross-section growth accounting approach has some weaknesses too. First, it requires prior ordering of countries, and TFP indices may be sensitive to the ordering chosen. Second, equation (11) shows that this index is also sensitive to inclusion/exclusion of countries. Third, computation of country specific values of the factor share parameter α_i is done on the basis of assumption of a uniform rate of return across countries. However, empirical studies suggest that the hypothesis of uncovered interest parity (UIP) does not hold. Fourth, while theoretically it is good to be able to use capital *stock* data (instead of just investment *rates*) and to take account of human capital in growth accounting, in reality it is not an unmixed blessing. Construction of capital stock data through the perpetual inventory method cannot avoid using investment rates. In addition, it requires assumptions regarding depreciation profiles and initial levels of capital stocks. Similarly, schooling data have often been found to be unreliable, and they do not take account of differences in quality. Also, estimates regarding returns to schooling for one region may not hold for others. Thus, in trying to use capital stock data and account for human capital in cross-country TFP comparison, it is possible to pick up noise as well as signal. It is difficult to be sure which of the two predominates. Despite these weaknesses, the cross-section growth accounting approach and results produced on its basis are a novel addition to the body of knowledge on TFP differences across countries.

3.3. *The Panel Regression Approach to International TFP Comparison*

The panel approach to international TFP comparison arose directly from recent attempts at better explaining cross-country growth regularities. Proceeding from a Cobb–Douglas aggregate production function $Y_t = K_t^{\alpha}(A_tL_t)^{1-\alpha}$, where Y is output, K is capital, L is labor growing at an exponential rate n, and A is labor augmenting technology growing at an exponential rate g, one can derive the following equation for steady state output per unit of labor:[7]

$$(12) \qquad \ln\left[\frac{Y_t}{L_t}\right] = \ln A_0 + gt + \frac{\alpha}{1-\alpha}\ln(s) - \frac{\alpha}{1-\alpha}\ln(n+g+\delta),$$

where s is the fraction of output invested, δ is the rate of depreciation, and t is the length of time required by an economy to reach its steady state starting from the initial period. In recent growth literature, this equation has often been termed as the *level-equation* because the variable on the left-hand side of this equation is in *level* form. Many researchers have used this level equation to investigate

[7]For details of this derivation, see Mankiw, Romer, and Weil (1992) or Islam (1995).

determinants of growth.[8] Note that one of the terms on the right hand side of equation (12) is A_0, which is the baseline TFP level of a particular country. Also note that under the assumption that g is common for all countries in the sample, relative TFP levels of any two countries, say i and j, remain unchanged and is equal to the ratio to their initial TFP levels, as we can see below:

$$\frac{A_{it}}{A_{jt}} = \frac{A_{0i}\, e^{gt}}{A_{0j}\, e^{gt}} = \frac{A_{0i}}{A_{0j}}. \tag{13}$$

Thus, under the above assumptions, ratios of estimated A_0's can serve as indices of relative TFP levels. The problem, however, lies in estimation of A_0. It is difficult to find any particular variable that can effectively proxy for it. It is for this reason that many researchers wanted to ignore the presence of the A_0 term in equation (12) and relegated it to the disturbance term. This, however, creates an omitted variable bias for the regression results. The panel approach can help overcome this unsatisfactory situation by providing indirect ways to control for A_0 and obtain its estimate.

One problem with the level equation is that it requires the assumption that all countries of the sample are in their steady states, or at least that the departures from steady states are random. This is obviously a questionable assumption. However, a corresponding equation can be derived that accommodates transitional behavior. This is the equation given by (14) below:

$$\begin{aligned} \ln y_{t_2} &= (1 - e^{-\lambda\tau})\frac{\alpha}{1-\alpha}\ln(s_{t_1}) - (1 - e^{-\lambda\tau})\frac{\alpha}{1-\alpha}\ln(n_{t_1} + g + \delta) \\ &\quad + e^{-\lambda\tau}\ln y_{t_1} + (1 - e^{-\lambda\tau})\ln A_0 + g(t_2 - e^{-\lambda\tau}\, t_1). \end{aligned} \tag{14}$$

In this equation, t_1 and t_2 are initial and subsequent points of time, y is output per labor, and $\lambda = (n + g + \delta)(1 - \alpha)$, known as the *rate of convergence*, because it measures the speed at which an economy closes the gap between its current level of output per labor and its steady state level. Finally, τ is the difference between t_2 and t_1. As we can see, the term A_0 appears in this equation as well. Neglect of this term causes the same omitted variable bias problem as was true for the level equation. Panel data methods can be applied to indirectly control for variations in A_0 and to estimate A_0's themselves. This approach is implemented in Islam (1995) using both Chamberlain's (1982, 1983) Minimum Distance estimator (based on the correlated-effects model) and the covariance estimator (based on the fixed-effects model). Econometric issues have been discussed in detail in that paper and in Islam (1998). The sample consists of 96 countries that figured in most of the recent empirical studies of growth. These estimates of relative TFP levels have been reproduced here in Table A3.

In comparison with the cross-section growth accounting approach, the panel regression approach has certain advantages. First, it does not require any prior ordering of countries. Second, the method is less sensitive to inclusion/exclusion

[8]Mankiw, Romer, and Weil (1992) is a famous example. In fact, Hall and Jones (1996) also use level equation for their regression exercises. However, their equation differs from that of Mankiw, Romer, and Weil in terms of the right-hand side variables of interest.

of countries. Third, the approach is flexible with regard to use of either investment rate or capital stock data and with regard to inclusion of human capital. The fourth advantage is that results from econometric estimation can provide a check for the severity of noise in the relevant data.

The approach has some weaknesses too. First, it has to start from a specified form of aggregate production function. Second, it imposes homogeneity of some parameter values including the factor share parameter. Third, it is based on econometric estimation of parameter values and hence is subject to certain pitfalls of econometric estimation.

4. Comparison of the Results from Different Approaches

It is clear from the above that there is a basic difference in scope of results produced by time-series approach on the one hand and cross-section and panel regression approaches on the other. This makes comparison of time-series results with results from either cross-section or panel approaches somewhat unsuitable. We, therefore, present the comparison in two formats. In the first, we compare results for only the G-7 countries as presented by Dougherty and Jorgenson (1998) (henceforth, DJ) and by Wolff (1991) (henceforth, WO). In the second, we compare TFP results for a wider sample of 96 countries presented by Hall and Jones (1996) (henceforth, HJ) and by Islam (1995) (henceforth, IS).

4.1. *Comparison of TFP Results for the G-7 countries*

Table A1 compiles indices of relative TFP levels presented by DJ and WO. In their paper, Dougherty and Jorgenson use U.S. TFP level of 1985 as the benchmark for their indices. Wolff, on the other hand, uses U.S. TFP level of 1950 as the base. In order to make these two sets of indices more comparable, we shift them to a common base of U.S. TFP level for 1960 as 100. Table A1 shows indices for three particular years, namely 1960, 1970, and 1979. Clearly, these indices contain both *ordinal* and *cardinal* information. Also, because indices for all countries and for all years are benchmarked to a single point, the cardinal information contained in these indices is useful for comparison across both countries and years. It is, therefore, possible to look at the numbers of Table A1 from many different angles and make many different observations.

To concentrate on just a few, we present Table A2. In this table, ordinal information contained in the indices is summarized in the form of ranks, and the cardinal aspect of the information is used to get a measure of change in TFP level over time by taking difference of indices. Thus figures in columns (2) and (4) of Table A2 give ranking of countries in 1960 and 1979 respectively on the basis of DJ TFP indices shown in columns (2) and (6) of Table A1. Figures in column (6) of Table A2 are arrived at by taking difference of DJ indices for 1979 and 1960 for respective countries. The numbers in column (8) of Table A2 are ranks based on the differences shown in column (6) of this table. The numbers in columns (3), (5), (7), and (9) of Table A2 are analogously derived based on the corresponding WO figures.

These transformations help us to see more clearly similarities and dissimilarities in results from these two studies. First of all, we see that there is broad agreement with regard to relative TFP levels of these countries in the initial year of 1960. This agreement is not only in ordinal terms, as can be seen by comparing numbers of columns (2) and (3) of Table A2, but also in cardinal terms, which can be seen by comparing the numbers of columns (2) and (3) of Table A1. The main difference seems to be with regard to change of TFP level over time. TFP ranking of countries for 1979 produced by DJ index differ considerably from the ranking produced by WO index. This can be seen by comparing numbers in columns (8) and (9) of Table A2. This can also be seen by looking at the numbers in columns (6) and (7) of Table A2. These numbers show the increase in respective TFP indices between 1960 and 1979. The difference is particularly significant with regard to the U.S. and Italy. As column (6) of Table A2 shows, according to DJ index, Italy seems to have experienced the greatest TFP growth, outstripping Japan by a significant margin. WO index also attests to Italy's exceptional TFP growth, but does not put Italy ahead of Japan. The TFP growth proves to be very modest for the U.S., according to the DJ index, but not so modest according to the WO index.

What explains these differences? Note that the production function used by DJ allowed for substitution possibilities at a much finer level than by Wolff's production function. This may explain why TFP growth for the U.S. proves to be lower in terms of DJ index than in terms of WO index. However, this cannot explain why the same does not happen for other countries of the sample. Differences in data, therefore, also played an important role. Exact quantification of the separate impacts of data and methodology will require replication of these papers' exercises with each other's data. These are questions that can be pursued in future.

4.2. *Comparison of the TFP results for Large Sample of Countries*

Hall and Jones indices are available for 133 countries. However, many of these are former socialist countries for which it is not clear whether the neoclassical assumptions for growth accounting held true or not. Also, they include many countries for which extraction of oil is the main economic activity. Although the authors try to correct for this by discounting GDP of these countries for oil revenues, some issues still remain. Hence, selection of countries is an issue for Hall and Jones's exercise. This is important in view of the fact that results of the cross-section growth accounting approach are sensitive to inclusion of countries. In Islam (1995), on the other hand, TFP indices are presented for 96 countries. This is basically the same sample of countries that have figured widely in growth studies of the recent period. In the following, we, per force, limit the comparison to this sample of 96 countries.

The basic TFP measures presented in Hall and Jones and in Islam have been compiled in columns (2) and (3) of Table A3. The comparison may again be conducted from both ordinal and cardinal points of view. Thus, columns (4) and (5) show ranking of countries in terms of HJ and IS indices, respectively. The difference in ranking is given in column (6). To make a cardinal comparison, we need to bring these indices to common origin and scale. We do this by taking the U.S. TFP level as 100 and expressing TFP levels of other countries as percentages of the U.S. level. These transformations can be seen in columns (7) and (8) of Table A3.

Looking at the numbers on rank, we see that countries that top the list according to HJ index are Syria, Jordan, Italy, Mexico and Hong Kong. The top five countries, according to IS index, are Hong Kong, Canada, the U.S., the U.K., and Norway. At the bottom of the list, according to HJ index, are Ethiopia, Malawi, Myanmar (Burma), Tanzania, and Chad. According to IS index, the worst performing countries are Somalia, Zambia, Chad, Tanzania, and Zaire. In general, it seems that there is more agreement regarding the bottom of the list than the top. For some countries, such as Senegal, Tanzania, Togo, and Zimbabwe, ranks from the two indices coincide exactly. For seven other countries, namely Nigeria, Singapore, Austria, Jamaica, Bolivia, Venezuela, and Australia, ranks differ by only one. Altogether, differences in rank remain within 5 for 33 countries. For another 25 countries, the difference lies between 6 and 10. Thus, for more than 60 percent of countries, the difference in rank remains within 10. However, for 30 countries, the difference in rank ranges between 11 and 20, and for another 7, between 21 and 30. The difference in ranking is particularly high for some of the countries that appear at the top of the HJ list. For example, the difference in rank for Jordan is as high as 42. For Syria, this difference is 24. Similar large differences are obtained for Mexico, Japan, Mauritius, and Angola.

One way of formalizing the closeness of these various rankings is to compute rank correlation. The Spearman rank correlation between IS and HJ ranks prove to be 0.9024, and the null hypothesis of independence of these two rankings is overwhelmingly rejected. Similar results are obtained by using Kendall's rank correlation coefficients.

A cardinal comparison lead to similar conclusions: there are more similarities regarding the bottom of the list than the top. For example, the difference between the two indices for Angola, Burundi, Ethiopia, Madagascar, Malawi, Myanmar (Burma), Niger, and Uganda remains within ten percent. However, very large differences are obtained, again, for such countries as Syria, Jordan, Mexico, and Brazil. According to HJ index, TFP level of these countries are 126, 118, 114, and 100.2 percent of the U.S. TFP level, respectively. According to the IS index, the corresponding numbers are 46, 26, 49, and 42. These are widely different numbers. However, for many other countries at the top, such as Japan, Denmark, Norway, and Canada, the difference does not exceed ten percent. For many other countries in the middle, the difference is also moderate. Altogether, for 41 countries (i.e. about half of the sample), the difference lies within twenty percent.

One way of capturing the situation regarding relative TFP levels is to produce the distribution. Such distributions have been presented in the form of histograms in Tables A4 and A5. Abbreviated names of the countries and the corresponding values of the index are also displayed in them. This allows us to see the ordinal and cardinal position of individual countries *within* respective distributions. We can now visually peruse the observations that we have made above. Apart from the relative position of different countries within the distributions, these histograms also help show the difference in the overall shape of the distributions. It is clear that the distribution according to the IS index is more bottom-heavy than that according to the HJ-index.

Can any conclusions be drawn from this? The two distributions come from very different methodology and data. Differences in results are therefore quite expected. In addition, note that there is also a difference in what is being measured by the HJ and IS indices. The HJ index is of relative TFP level for the particular year of 1988. In contrast, the IS index pertains to relative TFP level for the entire period of 1960–85. Hence, while the HJ index is, in a sense, *end of the period* indicator of relative TFP level, the IS index represents relative level on *average* for the 1960–85 period. Thus IS index may be closer to the initial situation than HJ index. That being the case, the fact that HJ distribution is less bottom-heavy than the IS distribution may indicate that over time more countries have benefited from technological diffusion and have moved away from very low TFP levels. This may be too definitive an inference to be drawn from the evidence above. However, this shows how TFP measures for broad samples of countries can help us raise and analyze important issues of technological diffusion and convergence. It is to the discussion of these questions that we now turn.

5. TFP Growth and Technological Change

It is recognized that TFP growth may not be synonymous to technological change. Although the neoclassical growth model serves as the framework for TFP computation, and, according to this model, TFP growth is generally attributed to technical change, there has always been a concern that the actual conditions of an economy may be at variance with the neoclassical assumptions. In particular, it has been felt that the neoclassical assumption of perfect factor mobility and equality of marginal product and factor return across sectors is rather stringent. The feeling toward the assumption of constant returns to scale in all sectors has also been the same.

These concerns resonated well with the initial finding of economists studying the U.S. economy that showed that the measured growth in labor and capital explained only a very small part of output growth. Abramovitz (1956) first brought this to notice, and in a series of subsequent articles, he and his co-authors argued against treating the entire residual as technological progress.[9] This was also the position taken by Denison (1967). In his Nobel address, Solow approvingly mentions "unpacking" by Denison of "technological progress in the broadest sense" into "technological progress in the narrow sense" and several other constituents. (Solow, 1987.) Among the latter were, for example, "improved allocation of resources" (which refers to movement of labor from low productivity agriculture to high productivity industry), economies of scale, etc. According to Denison's computation, eleven percent of total U.S. growth (between 1929–82) needs to be imputed to "*reallocation*," and another eleven percent to "*economies of scale*."[10]

Although Jorgenson emphasizes that measured growth of neoclassical inputs can explain more of output growth than has been believed, the issue of departure from neoclassical assumptions figures prominently in his works too. He deals

[9]See for example, Abramovitz (1956, 1993) and Abramovitz and David (1973).

[10]Some, like Abramovitz, however, argue that it is fundamentally difficult to separate out the effect of technological progress from the effect of changes in other inputs of production. See, for example, Abramovitz (1993). Recently, Harberger (1998) has propounded the "cost-reduction" view of TFP.

extensively with conditions of aggregation and, in particular, shows that the existence of the aggregate production function requires the value added function and the capital and labor input functions for each sector to be identical to corresponding functions at the aggregate level. Identical sectoral production functions in turn imply identical input and output prices. Jorgenson (1988) computes growth rates of output and input with and without allowing for these price differences across sectors and finds the results to differ, particularly for shorter periods. He interprets resulting differences as a contribution to aggregate productivity growth of *reallocation of value added, capital input, and labor input among sectors.*[11] Jorgenson's computation shows that over relatively shorter periods, the contribution of reallocation of factors to growth is significant.

What about "unpacking of technological progress in the broadest sense" to "technological progress in the narrow sense" in the context of international TFP comparison? This yet remains to be thoroughly done. One work that addresses this issue in the context of a small sample of developed countries is Maddison (1987). He works with the conventional (absolute form) time-series growth accounting approach, and his sample includes France, Germany, Holland, Japan, the U.K., and the U.S. Apart from standard neoclassical sources of growth, namely labor and capital, Maddison considers a long list of other sources of growth, e.g. "structural effect," "foreign trade effect," "economies of scale effect," "energy effect," "natural resource effect," and "regulation/crime effect," etc. He shows that allowing for these "non-neoclassical" sources of growth has an important effect on international TFP comparison. A country's relative position changes depending on whether or not these other effects are taken into account. This is because countries differ with regard to the degree of departure from the neoclassical assumptions, and, correspondingly, with regard to the importance of these sources of growth.

The problem of departure from neoclassical assumptions is certainly more acute for developing economies. It is, therefore, no wonder that non-neoclassical sources of growth figured prominently in works of development economists. In order to overcome the problem of the short length of time series data of the developing countries, these economists resorted to a cross-section *regression* approach to growth analysis. The methodology consisted of running cross-section regression with growth rate as the dependent variable and a variety of *structural variables* on the right-hand side, in addition to the standard neoclassical variables.[12,13] These regressions were not geared towards TFP computation, although residuals from these regressions had some potential in that regard. Their

[11]As Jorgenson explains, "For example, if labor input is reallocated from a sector with high wages to a sector with low wages, the rate of aggregate productivity growth increased with no corresponding increase in the rates of sectoral productivity growth. The rate of productivity growth can be represented as a weighted sum of sectoral productivity growth rates and the reallocations of value added and capital and labor inputs." (Jorgenson, 1995, Vol. 1, p. 8).

[12]The term *structural* refers to development economists' emphasis that developing economies are structurally different from the one described by neoclassical assumptions, and this difference creates the scope for various *structural* sources of growth. Development economists were also interested in the *proportion issue*. However, they focused on proportion of growth that is explained by neoclassical variables and the proportion that can be attributed to *structural sources.*

[13]Note that these cross-country regressions are the precursors of modern day growth regressions, although this link is not always recognized.

main purpose was to obtain a broad indication about the importance of various sources of growth, neoclassical and structural. Development economists' approach was therefore different from Hall and Jones's approach. The latter is a growth-accounting exercise, which does not rely on regression. Also, unlike development economists, Hall and Jones accept the neoclassical perfect competitive assumptions and do not try to net out contribution of non-neoclassical sources of growth from their estimate of TFP index.

6. TFP Comparison and the Issue of Convergence

As Fagerberg (1994) points out, for a long time, "formal theory" of growth was dominated by the assumption of identical technology. It was mainly in "appreciative theory" that existence of technological difference and hence the possibility of "technological catch-up" was recognized and emphasized. However, since the mid-eighties, the possibility of technological differences is gaining more recognition in formal theory too. There is a two-way interaction between theoretical and empirical research in this regard. On the one hand, empirical research is providing evidence of technological differences that theory can use as stylized facts. On the other hand, recognition of technological differences by formal theory is stimulating new impetus for empirical research on the issue. The result has been the emergence of a sub-field of convergence study, namely the study of TFP-convergence. In this section, we examine how various approaches discussed above can contribute to this study.

The "proportion-issue" dominated the TFP discussion of the sixties and the seventies. The convergence issue was not prominent at that time. Therefore, although time-series studies of international TFP comparison of that period produced results suitable for convergence analysis, it was generally not done. This was true of both absolute and relative forms of the time-series approach. It was not until Baumol's (1986) and Romer's (1987) discussion that the issue of convergence gained prominence.

Before the start of formal analysis of TFP-convergence, there were some informal beginnings. One such example is Maddison (1987), mentioned earlier. One of the effects that Maddison considered was the "technology catch-up effect." However, his treatment of the catch-up effect was somewhat arbitrary. He first computed convergence rates for individual countries on the basis of labor productivity (with the U.S. as the reference country), and then multiplied the rates by 0.2 to arrive at a "catch-up bonus" that he thought countries enjoyed vis-a-vis the leader (the U.S.)[14] Hence, Maddison's analysis was not a formal examination of the thesis of TFP-convergence. Also, since Maddison was working with data in the absolute form, dynamics of TFP *levels* were not explicitly considered. Similarly, relative TFP level comparison, as presented in Christensen, Cummings, and Jorgenson (1981) was also actually an analysis of convergence. However, it was not couched in the terminology that is now being used.

Despite these beginnings, the extension of time-series growth accounting to formal analysis of convergence had to wait till the convergence issue became

[14]For Maddison's full argument for the catch-up bonus see (pp. 668–9)

prominent. We see one such extension in Wolff's (1991) work. His analysis, as we noted, is similar to Christensen, Cummings, and Jorgenson (1980, 1981) in many respects. However, Wolff proceeds to conduct a formal analysis of TFP-convergence using the computed relative TFP indices. First, he uses several descriptive measures, such as coefficient of variation of TFP levels and correlation of TFP growth rates to initial levels of TFP. Judged by these criteria, Wolff finds significant evidence of TFP catch-up, particularly for the post-war period. Wolff also shows particular interest in possible interaction between the processes of capital deepening and technological diffusion.[15] More specifically, his hypothesis is that TFP catch-up depends, in part, on capital intensity catch-up. To test this hypothesis, he first switches to variables in relative (to the U.S.A.) form. Then he presents evidence in terms of simple correlation between TFP growth rate and capital-intensity growth rate. This correlation turns out to be positive. However, in order to check whether any such positive influence remains after controlling for the initial difference in TFP level (from that of the leading country, the U.S.), he regresses TFP growth rate on initial TFP level and capital-intensity growth rate. A positive coefficient on the latter variable is taken as indication of positive influence of capital accumulation on TFP catch-up that is over and above that predicted simply on the basis of the initial difference in TFP level from that of the leading country. In general, Wolff finds positive coefficients, though not always significant.

Reflecting the current interest in convergence issue, Dougherty and Jorgenson (1998) also use their growth accounting results to check for convergence. They trace the evolution of dispersion (measured by coefficient of variation) of output per capita, input per capita and TFP, and find convergence in terms of all these indices. They extend this analysis to dispersion of capital and labor input separately, and also distinguish between quality and quantity of these inputs. At this disaggregated level, Dougherty and Jorgenson find that while convergence holds for capital, it does not for labor, particularly for quality of labor. Dougherty and Jorgenson limit their convergence analysis to graphical treatment and do not run regressions.

Is TFP-convergence true for wider sample of countries? This issue has not yet been addressed using the time-series approach because, as we noted earlier, time-series growth accounting has so far remained limited to only small sample of countries. But, what about the cross-section growth accounting and panel regression approaches that work for large sample of countries? Unfortunately, the question has not been addressed using these approaches either. These approaches have so far produced TFP indices for only one time period. Unless a similar set of indices are produced for several consecutive time periods, the issue of TFP-convergence, and hence of technological diffusion, cannot be adequately studied for a large sample of countries.

Dowrick and Nguyen (1989) use a special variant of the cross-section regression approach to examine the issue of TFP convergence in a sample of 15 OECD countries. Instead of going through a two-stage process used in Wolff (1991) or Dougherty and Jorgenson (1998), Dowrick and Nguyen attempt to do

[15] In this regard, his concerns parallel those of Abramovitz and his associates.

growth accounting and testing of TFP-convergence in the same regression. However, in doing so, they have to assume that capital–output ratio is the same for all countries. This allows them to interpret the coefficient on the initial income variable of the cross-section growth equation to be indicative of TFP convergence. However, the assumption of common capital–output ratio across countries is somewhat problematic. This is more so in large sample of countries. A short-cut single cross-section regression procedure, like that of Dowrick and Nguyen above, may therefore not be entirely suitable for the task in hand.

The key, therefore, lies in further development of TFP measurement and comparison. This does not have to be limited to any particular approach. All three approaches discussed in this paper can be useful in this endeavor. Results from different approaches can complement each other, act as check on the validity of their results, and stimulate their further extension and development.

7. Concluding Remarks

The paper compared the methodologies and the results of three different approaches to international TFP comparison, namely the time-series growth accounting approach, the cross-section growth accounting approach, and the panel regression approach. The time-series approach is of most long standing and has attained a great degree of sophistication. The sophistication and data-intensity of this approach has however limited its application to small sample of developed countries. Yet, from the viewpoint of technological diffusion and convergence, processes working in wider sample of countries are of particular interest. The cross-section growth accounting and the panel regression approaches can be of help in this regard because both these approaches have produced relative TFP level indices for large samples of countries. None of these two methodologies is flawless; each has its own share of advantages and disadvantages, and both can contribute to enhance our understanding of the cross-country processes related to TFP and technology. Furthermore, with time-series data accumulating with each year, it is becoming increasingly feasible to extend the time-series approach (if not the sophisticated version, then at least its cruder variants) to larger samples of countries.

A comparison of results from different approaches shows both similarities and dissimilarities. While the similarities are heartening, the dissimilarities should not prove discouraging. TFP, by definition, is a complicated social phenomenon. It would be rather surprising if different approaches came out with too similar results. In fact, the dissimilarities of results help us to better understand many issues related to measurement and comparison of TFP.

On the whole, the current interest in international TFP comparison is a very welcome development. This is a departure from the neoclassical orthodoxy whereby all countries are assumed to have identical technology. This assumption does not correspond to reality. Recent empirical research on growth has shown that large differences exist among countries with regard to technology. Convergence of income requires both capital deepening and technological diffusion. Analysis of TFP differences across countries and evolution of these differences over time provides the point of departure for studying technological diffusion. All different approaches to TFP comparison have important roles to play in this study.

APPENDIX

TABLE A1

TFP COMPARISON FOR THE G-7 COUNTRIES

Country (1)	DJ-index of Relative TFP 1960 (2)	Wolff-index of Relative TFP 1960 (3)	DJ-index of Relative TFP 1970 (4)	Wolff-index of Relative TFP 1970 (5)	DJ-index of Relative TFP 1979 (6)	Wolff-index of Relative TFP 1979 (7)
Canada	99.1	88.5	110.4	103.5	119.7	108.9
France	79.4	69.0	101.0	99.1	117.7	115.9
Germany	63.3	67.3	82.5	89.4	96.1	99.1
Italy	65.1	57.5	101.0	92.0	119.7	107.1
Japan	39.0	31.9	77.8	73.5	84.0	89.4
U.K.	80.4	75.2	94.3	92.9	106.0	101.8
U.S.	100.0	100.0	109.4	113.3	109.0	122.1

Note: The DJ-indices are from Dougherty and Jorgenson (1997, Table A3), and the Wolff indices are from Wolff (1991, Table 1). Dougherty and Jorgenson presented their indices with U.S. TFP level for 1985 as 100. Wolff's indices, on the other hand, were based on U.S. TFP level for 1950 as 100. To make the indices comparable, we have shifted these to a common base of U.S. TFP for 1960 as equal to 100.

TABLE A2

TFP COMPARISON FOR THE G-7 COUNTRIES

Country (1)	Rank Based on DJ-index of Relative TFP 1960 (2)	Rank Based on Wolff-index of Relative TFP 1960 (3)	Rank Based on DJ-index of Relative TFP 1979 (4)	Rank Based on Wolff-index of Relative TFP 1979 (5)	Increase of DJ TFP index Between 1960–79 (6)	Increase of Wolff TFP index Between 1960–79 (7)	Rank in Terms of Growth of DJ TFP Index (8)	Rank in Terms of Growth of Wolff–TFP Index (9)
Canada	2	2	1	3	20.6	20.4	6	7
France	4	4	3	2	38.3	46.9	3	3
Germany	6	5	6	6	32.8	31.9	4	4
Italy	5	6	1	4	54.6	50.0	1	2
Japan	7	7	7	7	45.0	57.5	2	1
U.K.	3	3	5	5	25.6	26.6	5	5
U.S.	1	1	4	1	9.0	22.1	7	6

Note: The ranks, differences of TFP index, and the ranks based on the differences are all computed on the basis of the numbers of Table A1 of this paper.

TABLE A3

TFP COMPARISON IN LARGE SAMPLE OF COUNTRIES

Country (1)	Hall-Jones Estimate of Contribution of A (2)	Islam Estimate of A(0) (3)	Rank According to HJ Index (4)	Rank According to IS Index (5)	Difference in Rank in Terms of the Two Indices (6)	HJ–TFP Index with U.S. as 100 (7)	IS–TFP Index with U.S. as 100 (8)	Cardinal Difference in the Two Indices (9)
Algeria	−0.328	6.97	38	53	15	72.04	18.64	53.40
Angola	−1.874	6.63	90	65	−25	15.35	13.27	2.09
Benin	−1.172	6.00	70	81	11	30.97	7.07	23.91
Botswana	−0.991	7.06	63	51	−12	37.12	20.39	16.73
Burundi	−1.888	5.91	91	83	−8	15.14	6.46	8.68
Cameroon	−1.069	6.82	65	60	−5	34.34	16.04	18.29
Ctrl. Afr. Republic.	−1.762	5.76	85	88	3	17.17	5.56	11.61
Chad	−1.891	5.48	92	94	2	15.09	4.20	10.89
Congo	−0.731	6.53	54	68	14	48.14	12.00	36.14
Egypt	−0.520	6.77	43	62	19	59.45	15.26	44.19
Ethiopia	−2.264	6.10	96	76	−20	10.39	7.81	2.59
Ghana	−1.536	5.72	80	90	10	21.52	5.34	16.18
Ivory Coast	−0.973	6.87	62	58	−4	37.79	16.86	20.93
Kenya	−1.438	6.00	77	80	3	23.74	7.07	16.68
Liberia	−1.297	5.81	72	87	15	27.34	5.84	21.49
Madagascar	−1.820	6.20	87	74	−13	16.20	8.63	7.57
Malawi	−2.039	5.81	95	86	−9	13.02	5.84	7.17
Mali	−1.639	5.76	83	89	6	19.42	5.56	13.86
Mauritania	−1.493	5.57	78	91	13	22.47	4.60	17.87
Mauritius	−0.226	6.97	27	54	27	79.77	18.64	61.13
Morocco	−0.551	7.49	45	37	−8	57.64	31.35	26.29
Mozambique	−1.500	6.53	79	67	−12	22.31	12.00	10.31
Niger	−1.833	6.10	88	77	−11	15.99	7.81	8.19
Nigeria	−1.401	6.24	74	73	−1	24.64	8.98	15.65
Rwanda	−1.420	5.91	76	84	8	24.17	6.46	17.71
Senegal	−1.153	6.44	69	69	0	31.57	10.97	20.60
Sierra Leone	−1.096	6.05	67	78	11	33.42	7.43	25.99
Somalia	−1.566	5.33	81	96	15	20.89	3.62	17.27
S. Africa	−0.439	7.69	42	28	−14	64.47	38.29	26.18
Sudan	−1.116	5.86	68	85	17	32.76	6.14	26.62
Tanzania	−1.922	5.52	93	93	0	14.63	4.37	10.26
Togo	−1.617	6.00	82	82	0	19.85	7.07	12.78
Tunisia	−0.272	7.35	31	41	10	76.19	27.25	48.93
Uganda	−1.818	6.39	86	72	−14	16.24	10.44	5.80
Zaire	−1.871	5.52	89	92	3	15.40	4.37	11.03
Zambia	−1.649	5.48	84	95	11	19.22	4.20	15.02
Zimbabwe	−1.292	6.39	71	71	0	27.47	10.44	17.04
Bangladesh	−0.545	6.63	44	63	19	57.98	13.27	44.72
Hong Kong	0.086	9.08	5	1	−4	108.98	153.73	−44.75
India	−1.068	6.00	64	74	10	34.37	7.07	27.30
Israel	−0.174	8.17	22	17	−5	84.03	61.88	22.15
Japan	−0.296	8.41	34	10	−24	74.38	78.66	−4.28
Jordan	0.166	7.30	2	44	42	118.06	25.92	92.13
S. Korea	−0.410	7.69	40	33	−7	66.37	38.29	28.08
Malaysia	−0.580	7.69	47	31	−16	55.99	38.29	17.70
Mynamar (Burma)	−1.982	6.20	94	75	−19	13.78	8.63	5.15
Nepal	−1.412	6.53	75	66	−9	24.37	12.00	12.36
Pakistan	−0.640	7.01	50	52	2	52.73	19.40	33.33

TABLE A3—continued

Country (1)	Hall–Jones Estimate of Contribution of A (2)	Islam Estimate of A(0) (3)	Rank According to HJ Index (4)	Rank According to IS Index (5)	Difference in Rank in Terms of the Two Indices (6)	HJ–TFP Index with U.S. as 100 (7)	IS–TFP Index with U.S. as 100 (8)	Cardinal Difference in the Two Indices (9)
Philippines	−0.945	6.97	61	55	−6	38.87	18.64	20.23
Singapore	0.027	8.50	7	6	−1	102.74	86.07	16.67
Sri Lanka	−0.733	6.77	55	61	6	48.05	15.26	32.79
Syria	0.228	7.88	1	25	24	125.61	46.30	79.31
Thailand	−0.667	7.25	52	47	−5	51.32	24.66	26.66
Austria	−0.043	8.26	14	15	1	95.79	67.71	28.09
Belgium	−0.053	8.41	15	8	−7	94.84	78.66	16.18
Denmark	−0.251	8.36	29	11	−18	77.80	74.83	2.96
Finland	−0.223	7.97	25	23	−2	80.01	50.66	29.35
France	0.029	8.41	6	9	3	102.94	78.66	24.28
Germany	−0.015	8.26	18	14	−4	90.03	67.71	22.33
Greece	−0.298	7.69	35	30	−5	74.23	38.29	35.94
Ireland	−0.261	7.69	30	21	−9	77.03	38.29	38.74
Italy	0.089	8.12	4	19	15	109.31	58.86	50.45
Holland	−0.077	8.31	16	12	−4	92.59	71.18	21.41
Norway	−0.249	8.50	28	5	−23	77.96	86.07	−8.11
Portugal	−0.020	7.59	12	34	22	98.02	34.65	63.37
Spain	−0.017	8.41	11	7	−4	98.31	78.66	19.65
Sweden	−0.093	8.31	17	13	−4	91.12	71.18	19.94
Switzerland	−0.136	8.17	20	18	−2	87.28	61.88	25.41
Turkey	−0.287	7.35	33	43	10	75.05	27.25	47.80
U.K.	−0.039	8.31	13	4	−9	96.18	71.18	25.00
Canada	−0.013	8.69	10	2	−8	98.71	104.08	−5.37
Costa Rica	−0.307	7.69	36	27	−9	73.57	38.29	35.28
Dom. Rep.	−0.430	7.11	41	50	9	65.05	21.44	43.61
El Salvador	−0.586	7.25	48	46	−2	55.65	24.66	31.00
Guatemala	−0.192	7.49	24	38	14	82.53	31.35	51.18
Haiti	−1.306	6.48	73	70	−3	27.09	11.42	15.67
Honduras	−0.801	6.58	58	64	6	44.89	12.62	32.27
Jamaica	−0.891	6.87	60	59	−1	41.02	16.86	24.16
Mexico	0.134	7.93	3	24	21	114.34	48.68	65.66
Nicaragua	−0.814	7.45	59	39	−20	44.31	30.12	14.19
Panama	−0.770	7.40	57	42	−15	46.30	28.65	17.65
Trinidad	−0.182	8.17	23	16	−7	83.36	61.88	21.48
U.S.A.	0.000	8.65	9	3	−6	100.00	100.00	00.00
Argentina	−0.315	7.30	37	45	8	72.98	25.92	47.05
Bolivia	−0.757	6.87	56	57	1	46.91	16.86	30.04
Brazil	0.002	7.78	8	26	18	100.20	41.90	58.31
Chile	−0.651	7.16	51	49	−2	52.15	22.54	29.62
Colombia	−0.223	7.40	26	40	14	80.01	28.65	51.36
Ecuador	−0.685	7.21	53	48	−5	50.41	23.69	26.72
Paraguay	−0.614	7.54	49	36	−13	54.12	32.96	21.16
Peru	−0.571	7.54	46	35	−11	56.50	32.96	23.54
Uruguay	−0.363	7.69	39	32	−7	69.56	38.29	31.27
Venezuela	−0.136	8.02	21	22	1	87.28	53.26	34.03
Australia	−0.108	8.12	19	20	1	89.76	58.86	30.90
New Zealand	−0.282	8.12	32	21	−11	75.43	58.86	16.57
P. N. Guinea	−1.071	6.92	66	56	−10	34.27	17.73	16.54

Note: The Hall and Jones index are taken from Hall and Jones (1996), and the Islam index is from Islam (1995).

TABLE A4

HISTOGRAM ON THE BASIS OF HALL AND JONES INDEX

(10–20)%	(20–30)%	(30–40)%	(40–50)%	(50–60)%	(60–70)%	(70–80)%	(80–90)%	(90–100)%	100%+
ETH (10.4)									
MWI (13.0)									
BUR (13.8)									
TZA (14.6)						DZA (72.0)			
TCD (15.1)	SOM (20.9)			ECU (50.4)		ARG (73.0)			
BDI (15.1)	GHA (2.5)	BEN (31.0)		THA (51.3)		CRI (73.6)			
AGO (15.4)	MOZ (22.3)	SEN (31.6)		CHL (52.1)		GRC (74.2)		DEU (90.0)	USA (100.0)
ZAR (15.4)	MRT (22.5)	SDN (32.8)		PAK (52.7)		JPN (74.4)	FIN (80.0)	SWE (91.1)	BRA (100.2)
NER (16.0)	KEN (23.7)	SLE (33.4)	JAM (41.0)	PRY (54.1)		TUR (75.1)	COL (80.0)	NLD (92.6)	SGP (102.7)
MDG (16.2)	RWA (24.2)	PNG (34.3)	NIC (44.3)	SLV (55.7)		NZL (75.4)	GTM (82.5)	BEL (94.8)	FRA (102.9)
UGA (16.2)	NPL (24.4)	CMR (34.3)	HND (44.9)	MYS (56.0)		TUN (76.2)	TTO (83.4)	AUT (95.8)	HKG (109.0)
CAR (17.2)	NGA (24.6)	IND (34.4)	PAN (46.3)	PER (56.5)	ZAF (64.5)	IRL (77.0)	ISR (84.0)	GBR (96.2)	ITA (109.3)
ZMB (19.2)	HTI (27.1)	BWA (37.1)	BOL (46.9)	MAR (57.6)	DOM (65.1)	DNK (77.8)	CHE (87.3)	PRT (98.0)	MEX (114.3)
MLI (19.4)	LBR (27.3)	CIV (37.8)	LKA (48.0)	BDG (58.0)	KOR (66.4)	NOR (78.0)	VEN (87.3)	ESP (98.3)	JOR (118.1)
TGO (19.9)	ZWE (27.5)	PHL (38.9)	COG (48.1)	EGY (59.5)	URY (69.6)	MUS (79.8)	AUS (89.8)	CAN (98.7)	SYR (125.6)

Note: The codes are World Bank abbreviations of the country names. The numbers in the parentheses are the relative TFP levels, according to Hall and Jones (1996) index, of the respective countries for 1988 with the TFP level of the U.S. as 100.

TABLE A5

HISTOGRAM ON THE BASIS OF ISLAM INDEX

(10–20)%	(20–30)%	(30–40)%	(40–50)%	(50–60)%	(60–70)%	(70–80)%	(80–90)%	(90–100)%	100%+
SOM (3.6)									
TCD (4.2)									
ZMB (4.2)									
TZA (4.4)	UGA (10.4)								
ZAR (4.4)	ZWE (10.4)								
MRT (4.6)	SEN (11.0)								
GHA (5.3)	HTI (11.4)								
CAR (5.6)	COG (12.0)								
MLI (5.6)	MOZ (12.0)								
LBR (5.8)	NPL (12.0)								
MWI (5.8)	HND (12.6)								
SDN (6.1)	AGO (13.3)	BWA (20.4)	NIC (30.1)						
BDI (6.5)	BDG (13.3)	DOM (21.4)	MAR (31.3)						
RWA (6.5)	EGY (15.3)	CIV (37.8)	GTM (31.4)						
BEN (7.1)	LKA (15.3)	CHL (22.3)	PRY (33.0)						
KEN (7.1)	CMR (16.0)	ECU (23.7)	PER (33.0)						
TGO (7.1)	CIV (16.9)	THA (24.7)	PRT (34.6)				NLD (71.2)		
IND (7.1)	JAM (16.9)	SLV (24.7)	ZAF (38.3)				SWE (71.2)		
SLE (7.4)	BOL (16.9)	JOR (25.9)	KOR (38.3)				GBR (71.2)		
ETH (7.8)	PNG (17.7)	ARG (25.9)	MYS (38.3)		FIN (50.7)	ISR (6.19)	DNK (74.8)		
NER (7.8)	DZA (18.6)	TUN (27.3)	GRC (38.3)		VEN (53.3)	CHE (61.9)	PJN (78.7)		
MDG (8.6)	MUS (18.6)	TUR (27.3)	IRL (38.3)	BRA (41.9)	ITA (58.9)	TTO (61.9)	BEL (78.7)		USA (100.0)
BUR (8.6)	PHL (18.6)	PAN (28.7)	CRI (38.3)	SYR (46.3)	AUS (58.9)	AUT (67.7)	FRA (78.7)	SGP (86.1)	CAN (104.1)
NGA (9.0)	PAK (19.4)	COL (28.7)	URY (38.3)	MEX (48.7)	NZL (58.9)	DEU (67.7)	ESP (78.7)	NOR (86.1)	HKG (153.7)

Note: The codes are World Bank abbreviations of the country names. The numbers in the parentheses are the relative TFP levels, according to results of Islam (1995), of the respective countries for 1960–85 period with the TFP level of the U.S. as 100.

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