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Different Approaches to International Comparison of Total Factor Productivity

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11.1 Introduction

Neoclassical economic theory has generally emphasized difference across countries in factor endowments and has devoted less attention to the possibility and actuality of difference in productivity and technology. However, empirical researchers have noticed that countries persistently differ in terms of productivity too. 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 such researchers as Kendrick, Denison, Jorgenson, and others. However, because of data constraints mainly, the application of this methodology has until recently remained limited to small samples of developed countries. Yet, from the point of view of technological diffusion and TFP-convergence, the extent and evolution of TFP difference in wider samples of countries are of particular interest. This has given rise to two new approaches to international TFP comparison. These are: (1) the cross-section growth accounting approach suggested by Hall and Jones (1996), and (2) the panel regression approach presented in Islam (1995). In this paper, we provide a comparison of methodologies of these three approaches and of results that have been presented on their basis.

The time series growth accounting approach has been implemented in

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two forms, namely the *absolute form* and the *relative form.* The main limitation of the absolute form is that it can give TFP comparison only in terms of TFP growth rates and not in terms of TFP levels. The relative form of the time series approach overcomes this limitation. It produces TFP levels and growth rates for all years of a sample period. The more sophisticated form of time series approach, as of Jorgenson and his associates, distinguishes growth in both quality and quantity of inputs. This requires disaggregated data on different types of capital and labor and their compensation. It is difficult to find this type of data for wider samples of countries. Hence, it is likely that the application of the sophisticated version of the time series approach will remain limited to only the developed countries for some time to come.

Both the cross-section growth accounting approach and the panel regression approach 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 the parameters. It also allows factor share parameter to vary across countries. However, this approach requires prior ordering of countries and is sensitive to inclusion/exclusion of countries. It also 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 that sensitive to the inclusion/exclusion issue. However, it imposes homogeneity of the share parameter across countries and requires econometric estimation based on specified functional form.

The paper compares the 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 by Dougherty and Jorgenson (1997) and Wolff (1991) for the G-7 countries show that these agree more with regard to the *initial* TFP-level distribution of the countries than with regard to the *subsequent* TFP distribution. This implies that the two studies differ with regard of the TFP *growth* experienced by countries in the sample. These differences arise from the fact that Dougherty and Jorgenson (1997) and Wolff (1991) use different data and very different production functions for growth accounting, although both these works represent the relative form of the time-series growth accounting approach.

The comparison for 96 countries is between relative TFP level indices produced by Hall and Jones (1996) on the one hand and by Islam (1995) on the other. This comparison shows that there is more agreement with regard to the bottom end of the distribution than with regard to the top. 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 focus of measurement. While the Hall and Jones index was for relative productivity levels of 1988, the Islam index pertained 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 shape of distributions obtained from the Hall and Jones index and the Islam index helps to pose the question of TFP convergence. This question has already been investigated in the context of small samples of developed countries using time-series growth accounting approach. However, similar analysis is yet to be done for larger samples of countries. Also, before conclusions can be drawn regarding technological diffusion from results regarding the TFP, it is necessary to decompose the TFP into its various components. This is again something that has not yet been attempted for a large cross-section of countries. Both the cross-section growth accounting and the panel regression approach can prove fruitful in undertaking these tasks. In fact, with each year, the length of time series for all countries is getting longer. 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.

One such recent application has been to the East Asian countries. Young (1992, 1995) and Kim and Lau (1994) apply various forms of the time series growth accounting approach to the East Asian "tiger" economies and find that the TFP growth has very little or no role behind these economies' fast growth. However, subsequent results presented by Collins and Bosworth (1997), Klenow and Rodriguez-Clare (1997), and others show that the role of the TFP growth might not have been that minimal. The results obtained from applications of the cross-section regression methodology have also differed on this issue.

All this shows that there are considerable scope and necessity for further development of the international TFP study. All three approaches that we discuss in this paper can play important role in this regard. Results from one approach can provide useful checks on the results from the other. Moreover, the list of possible approaches is not exhausted by the above three. The *frontier approach* has also been used for international TFP comparison. This approach uses linear programming and has the additional capacity for distinguishing between improved efficiency in using existing technology and advance of the technology itself. However, this approach is also data intensive, and its application has remained limited to developed economies and specific sectors.

The paper is organized as follows. In section 11.2, we provide some broad perspective to the research on international TFP comparison. The methodologies of the three approaches to the TFP comparison are discussed and compared in section 11.3. In section 11.4 we compare the results obtained by use of these different approaches. The issue of decomposition of the TFP is discussed in section 11.5, and in section 11.6, we discuss the issue of TFP convergence. Section 11.7 discusses the controversy regarding the East Asian growth. Section 11.8 contains the concluding remarks.

11.2 Renewed Interest in the 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 the TFP are related to differences in technology, this indicates a certain departure from the standard neoclassical paradigm. One of the main distinctions between the Ricardian and the neoclassical trade theories concerns assumption regarding technology. While the Ricardian theory allows for long-term technology/productivity differences across countries, the neoclassical trade theory assumes that identical technology is available to all countries, and differences lie only in factor endowment.[1] Similarly, cross-country application of the neoclassical growth theory has generally proceeded on the basis of the assumption of identical production technologies. A central issue around which recent growth discussion has evolved is that of convergence, which is the hypothesis that poorer countries grow faster than richer countries so that the former eventually catch up with the latter. Convergence is an implication that has been ascribed to the neoclassical growth theory (NCGT) because of its property of diminishing returns to capital. However, along the way, the assumption of identical production technology has creeped in. This assumption, often not even recognized, has had considerable influence on the results presented in many prominent recent works on growth.

However, other researchers have not failed to notice that the assumption of identical technologies may not hold. 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 un-

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

> tenable. There is not 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 (1995b, 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 suggests 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, 365).

In the light of the above, interest in cross-country TFP-differences is a welcome development. Of course, the TFP-differences are not identical to technology-differences. There are other factors, besides differences in technology, which contribute to the 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 that may lead to convergence: (1) reaching similar levels of capital intensity, and (2) 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 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, the neoclassical growth theory assumes that technological progress is exogenous and is accessible to all and without any costs. As Solow (1994) explains, this was an abstraction, necessary at that early stage of development of the growth theory. Rise of the new growth theories has been, in part, a response to this abstraction, and this has now brought the issue of generation and diffusion of technology to the forefront of mainstream economics research. Needless to say, current interest in the TFP differences across countries is closely related with recent developments in the growth theory, and international TFP comparison can be an important complement to research on growth theory in general.

11.3 Different Approaches to the TFP Comparison

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

1. the time series growth accounting approach
2. the cross-section growth accounting approach
3. the panel regression approach

Not every international growth accounting work falls neatly under one or other of the above approaches. There is some overlap. Also, in addition to the above, there is the *frontier approach* to productivity analysis, represented by such works as Färe et al. (1994) and Nishimizu and Page (1982). This approach relies on linear programming and activity analysis and does not impose any parametric production function on the data. The approach can also distinguish between improved efficiency in using existing technology and advance of the technology itself. However, the frontier approach is data intensive, and its application has been limited to developed countries and often to particular sectors of the economy. In this paper, we therefore limit the comparison to the three approaches listed above and leave the extension of the comparison to other approaches to future efforts. We begin by looking briefly at the methodologies of these approaches.

11.3.1 Time Series Approach to International TFP Comparison

By the time series approach to international TFP comparison, we refer to that growth accounting tradition in which the time series of individual countries are analyzed separately, that is, on a country-by-country basis. This, in turn, has taken two forms, namely the *absolute form* and the *relative form.* In the absolute form, the 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, which are then compared and analyzed. Implementation of the absolute form, therefore, does not require time series data of different countries to be brought to a common denominator. However, by the same token, the absolute form of time series approach can not give comparison of the TFP levels. Instead, the comparison has to be limited to that of the TFP growth rates. The relative form of the time-series approach overcomes this limitation. In this form, data for different countries are brought 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 the TFP growth rates within each country but also the relative TFP levels of these countries.

Time Series Approach in the Absolute Form

So far as the absolute form of the time series approach is concerned, international TFP comparison is as old as the study of the TFP itself.

The latter goes back to Tinbergen (1959) who extends Douglas's idea of production function to include a time trend representing the level of efficiency. Tinbergen uses this framework to conduct a comparison of TFP growth in France, Germany, the United Kingdom, and the United States for the period of 1870–1910. Solow's (1957) seminal article "Technical Change and Aggregate Production Function" puts growth accounting on firm theoretical foundations and allows (unlike in Tinbergen) the rate of TFP growth to vary from year to year. Initial research that follows Solow's paper focuses on growth accounting for the United States. However, from the confinement of a single country, growth accounting soon spread to samples of countries. Denison (1967) presents a comparison of TFP growth rates among Belgium, Denmark, France, Germany, Italy, the Netherlands, Norway, the United Kingdom, and the United States. Other works of this tradition include Barger (1969), Bergson (1975), Domar et al. (1964), and Kuznets (1971). The sample size of these studies was limited to nine, seven, five, and five, respectively, and all countries included in the samples were the Organization for Economic Cooperation and Development (OECD) members.

Jorgenson raises the TFP computation to a great level of sophistication. He and his associates introduce the use of Divisia and translog indices to growth accounting, integrate income accounting with wealth accounting, and connect growth accounting with multisectoral general equilibrium analysis.[2] Having developed the methodology on the basis of the US data, Jorgenson and his associates proceed to use it for international TFP comparison. In Ezaki and Jorgenson (1973), the methodology is used to analyze economic growth of Japan. In Christensen, Cummings, and Jorgenson (1980), the analysis is extended to a sample of nine countries that includes the United States and its eight major trading partners, namely Canada, France, Germany, Italy, Japan, Korea, the Netherlands, and the United Kingdom.

In its initial phase, growth accounting was mainly focused on the *proportions issue.* This concerns the question of how much of the output growth can be explained by the measured input growth and how much is left to be explained by the TFP growth. Interest in the proportions issue carried over to international TFP comparison as well. In all the studies mentioned above, researchers first show how countries compare with each other in terms of growth rate of output, input, and TFP. They then show how these countries compare among themselves in terms of proportion of output growth that is explained by input growth and by the TFP growth. Since the absolute form of the time series approach readily provides growth rates of input, output, and the TFP, this approach is adequate for investigating the proportions issue.

The studies following the absolute form of time-series growth account-

2. See Jorgenson (1995a) for a recent compilation of important papers on this topic.

ing approach were reviewed earlier by Nadiri (1970, 1972). He compiles results from a number of papers, some of which are TFP studies of single countries. Nadiri provides an insightful analysis of differences in TFP growth rates across countries and relates these to corresponding differences in the various input growth rates and other factors. Kravis (1976) presents a similar review. Christensen, Cummings, and Jorgenson (1980) also start their paper with a very useful survey of previous works that employ the absolute form of the time series growth accounting approach.

Time Series Approach in the Relative Form

Jorgenson and Nishimizu (1978) initiate the relative form of the time series approach to international TFP comparison. In this paper, the authors conduct a growth accounting exercise for the US and Japan by considering their data in the 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 the relative form, Jorgenson and his associates use the following translog production function:

$$
\begin{aligned}
(1)\quad Y = \exp\Big[& \alpha_0 + \alpha_K \ln K + \alpha_L \ln L + + \alpha_T T + \sum \alpha_C \mathrm{D}_\mathrm{C} \\
& + \frac{1}{2}\beta_{KK}(\ln K)^2 + \beta_{KL}\ln K \ln L + \beta_{KT} T \ln K + \sum \beta_{KC}\mathrm{D}_\mathrm{C} \ln K \\
& + \frac{1}{2}\beta_{LL}(\ln L)^2 + \beta_{LT} T \ln L + \sum \beta_{LC}\mathrm{D}_\mathrm{C} \ln L + \frac{1}{2}\beta_{TT} T^2 \\
& + \frac{1}{2}\sum \beta_{TC} T \mathrm{D}_\mathrm{C} + \frac{1}{2}\sum \beta_{CC}\mathrm{D}_\mathrm{C}^2 \Big],
\end{aligned}
$$

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

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

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

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

where $\bar{v}_K = 1/2[v_K(T) + v_K(T - 1)]$, and similarly 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 the TFP level among the countries. Thus, the TFP difference between any country C and the United States 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:

$$\begin{aligned}(5) \qquad \hat{v}_C = {} & \ln Y(C) - \ln Y(\text{US}) - \hat{v}_K(C)[\ln K(C) - \ln \overline{K}] \\ & + \hat{v}_K(\text{US})[\ln K(US) - \ln \overline{K}] - \hat{v}_L(C)[\ln L(C) - \ln \overline{L}] \\ & + \hat{v}_L(\text{US})[\ln L(\text{US}) - \ln \overline{L}],\end{aligned}$$

where

$$\hat{v}_K(C) = \frac{1}{2}\left[v_K(C) + \frac{1}{2}\sum v_K\right], \qquad \hat{v}_L(C) = \frac{1}{2}\left[v_L(C) + \frac{1}{2}\sum v_L\right],$$

and $\ln \overline{K}$ and $\ln \overline{L}$ 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. The translog multilateral index of relative output is given by

$$\begin{aligned}(6) \qquad \ln Y(C) - \ln Y(\text{US}) = {} & \sum \hat{w}_i(C)[\ln Y_i(C) - \ln \overline{Y_i}] \\ & - \sum \hat{w}_i(\text{US})[\ln Y_i(\text{US}) - \ln \overline{Y_i}],\end{aligned}$$

where $\hat{w}_i$, the weight of the ith component in the value of the aggregate output, is given as

$$\hat{w}_i = \frac{1}{2}\left[w_i(C) + \frac{1}{n}\sum w_i\right],$$

and $i = 1 \ldots m$, with m being the dimension of disaggregation. The translog multilateral indexes of relative capital and labor inputs are defined in an analogous manner. This framework allows Christensen, Cummings, and Jorgenson (1981) to conduct TFP comparison in terms of not only the growth rates but also the levels, using the translog indices presented above. The authors use the PPP prices provided by Kravis, Heston, and Summers (1978) to relate time series data of different countries. These PPP prices were available only for 1970. To the extent that the indices computed by Christensen, Cummings, and Jorgenson are tied to the PPP prices of 1970, these indices are not base-year invariant though these are base-country invariant. The indexes of the relative TFP level presented in this study are for 1947–1973, and the coverage for the nine countries was complete from 1960 onwards. Dougherty and Jorgenson (1996, 1997) return to this body of work and present relative TFP level indices for the G-7 countries for the years of 1960–1989.

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

$$\text{(7)} \qquad \text{TFP}_i = \frac{Y_i}{[\alpha_i K_i + (1 - \alpha_i)L_i]},$$

where Y is output, L is labor measured by hours, and K is aggregate capital stock measured by nonresidential fixed plant and equipment. Wolff (1991) uses Maddison (1982) data which are already converted to the US dollar. This also allows him to take a long historical view. Wolff presents relative TFP indexes for the G-7 countries for the period 1870–1979 with intervals of roughly a decade. The set of TFP indices for the seven countries is complete from 1950 onwards. Dollar and Wolff (1994) concentrate on the manufacturing sector and present relative TFP indices for selected years between 1963 and 1985. Their sample consists of fourteen developed countries, and they use two different databases for their computation.[3]

Time series growth accounting generally requires data over long time periods. 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 compensation. This kind of data is available only for a small number of developed countries. Because of these data requirements, the time series growth accounting approach to international TFP comparison has generally remained limited to the G-7 or the OECD member countries. Yet, with regard to the TFP-convergence and technology diffusion, the experience of wider samples of countries is of particular interest. In such global samples, differences in technology and productivity are greater. The knowledge of what is happening to relative levels of labor and total factor productivity in such wider samples of countries should be useful for further development of the growth theory. From this point of view, the cross-section and the panel approaches to the TFP comparison are helpful, because both these approaches can be applied to large samples of countries.

3. The sample includes Australia, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, the United Kingdom, and the United States. Two databases used are the Dollar-Wolff database and the OECD database.

11.3.2 Cross-section Approach to International TFP Comparison

Cross-section Growth Regressions

While Denison, Jorgenson, and others were perfecting the time-series growth accounting approach in the 1960s, a cross-section approach to growth analysis also emerged. Chenery and his associates played an important role in developing this line of research. These economists were also interested in the proportions issue. In their case, however, the focus is on the proportion of growth that is explained by the neoclassical variables (namely, labor and capital) and the proportion that can be attributed to, what is called, the *structural sources* of growth. The concept of structural sources of growth arose from the observation that many assumptions of the neoclassical growth theory do not hold in developing economies. It was argued that basic, structural departures of developing economies from the neoclassical description create the scope for other, structural sources of growth. (We shall see in section 11.5 that the idea of 'non-neoclassical' sources of growth is not unique with the development economists.) This idea was further developed to formulate the notion of *patterns of development.* Investigation of the proportion issue also became a quest for finding development patterns. In either case, it was required to have long historical data, which unfortunately were not available for developing countries. Note that we are referring to the sixties when many of these countries had just become independent. This prompted development economists to turn to cross-section data in order to compensate for the paucity of time series data. A wide body of literature developed as a result of this line of work, a summary of which can be found in Chenery, Robinson, Sirquin (1985).

The methodology that these development economists pursue is to run cross-section regression with growth rate as the dependent variable and a variety of explanatory variables on the right hand side. Among the latter are the standard neoclassical variables such as the saving and the labor force growth rates. In addition, development economists included variables representing structural sources of growth.[4] Although residuals from these regressions had potentiality with regard to TFP comparison across countries, this was generally not done because the focus was on the proportions-issue.[5]

Cross-section Growth Accounting

The cross-section growth accounting approach to the TFP level comparison has been suggested recently by Hall and Jones (1996, 1997). Their

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

5. As we shall see, growth researchers currently are indeed using residuals from growth regressions to make inferences about productivity.

approach is not based on cross-section regression. Instead, the methodology is similar to the time-series growth accounting approach but now applied along the cross-section dimension. The authors 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 the Hicks-neutral productivity, and i is the country index. H is related to L through the relationship

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

where $e^{\phi(S_i)}$ shows the extent by which the efficiency of raw labor gets multiplied because of S years of schooling. Proceeding from equation (8), Hall and Jones arrive, following Solow (1957), 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 differencing proceeds in the direction of time t, Hall and Jones propose to apply the procedure in the cross-sectional direction, that is, in the direction of the subscript i.

This, however, poses a problem. In the usual case of time series growth accounting, there is no ambiguity regarding the direction in which t moves. In the cross-sectional case, however, it depends on the particular way countries are ordered. Hall and Jones order countries on the basis of an index which 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, that is allowed to vary across countries. However, in order to get country specific α, the authors make the assumption that the 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, that is, $\bar{\alpha}_i = 0.5(\alpha_i + \alpha_{i-1})$. 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 zero to four, four to eight, and eight and more years of schooling. These values are taken mainly from studies by Psacharopoulos (1994) for different regions of the world.

With this arrangement and parameter values, Hall and Jones compute the TFP-level indexes for different countries by summing up the TFP differences over relevant ranges of ordering using the equation

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

where A_1 is the TFP value for the base country and is normalized to some arbitrary value. The authors implement this procedure for a very large sample of 133 countries. These TFP indexes are presented in their table 9, and we reproduce them later, in table 11.3.

There are several advantages of the cross-section growth accounting approach. First is that it does not involve imposition of a specific form on the aggregate production function. As the authors emphasize, what is required to arrive at the growth accounting equation (10) is constant returns to scale and differentiability. Second, it allows the factor income share parameters to be different across countries. Third, the approach does not require econometric estimation and hence can avoid the problems associated with such estimation.

However, the cross-section growth accounting approach has some weaknesses too. First, it requires prior ordering of the countries, and the indices may be sensitive to the ordering chosen. Second, equation (11) shows that this index is sensitive to inclusion/exclusion of countries. Third, computation of the country specific values of the factor share parameter is done on the basis of the assumption of a uniform rate of return across countries. Empirical studies however suggest that the hypothesis of uncovered interest rate parity (UIP) does not hold in reality. This contradicts the assumption of a uniform rate of return. 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 differences in growth accounting, in reality it is not always an unmixed blessing. Construction of capital stock data through 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 across countries have often been found to be unreliable and do not take any note of differences in quality of schooling. Also, estimates regarding returns to schooling for one region may not hold for other regions. Thus, in trying to use capital stock data and to take account of human capital differences in cross-country TFP comparison, it is possible to pick up considerable noise as well as signal. It is difficult to be sure about which of these two predominates. Despite these weaknesses, the cross-section growth accounting approach and the results produced on its basis is a novel addition to the body of knowledge on TFP differences across countries.

In a later paper, Hall and Jones (1999) modify many aspects of their cross-section growth accounting methodology. In particular, they discard the attempt to allow country-specific values of the capital share parameter, α. Instead, they now assume a common value of α and set it to be equal to 1/3. They also now assume the productivity parameter A to be Harrod-neutral instead of being Hicks-neutral. These modifications bring their cross-section methodology closer to the methodology of the panel approach that we discuss next. It appears that the modifications also lead to considerable changes in the results regarding the productivity indexes, and these results now agree more with the results obtained from the panel approach. Unfortunately, Hall and Jones (1999) do not provide the results for the full sample. The comparison in this paper is therefore based on the results presented in their earlier papers.

11.3.3 The Panel Regression Approach to International TFP Comparison

The panel approach to international TFP comparison arose directly from recent attempts to explain the 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, and L is labor that grows at an exponential rate n, and A is the labor augmenting technology also growing at an exponential rate g, one can derive the following equation for the steady state output per unit of labor[6]:

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

where s is the fraction of output invested, δ is the rate of depreciation, and t is the length of time required by the economy to reach its steady state starting from the initial period. In the recent growth literature, this equation has been called the *level equation* because the variable on the left-hand side of this equation is in the level form. Many researchers have used this level equation to investigate the determinants of growth.[7] 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, the relative TFP level of any two countries, say i and j, remains unchanged and is equal to the ratio of their initial TFP levels, as we can see below:

$$(13)\quad \frac{A_{it}}{A_{jt}} = \frac{A_{0j}e^{gt}}{A_{0j}e^{gt}} = \frac{A_{0i}}{A_{0j}}.$$

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 variables that can effectively proxy for A_0. It is for this reason that many researchers wanted to ignore the presence of the A_0 term in equation (12) by relegating it to the disturbance term of the

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

7. 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.

regression equation. This however creates an omitted variable bias problem for the regression results. The panel approach helps to overcome this problem, because under this approach it is possible to control for A_0 indirectly 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 a questionable assumption. However, a corresponding equation can be derived that can accommodate the transitional behavior. This is given by equation (14):

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

In this equation t_1 and t_2 are initial and subsequent points of time, respectively; y is the output per unit of labor, and $\lambda = (n + g + \delta)(1 - \alpha)$ and is known as the rate of convergence, because it measures the speed at which the economy closes the gap between its current and steady state levels of output per unit of labor. As we can see, the term A_0 appears in this equation too, and ignoring it causes the same omitted variable bias problem for this equation, as was the case with the level equation considered earlier. Again, panel data procedures can be applied to overcome this problem by indirectly controlling for variations in A_0. It is then also possible to obtain estimates of A_0.

Islam (1995) implements the panel data approach using both Chamberlain's (1982, 1984) minimum distance estimator (based on the correlated effects model) and the covariance estimator (based on the fixed effects model). The estimated values of A_0 obtained from the procedure provide information to construct indices of relative productivity indexes. The sample consists of 96 countries, which figure in most of the recent empirical studies of growth. These estimates of the relative TFP levels are reproduced later in table 11.3.

Compared with the cross-section growth accounting approach, the panel regression approach has certain advantages. First, it does not require any prior ordering of the countries. Second, the method is less sensitive to inclusion/exclusion of countries. Third, the approach is flexible with regard to use of either the investment rate or the capital stock data and with regard to inclusion of human capital. The fourth advantage is that the results from econometric estimation that this approach relies upon can provide, to an extent, a check on the severity of noise in the data.

However, the approach has some weaknesses too. First, it has to start with a specified form of the aggregate production function. Second, in its applications so far, the approach relies on the homogeneity assumption regarding the factor share parameters. Third, to the extent that the approach relies on econometric estimation, it is subject to the usual pitfalls of such estimation work. One such problem is the potential small sample bias. The theoretical properties of most of the panel estimators are asymptotic in nature and hence are subject to potential small sample bias. It is therefore necessary to be on guard regarding this bias.[8] Another potential econometric problem is endogeneity. Note that equation (14) per se does not have this problem. The right hand-side variables of this equation, namely s_{t_1} and n_{t_1}, are one period into the past compared with the dependent variable y_{t_2}. While the current period's income and growth rate may influence future (and perhaps also current period's) investment and labor force growth rates, these cannot influence saving and fertility behavior of the past. In other words, the right-hand side variables are predetermined and hence cannot create endogeneity. However, a problem of endogeneity may arise via the estimation procedure. Some panel estimators that avoid the endogeneity problem suffer from significant small sample bias. However, through appropriate modification, it is possible to have panel estimator that avoid both small sample bias and the potential endogeneity problem.[9]

11.4 Comparison of Results from Different Approaches

It is clear from the above that there is a basic difference in scope of results obtained from the time series approach on the one hand and the cross-section and the panel regression approaches on the other. This makes comparison of the time series results with results from either the cross-section approach or the panel approach somewhat unsuitable. The paper therefore presents the comparison in two formats. In the first, we compare results for the G-7 countries as presented by Dougherty and Jorgenson (1997, henceforth DJ) and by Wolff (1991, henceforth WO). In the second, we compare the TFP results for a wider sample of ninety-six countries presented by Hall and Jones (1996) and Islam (1995).

11.4.1 Comparison of the TFP Results for the G7 Countries

Both the DJ and the WO indexes are product of application of the relative form of time series approach of growth accounting. However, as noted above, DJ and WO use different data and different production function for growth accounting. These differences show up in the results. Table 11.1 compiles the relative TFP-level indexes presented by DJ and WO in their

8. Islam (2000a) provides a Monte Carlo study of the small sample properties of many of the panel estimation procedures used for estimation of the growth convergence equation (14). The results show that the minimum distance procedure and the least squares with dummy variables (LSDV) procedure each have smaller bias than many of the other panel estimators.

9. Islam (2000b) presents a modified minimum distance estimation procedure that avoids the endogeneity problem in estimating the growth convergence equation.

Table 11.1 TFP Comparison for the G7 Countries

	DJ Index of Relative TFP, 1960 (1)	DJ Index of Relative TFP, 1970 (2)	DJ Index of Relative TFP, 1979 (3)	WO Index of Relative TFP, 1960 (4)	WO Index of Relative TFP, 1970 (5)	WO Index of Relative TFP, 1979 (6)
Canada	99.1	110.4	119.7	88.5	103.5	108.9
France	79.4	101.0	117.7	69.0	99.1	115.9
Germany	63.3	82.5	96.1	67.3	89.4	99.1
Italy	65.1	101.0	119.7	57.5	92.0	107.1
Japan	39.0	77.8	84.0	31.9	73.5	89.4
United Kingdom	80.4	94.3	106.0	75.2	92.9	101.8
United States	100.0	109.4	109.0	100.0	113.3	122.1

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

table A3 and table 1, respectively. Dougherty and Jorgenson (1997) benchmark their indexes to the U.S. TFP level of 1985 as 100, while WO uses the U.S. TFP level of 1950 as the base. In order to make these two sets of indexes more comparable, we shift them to a common base that takes the U.S. TFP level for 1960 as 100. Table 11.1 shows indexes for three particular years, namely 1960, 1970, and 1979. Clearly, these indexes contain both ordinal and cardinal information. Also, because the indexes for all countries and for all years are benchmarked to a single point, the cardinal information contained in these indexes is useful for comparison across both countries and years. It is therefore possible to look at the numbers of table 11.1 from many different angles and observe many different features.

To concentrate on just a few, we present table 11.2. In this table, the ordinal information contained in the indexes is summarized in the form of ranks, and the cardinal aspect of the information is used to get a measure of change in the TFP level over time by taking difference of the indexes. Thus figures in columns 1 and 2 of table 11.2 give the ranking of the countries in 1960 and 1979, respectively, on the basis of the DJ TFP indexes shown in columns 1 and 3 of table 11.1. Figures in column 3 of table 11.2 are obtained by taking the difference of the DJ indexes for 1979 and 1960 for individual countries. The numbers in column 4 of table 11.2 are ranks based on the differences shown in column (3). The numbers in columns 5–8 of table 11.2 are analogously derived based on the corresponding WO figures of table 11.1.

These transformations help us to see more clearly the similarities and dissimilarities in the results from these two studies. First of all, we see that there is a broad agreement with regard to the 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 the numbers of columns 1 and 5 of table 11.2), but also in cardinal term, as can be seen by comparing the numbers of columns 1 and 4 of table 11.1. The main difference seems to arise with regard to the change in the TFP level over time. The TFP ranking of the countries for 1979 produced by the DJ index varies considerably from the ranking produced by the WO index. A comparison of the numbers of columns 2 and 6 of table 11.2 illustrates this. The numbers of columns 3 and 7 of table 11.2 that show the increase of the respective TFP indexes between 1960 and 1979 also demonstrate this aspect of the results. The difference is particularly significant with regard to the United States and Italy. As column 3 of table 11.2 shows, according to the DJ index, Italy seems to have experienced the greatest TFP growth, outstripping Japan by a significant margin. The WO index also attests to Italy's exceptional TFP growth, but does not put Italy ahead of Japan in this respect. The TFP growth proves to be very modest for the United States, according to the DJ index, but not so modest according to the WO index.

This comparison shows that the TFP results may vary even when similar

Table 11.2 **TFP Ranking for the G7 Countries**

	Rank Based on DJ Index of Relative TFP, 1960 (1)	Rank Based on DJ Index of Relative TFP, 1979 (2)	Increase of DJ-TFP Index, 1960–79 (3)	Rank in Terms of Growth of DJ-TFP Index (4)	Rank Based on WO Index of Relative TFP, 1960 (5)	Rank Based on WO Index of Relative TFP, 1979 (6)	Increase of WO-TFP Index, 1960–79 (7)	Rank in Terms of Growth of WO-TFP Index (8)
Canada	2	1	20.6	6	2	3	20.4	7
France	4	3	38.3	3	4	2	46.9	3
Germany	6	6	32.8	4	5	6	31.9	4
Italy	5	1	54.6	1	6	4	50.0	2
Japan	7	7	45.0	2	7	7	57.5	1
United Kingdom	3	5	25.6	5	3	5	26.6	5
United States	1	4	9.0	7	1	1	22.1	6

Note: The ranks, differences of TFP index, and ranks based on differences all are computed on the basis of the numbers of table 11.1 of this paper.

approach is used. This is because the same approach can be implemented in different ways. To the extent that Dougherty and Jorgenson (1997) and Wolff (1991) were using very different production functions and different data, it is not surprising that the results differ. An interesting question is how much of the difference can be attributed to difference in the data and how much to the difference in the production function used. Answering this question will require further investigation.

11.4.2 Comparison of the TFP results for a Large Sample of Countries

As noted earlier, the Hall and Jones indexes are available for 133 countries. However, their sample includes former socialist countries for which it is not clear whether many of the neoclassical assumptions for growth accounting held true. Their sample also includes many countries for which extraction and export of oil is the dominant economic activity. Although the authors try to correct for this by discounting the GDP of these countries for oil revenues, some issues may still remain. In short, selection of countries may be an issue for Hall and Jones's (1996, hereafter HJ) exercise. This is important because the cross-section growth accounting results are very sensitive to inclusion of countries. In Islam (1995, hereafter IS), as mentioned earlier, the TFP indexes were produced for 96 countries. This is basically the same sample of countries that have widely figured in recent empirical growth studies.[10] In the following, we limit the comparison to this sample of countries.

In one sense, there is an important difference in what is being measured by the HJ and the IS indexes. The HJ indexes are of the relative TFP levels for the particular year of 1988. In contrast, the IS indexes pertain to the relative TFP levels for the entire period of 1960–85. Thus, while the HJ indices are, in a sense, end-of-period indicators of the relative TFP levels, the IS indices represent the relative TFP levels that are in a sense average for the 1960–85 period as a whole. In perusing the comparison below, this important difference must be kept in mind. We shall also try to relate this difference with the difference in observed results.

The basic TFP measures presented in HJ and IS have been compiled in columns 1 and 2 of table 11.3. In addition, the table contains some transformations of these basic measures. The comparison may again be conducted from both the ordinal and the cardinal points of view. Columns 3 and 4 show the ranking of the countries in terms of the HJ and the IS indexes, respectively. The differences in rank are given in column 6. For the cardinal comparison, we need to bring these indices to a common origin and scale. We do this by taking the U.S. TFP level as 100 and expressing the TFP levels of other countries as percentages of the U.S. level. These transformations can be seen in columns 6 and 7 of table 11.3.

10. The sample originates with Barro's (1991) pioneering work and continues through Mankiw, Romer, and Weil (1992) and many other subsequent studies.

Table 11.3 TFP Comparison in Large Sample of Countries

	HJ Estimate of Contribution of *A* (1)	IS Estimate of *A*(0) (2)	HJ Index Rank (3)	IS Index Rank (4)	Ordinal Difference[a] (5)	HJ-TFP Index (U.S./100) (6)	IS-TFP Index (U.S./100) (7)	Cardinal Difference[b] (8)
Africa								
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
Central African 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

(*continued*)

Table 11.3 (continued)

	HJ Estimate of Contribution of A (1)	IS Estimate of $A(0)$ (2)	HJ Index Rank (3)	IS Index Rank (4)	Ordinal Difference[a] (5)	HJ-TFP Index (U.S./100) (6)	IS-TFP Index (U.S./100) (7)	Cardinal Difference[b] (8)
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
South 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
Asia								
Bangladesh	−0.545	6.63	44	63	19	57.98	13.27	44.72
Burma	−1.982	6.20	94	75	−19	13.78	8.63	5.15
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
South 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
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
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
Europe								
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	−0.105	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
Netherlands	−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
United Kingdom	−0.039	8.31	13	4	−9	96.18	71.18	25.00
Americas								
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
Canada	−0.013	8.69	10	2	−8	98.71	104.08	−5.37
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

(*continued*)

Table 11.3 (continued)

	HJ Estimate of Contribution of A (1)	IS Estimate of $A(0)$ (2)	HJ Index Rank (3)	IS Index Rank (4)	Ordinal Difference[a] (5)	HJ-TFP Index (U.S./100) (6)	IS-TFP Index (U.S./100) (7)	Cardinal Difference[b] (8)
Costa Rica	−0.307	7.69	36	27	−9	73.57	38.29	35.28
Dominican Republic	−0.430	7.11	41	50	9	65.05	21.44	43.61
Ecuador	−0.685	7.21	53	48	−5	50.41	23.69	26.72
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
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
Trinidad	−0.182	8.17	23	16	−7	83.36	61.88	21.48
Uruguay	−0.363	7.69	39	32	−7	69.56	38.29	31.27
United States	0.000	8.65	9	3	−6	100.00	100.00	00.00
Venezuela	−0.136	8.02	21	22	1	87.28	53.26	34.03
Australia and Other Pacific Countries								
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
Papua New Guinea	−1.071	6.92	66	56	−10	34.27	17.73	16.54

Note: HJ indexes from Hall and Jones (1996); IS indexes from Islam (1995).

[a]HJ Index Rank minus IS Index Rank.

[b]HJ-TFP Index minus IS-TFP Index.

Looking at the numbers on rank, we see that countries that top the list according to the HJ index are Syria, Jordan, Italy, Mexico, and Hong Kong. The top five countries, according to the IS index, are Hong Kong, Canada, the United States, the United Kingdom, and Norway. At the bottom of the list, according to the HJ index, are Ethiopia, Malawi, Burma, Tanzania, and Chad. According to the 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 of the countries, such as Senegal, Tanzania, Togo, and Zimbabwe, ranks from the two indexes coincide exactly. For seven other countries, namely Nigeria, Singapore, Austria, Jamaica, Bolivia, Venezuela, and Australia, the ranks differ by only 1. Altogether, difference in rank remains within 5 for thirty-three countries. For another twenty-five countries, the difference lies between 6 and 10. Thus, for more than 60 percent of the countries, the difference in rank remains within 10. However, for thirty countries, the difference in rank ranges between 11 and 20, and for another seven, 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. Thus, for example, for Jordan, the difference in rank is as high as 42. For Syria, this difference is 24. Similarly large differences are obtained for Mexico, Japan, Mauritius, and Angola. One way of formalizing the closeness of various rankings is to compute the rank correlation. The Spearman rank correlation coefficient between the IS and the 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 the Kendall rank correlation coefficient.

A cardinal comparison leads to similar conclusions: There are more similarities at the bottom of the list than at the top. Thus, for example, the difference between the two indexes remains within 10 percentage points for Angola, Burundi, Ethiopia, Madagascar, Malawi, Myanmar (Burma), Niger, and Uganda. Very large differences, however, are obtained again for such countries as Syria, Jordan, Mexico, and Brazil. According to the HJ index, the TFP levels of these countries are 126, 118, 114, and 100.2 percent of the TFP level of the United States. The corresponding numbers according to the IS index are 46, 26, 49, and 42, respectively. 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 10 percentage points. For many countries in the middle, the difference is also moderate. Altogether, for 41 countries (i.e., about half the sample), this difference is less than 20 percentage points.

One way of capturing the picture regarding the relative TFP level across countries is to produce the entire distributions. Such distributions are presented in the form of histograms in tables 11.4 and 11.5. The abbreviated names of the countries and the respective indices are also displayed in

Table 11.4 **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 (21.5)	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 parentheses are the relative TFP levels (according to the Hall and Jones 1996 index of the respective countries for 1988, with the TFP level of the United States as 100).

Table 11.5 **Histogram on the Basis of Islam Index (percent)**

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)	UGA (10.4)								
MRT (4.6)	SEN (11.0)								
GHA (5.3)	HTI (11.4)								
CAR (5.6)	CO (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 (61.9)	DNK (74.8)		
NER (7.8)	DZA (18.6)	TUN (27.3)	GRC (38.3)		VEN (53.3)	CHE (61.9)	JPN (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 parentheses are the relative TFP levels (according to the results of Islam 1995), of the respective countries for the 1960–85 period, with the TFP level of the United States as 100.

these histograms. This allows us to see the ordinal and the cardinal positions of the individual countries *within* the respective distributions. We can now visually confirm the observations made earlier. These histograms also help us see 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 the distribution according to the HJ index.

In interpreting this difference, we first note that the two distributions come from very different methodologies and data. Second, as we have noted, while the HJ indexes can be thought as the end-of-period indexes of the TFP, the IS indexes can be regarded as the average TFP indexes for the period as a whole. Thus the IS indexes may be closer to the initial situation than are the HJ indexes. The fact that the HJ distribution is less bottom-heavy than the IS distribution may therefore indicate that over time more countries have benefited from the technological diffusion process and have been able to move away from their initial low levels of the TFP. More research is required before such a definitive conclusion can be made. However, the above shows how the TFP measures for a broad sample of countries can help us raise and analyze important issues of technological diffusion and convergence. It is to these issues that we now turn.

11.5 TFP Growth and Technological Change

It is widely recognized that the TFP growth may not be synonymous to technological change. Although neoclassical growth model serves as the framework for the TFP computation, and, according to this model, the TFP growth is generally attributed to technical change, the possibility of departures of the actual economy from the neoclassical assumptions has always been a source of concern. In particular, it has been felt that the neoclassical assumptions of perfect factor mobility and equality of marginal product and factor return across sectors are rather stringent. Similar has been the feeling toward the assumption of constant returns to scale in all sectors of the economy. Earlier we noticed how the development economists responded to these departures by proposing the structural sources of growth in addition to the neoclassical ones. However, development economists were not alone in this regard. Initial growth accounting efforts for the U.S. economy (such as Abramovitz 1956 and Solow 1957) showed that growth in labor and capital inputs explained very little of the output growth. The residual obtained was embarrassingly large. This led Denison not to equate the entire residual to technological progress. Instead he resorted to what Solow (1988) describes as the unpacking of the "technological progress in the broadest sense" into the "technological progress in the narrow sense" and several other constituents. Among the latter are, for example, "improved allocation of resources" (which refers to movement of labor from low-productivity agriculture to high-productivity industry) and "economies of scale." According to Denison's (1985) computation, 11 percent of the total U.S. growth (between 1929 and 1982) needs to be imputed to "reallocation," and another 11 percent to "economies of scale."

Jorgenson emphasizes that measured growth of the neoclassical inputs can explain more of output growth than is popularly believed. However, the issue of departure from neoclassical assumptions figures prominently in his works too. He deals extensively with conditions of aggregation and, in particular, shows that existence of the aggregate production function requires that the value-added function and the capital and labor input functions for each sector are identical to corresponding functions at the aggregate level. Identical sectoral production functions in turn imply identical input and output prices. Jorgenson computes input and output growth rates with and without allowing for these price differences and finds that the results differ, particularly for shorter periods. He interprets the resulting differences as 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 of time, contribution of reallocation of factors to growth is significant.

But what about the "unpacking of technological progress in the broadest sense" to "technological progress in the narrow sense" in the context of international TFP comparison? This remains yet to be thoroughly done. One work that addresses this issue is Maddison (1987). He works with a conventional (absolute form) time-series growth accounting approach, and his sample includes France, Germany, Holland, Japan, the United Kingdom, and the United States. Apart from the standard neoclassical sources of growth, namely labor and capital, Maddison considers a long list of other possible sources of growth. He refers to these as the "structural effect," the "foreign trade effect," the "economies of scale effect," the "energy effect," the "natural resource effect," the "regulation/crime" effect, and so on. He shows that allowing for these non-neoclassical sources of growth has important influence on international TFP comparison. The relative position of countries change depending on whether or not these non-neoclassical effects are taken into account in computation of the TFP growth. This is because countries differ with regard to the degree of departure from the neoclassical assumptions, and correspondingly with regard to the importance of the non-neoclassical sources of growth in their econ-

11. He explained, "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 1995a, 8).

omy. In his analysis, Maddison considers yet another effect, namely the catch-up effect. Consideration of this effect brings us to the issue of TFP convergence.

11.6 TFP Comparison and the Issue of Convergence

The TFP discussion of the 1960s, 1970s, and early 1980s was dominated by the proportions issue. The convergence issue was not prominent yet.[12] Although the time series studies of international TFP comparison of that period produced results that could be used for convergence analysis, this was generally not done. This is true of works of both the absolute and the relative forms of the time series approach.

The treatment of the catch-up effect in Maddison's (1987) growth accounting was novel. He first computes the convergence rates for individual countries on the basis of labor productivity (with the United States as the reference country), and then multiplies these rates by 0.2 to arrive at a "catch-up bonus" that he thinks the countries enjoyed vis-à-vis the leader (the United States). The factor of 0.2 was a speculation, and by "catch-up bonus" Maddison means the advantage that (technologically) follower countries enjoy vis-à-vis the technologically leading countries.[13] However, as is clear, Maddison's analysis is not a formal examination of the TFP convergence. Also, because Maddison is working with data in absolute form, dynamics of the TFP levels are not explicitly considered. By contrast, the TFP comparison in relative form, as presented by Christensen, Cummings, and Jorgenson (1981), is in fact an analysis of convergence though not couched in the terminology that is now being used. The extension of the time series growth accounting to formal analysis of convergence had to wait until the convergence issue became prominent.

12. For surveys of the recent convergence literature, see Durlauf and Quah (1998), Islam (1996), and Temple (1999).

13. It may be worthwhile to note Maddison's full argumentation for the catch-up bonus: "If the follower countries follow an appropriate policy mix and are not disturbed in the convergence process by war, they should be able to increase productivity at a faster pace than the lead country. They enjoy 'opportunities of backwardness,' which means that over a considerable range of technology, they can emulate the leader and get a given amount of growth with less expenditure on research and development. They can push the rate of capital formation per worker faster without running into diminishing returns, and structural change is rapid. Most of these effects enter into the accounts elsewhere, but when a country mount a successful process of catch up, they are in a 'virtuous circle' situation, which we have assumed will provide an extra efficiency bonus augmenting the yield of factor inputs and other growth components in a way that is not true of the lead country, which is nearer to a 'best practice' situation over a wide range of productive activity" (668–69). What is important in this explanation of the catch-up effect is his observation that "most of these effects enter into accounts elsewhere." Obviously, Maddison is referring to higher rates of capital formation, rapid structural change, etc. It is, however, interesting to delve further into what enters elsewhere and what remains for the catch-up effect to stand for.

We see such an extension in Wolff's work. His analysis, as noted earlier, is similar to that of Christensen, Cummings, and Jorgenson (1980, 1981) in many respects. However, Wolff (1991) proceeds to formalize the findings regarding the TFP convergence. First, he uses several descriptive measures, such as the coefficient of variation of the TFP levels and correlation of the TFP growth rates with the initial levels of TFP to draw conclusions about convergence. Judged by these criteria, Wolff finds significant evidence of TFP catch-up, particularly for the postwar period. Wolff also shows particular interest in possible interaction between the processes of capital deepening and technological diffusion. 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 United States) form, then presents evidence in terms of simple correlation between the TFP growth rate and the 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 initial difference in the TFP level (from that of the leading country, the United States), he regresses the TFP growth rate on the initial TFP level and capital intensity growth rate. A positive coefficient on the latter variable is taken to be indicative of a positive influence of capital accumulation on TFP catch-up that is over and above the influence that could be predicted simply on the basis of initial TFP level difference. In general, Wolff finds positive coefficients, though not always significant.

Reflecting current interests, Dougherty and Jorgenson (1997) also analyze their growth-accounting results from the viewpoint of the convergence issue. They compute coefficient of variation in per capita output, per capita input, and the TFP across the G7 countries and find that these coefficients have decreased over time for each of these variables. This reflects a process of convergence. Dougherty and Jorgenson extend this analysis to consider the dynamics of capital and labor inputs separately, and distinguish between quality and quantity of these inputs. At this disaggregated level it is found that convergence does not hold for labor, particularly for labor quantity (as measured by hours). However, convergence was true for capital, in terms of both quantity and quality. Dougherty and Jorgenson limit their convergence analysis to graphical treatment and do not run regressions.

Does the TFP convergence hold in wider samples of countries? Since the time series growth-accounting approach has not yet been applied to large sample of countries, this question has not yet been addressed using this approach. But, what about the cross-section growth-accounting or the panel regression approach, both of which work for large sample of countries? These two approaches are relatively new, and so far these have mainly produced TFP indexes for only one time period. Unless similar sets of TFP indexes are produced for several consecutive time periods, the issue of TFP convergence, and hence of technological diffusion, cannot be adequately addressed for large sample of countries.[14]

Dowrick and Nguyen (1989) use a cross-section regression approach to examine TFP convergence in a sample of fifteen OECD countries. Instead of going through a two-stage process, as in WO or DJ, Dowrick and Nguyen want to conduct growth accounting and TFP-convergence testing in the same regression. In doing so, however, they have to assume that the capital-output ratio is the same for all countries of the sample. This assumption allows them to interpret the coefficient on the initial income variable as evidence of TFP convergence. However, the assumption of equal capital-output ratios across countries is somewhat problematic; this is even more true in the context of large samples of countries. A short-cut, single, cross-section regression procedure therefore may not be suitable for TFP convergence analysis.

11.7 Controversy regarding TFP Growth in the East Asian Countries

With each passing year, longer time series are becoming available for developing countries, and this is making application of some versions of the time series growth-accounting procedure possible for these economies too. In fact it is application of this approach to the East Asian economies that has given rise to the recent exciting debate regarding sources of economic growth.[15] It starts with Yuan Tsao Lee's (1990) growth-accounting exercise for Singapore that revealed little evidence of TFP growth. However, Alwyn Young provides the more renowned results in this debate. Young (1992) finds practically no TFP growth for Singapore and less than spectacular TFP growth in Hong Kong. Young (1995) extends the analysis to South Korea and Taiwan and finds limited role of the TFP growth for these countries too. Young (1994) conducts a cross-section regression analysis of growth and uses the residuals to gauge the importance of the TFP growth. The conclusions are similar to those he reached on the basis of time series growth-accounting analysis in Young (1992, 1995). Jong-Il Kim and Lawrence Lau (1994) also reach similar conclusions. Their work is in the tradition of Christensen, Cummings, and Jorgenson (1981) and is an application of the relative form of the time series growth-accounting approach.

Response to the above results has varied. At one extreme are those who have accepted these results, championed them, and have provided various explanations and interpretations for them. Paul Krugman is the most fa-

14. See Islam (2000b) for a recent attempt to compute productivity dynamics in a large sample of countries.
15. For a survey of the East Asian TFP debate, see Felipe (1999).

mous name in this regard. Krugman has popularized these conclusions through his influential articles in *Foreign Affairs* (1994) and other periodicals. This has now created a major stir in circles beyond those of economists. In the literature this has been referred to as the "accumulation" view. According to this view, East Asian growth has been mainly due to (factor) accumulation.

However, not everybody agrees with the accumulation view. To begin with, many researchers are reluctant to use the aggregate production function to separate the role of technological progress from that of factor accumulation. There are many sources of this reluctance. One of these goes back to the interaction issue that is emphasized by Moses Abramovitz, Paul David, Richard Nelson, and others (see, e.g., Abramovitz 1956 and 1993, Abramovitz and David 1973, and Nelson 1973, 1981). Proceeding from this issue, Nelson argues for an evolutionary theory of technological progress that emphasizes industry- or firm-level analysis. In studying the East Asian growth, many researchers of this tradition and others have emphasized the role of assimilation of new technology, giving rise to the "assimilation" view of the East Asian growth.[16] However, the assimilation view may not be always in a clear contradiction with the accumulation view because adoption of new technology can occur without accompanying TFP growth. This will happen if the new technology is excessively costly or not efficiently utilized (or both), a point that Krugman (1994) notes.

Since the appearance of the accumulation view, several researchers have published works showing that the role of TFP growth in East Asian economies has not been as small as claimed by accumulationists; this may be called the "revisionist" view. Among works of this view are Collins and Bosworth (1997), Klenow and Rodriguez (1997), and Marti (1996). Both Collins and Bosworth (1997) and Klenow and Rodriguez (1997) use the time series growth-accounting procedure. According to Collins and Bosworth, the TFP growth for Singapore averages to 1.5 percent per year and accounts for 27.8 percent of the output growth for 1960–1994. For more recent periods, the role of the TFP growth is found to be more pronounced. Between 1984 and 1994, according to these authors, the TFP growth averages to 3.1 percent per year and accounts for 51.7 percent of Singapore's output growth. Similarly, Klenow and Rodriguez find that for the 1960–1985 period, the TFP growth in Singapore averages to 3.3 percent per year and accounts for 64.4 percent of that country's output growth. Marti (1996) presents a cross-section growth regression similar to that of Young (1994), but estimated using a more recent version of the

16. Among works representing this view are Dahlman and Westphal (1981), Dahlman, Larson, and Westphal (1987), Hobday (1994a,b), Nelson and Pack (1996), Pack and Page (1994), and Page (1994).

Summers-Heston data set. The results prove to be very different. The TFP growth rate for Singapore proves to be 1.49 percent during 1970–1985 compared to 0.1 percent obtained by Young (1994).

The views expressed in these revisionist papers agree in spirit with the TFP results of Hall and Jones and Islam reviewed earlier. According to Hall and Jones, the TFP indexes for Singapore and Hong Kong in 1988 are 103 and 109 percent of the U.S. level, respectively (see tables 11.3 and 11.4.) It is difficult for these economies to attain such high relative TFP levels in 1988 unless they have experienced significant TFP growth during the past years. According to the Islam index, the TFP levels of Singapore and Hong Kong for 1960–1985 are 86.1 and 153.7 percent of the U.S. level, respectively (see tables 11.3 and 11.5). The Islam results agree with one aspect of Young's results, which show that Singapore's TFP performance is significantly worse than that of Hong Kong.[17] However, according to the Islam index, Singapore's relative TFP level is among the top five economies of the world.

The dispute regarding sources of the East Asian growth is yet to be settled. There is clearly some scope of agreement between the assimilation and the revisionist views. The latter concedes an important role to the TFP growth but does not generally inquire into the precise mechanism through which the TFP growth is achieved. The insights obtained from microanalysis are certainly valuable in that regard and can play an important complementary role in our overall understanding of the nature and sources of the East Asian growth.[18]

11.8 Concluding Remarks

This paper compares the methodologies and results of several approaches to the international comparison of TFP. The comparison of results reveals both similarities and dissimilarities. While similarities are heartening, dissimilarities should not prove discouraging. The results compared here were obtained not only from different methodologies but also from different data, different sample, and different time periods. The TFP, by definition, is a complicated social phenomenon. It would rather be surprising if different approaches came out with too similar results. The important thing is to understand why the results differ. This paper tried to enhance this understanding.

In fact, the dissimilarities in results can be a stimulus for further research. In general, the current interest in international TFP comparison is a welcome development. To a certain extent this signifies a departure from

17. The same may be said of Hall and Jones results. In their case, however, the difference between TFP levels of Singapore and Hong Kong is not that notable.

18. Wade (1990) presents a very valuable work of this nature.

the erroneous assumption that all countries have identical technologies and differ only in factor proportion. As Lucas (1990) shows, it is difficult to explain international capital flows without recognizing significant productivity differences across countries. Prescott (1998) notes that savings rate differences are not that important—what is all-important is the TFP. Hence he concludes that, " . . . a theory of TFP is needed" (p. 1).

The first step in the development of a theory of TFP has to be better computation and understanding of the TFP differences across countries. The recent extension of the TFP comparison to large samples of countries is a positive development. It is now necessary to go beyond a *static* comparison of levels to an examination of productivity *dynamics* in these large samples. The observed large productivity differences also bring to fore the importance of technological and institutional diffusion, which is now recognized as an important source of convergence. From a policy perspective, it is therefore extremely valuable to know the factors that can accelerate the diffusion process. Study of the TFP dynamics provides the necessary point of departure for the study of technological and institutional diffusion. All the three approaches reviewed in this paper can play important roles in this study.

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Comment Charles I. Jones

This paper provides a nice discussion of the literature on productivity comparisons. My comments on the paper are divided into three parts. I begin narrowly, presenting a closer look at the Islam (1995) and Hall and Jones (1996, 1999) productivity calculations. Next, I try to summarize what I take to be the most important empirical finding of these productiv-

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ity comparisons. Finally, I end by speculating on the reasons for differences in productivity across countries.

First, let me present some narrow remarks on the productivity levels that Islam compares. The Islam productivity levels are computed from a regression with panel data from the fixed country effects. Islam (1995) assumes a Cobb-Douglas functional form for the production function and estimates the parameters of the production function econometrically. The key identifying assumptions in this approach are that the idiosyncratic changes in the productivity level over time are orthogonal to the included "exogenous" variables, including investment rates in physical and human capital.

The Hall and Jones (1996, 1999) productivity levels are calculated in two ways. The first approach, discussed in Islam's paper, is to apply the accounting methods of Solow (1957) across space instead of across time—one can interpret Solow's t as indexing countries instead of years. This approach does not require specifying a functional form for the production function. Rather, one assumes something like constant returns to scale and perfectly competitive factor markets. In addition, one must make assumptions about the ordering of countries (notice that time has a natural order but space does not). In the second approach, emphasized in the published version, Hall and Jones (1999) assumes a Cobb-Douglas functional form for production and obtain the parameter values from existing empirical work or "neoclassical" assumptions. For example, we assume an elasticity with respect to physical capital of one-third and a return to education that is 13.4 percent for the first four years, 10.1 percent for the next four years, and 6.8 percent for additional years beyond the eighth year of education. These returns come from the microestimates reviewed by Psacharopoulos (1994). While the Solow approach is preferable from an intellectual standpoint, it turns out not to produce very different estimates from the Cobb-Douglas approach, at least for reasonable parameter values.

So the difference between the Islam approach and the Hall and Jones approach is one of identifying assumptions. Islam, like Mankiw, Romer, and Weil (1992) before him, uses orthogonality conditions to estimate the shape of the production function. Hall and Jones use neoclassical assumptions about production to get the parameters. Clearly, the two approaches are complementary. We preferred not to use the econometric approach because it seems plausible to us that productivity levels, and changes in the level, are correlated with investment rates in physical and human capital. Indeed, under our assumptions, we show that the correlation between levels is quite strong. A drawback of our approach is that if there are large externalities to physical or human capital accumulation, the neoclassical assumptions will be misleading.

The levels of productivity calculated in these two different ways are plotted in figure 11C.1.

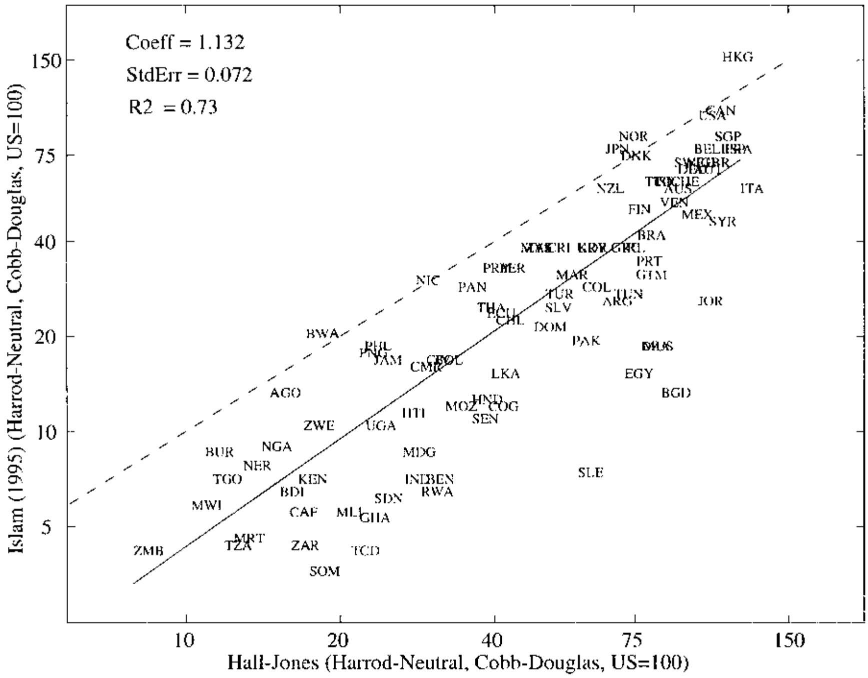

Fig. 11C.1 Productivity levels: Islam and Hall-Jones

Note: The solid line is a regression line; the dashed line is the 45-degree line.

The first thing one sees from this figure is that the productivity levels are fairly similar, at least to a first approximation. The correlation between the two series is 0.85. Of course, there are also some sharp differences for individual countries. The second thing one notices is that the regression line is different from the 45-degree line, mainly due to the intercept. That is, Islam's productivity levels are typically lower than the Hall and Jones productivity levels.

What accounts for the differences? One key difference comes from looking at the shape of the production function implied by Islam's econometric estimates. In particular, led by these estimates, Islam assigns a zero weight to human capital. His econometric specifications with human capital actually suggest a negative coefficient. The weight on physical capital, estimated imposing a zero coefficient on human capital, is about 0.44. To compare our results on a more equal footing, I recalculated the Hall and Jones productivity levels assuming these parameter values. The results are shown in figure 11C.2.

The differences in productivity across countries line up much better in terms of the actual levels, but there is still a fair amount of disagreement

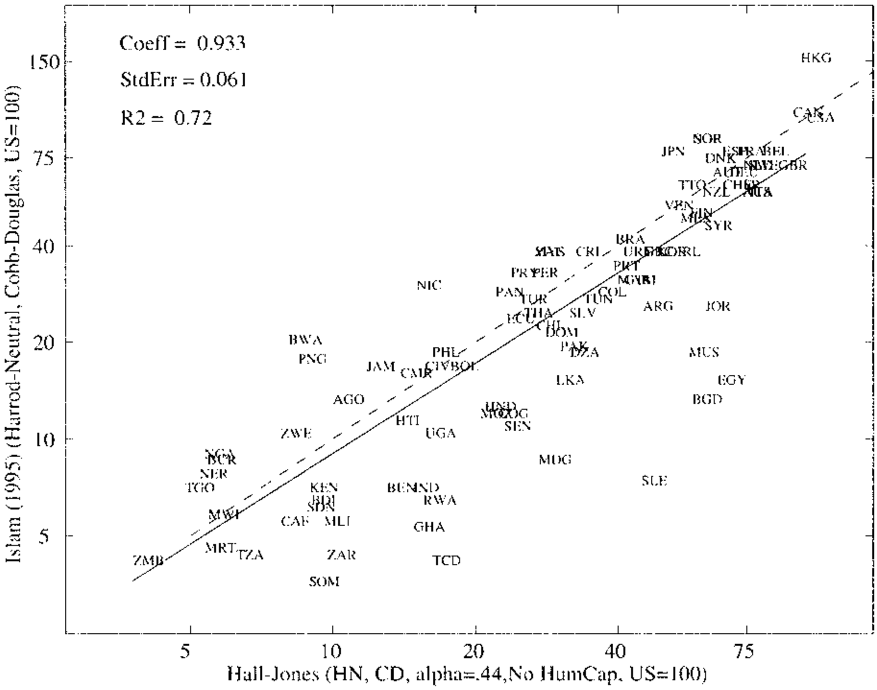

Fig. 11C.2 **Productivity levels: Islam and Hall-Jones with Islam's parameters**
Note: The solid line is a regression line; the dashed line is the 45-degree line.

for individual countries. This could reflect the fact that Islam's numbers correspond roughly to an average over the 1960 to 1985 period while the Hall and Jones numbers correspond to the year 1988. Or, there could be something else going on. Clearly, however, ignoring human capital is important—any differences in human capital that actually matter for production will show up in Islam's productivity level, largely explaining why he finds lower levels on average. My hunch is that differences in human capital across countries are probably an important contributing factor to differences in output, and that the negative econometric estimates on human capital that Islam and Benhabib and Spiegel (1994) and others find reflect primarily a problem with the econometric approach.

The second comment I would like to make is to provide a summary of what I think is the most important thing we learn from levels accounting. In a paper like this, it is natural to emphasize differences, such as differences in method. Nevertheless, by taking a step back, one can see that many different methods yield the same qualitative answer: Levels accounting finds a large residual.

To put this in perspective and explain how the finding arises, let me introduce some notation. Consider an aggregate production function of the form $Y = K^{\alpha}(AH)^{1-\alpha}$, where Y is output, K is physical capital, H is human capital, A is productivity (written as labor augmenting or Harrod-neutral), and $0 < \alpha < 1$. Assume that capital is simply foregone consumption, as usual, and assume that human capital per person arises from schooling: $h \equiv H/L = e^{\phi S}$, where $\phi > 0$ is the Mincerian return to schooling and S is years of schooling. In a framework like this, one can decompose output per worker, $y \equiv Y/L$ into the product of three terms:

$$y = \left(\frac{K}{Y}\right)^{\alpha/1-\alpha} hA.$$

That is, output per worker is the product of a capital intensity term, a human capital term, and a productivity term.

We can apply this equation across countries at a point in time to conduct a levels accounting exercise, assuming neoclassical values for α and ϕ, as discussed above. A useful summary of this accounting, taken from Hall and Jones (1999), is found by considering the ratios of the terms in the above equation for the five richest and five poorest countries. The ratio of output per worker in the five richest countries to the five poorest countries is a factor of 31.7. A relatively small portion of this difference is due to differences in capital intensity and human capital, factors of 1.8 and 2.2, respectively. Differences in productivity between these countries are far more important, contributing a factor of 8.3 to the difference in output per worker. (Notice that $31.7 \approx 1.8 \times 2.2 \times 8.3$.)

The intuition for this result is also fairly easy to see. In a standard neoclassical model, the capital-output ratio is proportional to the investment rate in steady state. Differences in investment rates between the rich countries and poor countries are fairly small; for this sample the average difference is about a factor of 3. With $\alpha = 1/3$, it is the square root of this difference that matters, which is why capital intensity accounts for only about a factor of 1.8. A similar calculation applies to human capital. The rich countries have about eight more years of schooling on average than the poor countries. With a return to education of about 10 percent per year, this can explain a difference of 0.8 in logs, and the exponential of 0.8 is about 2.2. Differences in investment rates and educational attainment are fairly small across countries, particularly when "multiplied" by neoclassical parameter values. Therefore, the residual (productivity) is left to explain the bulk of differences in output per worker across countries.

My third and final comment, then, concerns the economic factors that can explain the differences in these residuals across countries. I can think of three possible explanations. One explanation is other inputs that are not included in the analysis. For example, differences in the experience of the labor force, the quality of education, or the quality of capital (e.g., vintage effects) could explain the differences. Klenow and Rodriguez-Clare (1997) and Sinclair (1998) have looked into these explanations and find that differences in productivity are still substantial even after these effects are taken into account. Another explanation is that differences in productivity reflect true differences in technologies across countries. This seems plausible, but begs the question of why countries do not use the latest new ideas. The answer may be quite similar to the answer to the question of why some countries have so much lower capital intensity and educational attainment than others. A final possible explanation is differences in the utilization of resources. In part, this is simply a measurement story, but it could have deeper roots. For example, in a simple farmer and thief model, some of the farmer's education and labor effort could go to protecting his output rather than to producing output, and some capital could be used as fences rather than as tractors. Hall and I explore these explanations in greater detail.

According to the results of several approaches, differences in productivity levels across countries are substantial. If we are to understand why some countries are so much richer than others, then it seems likely that we will require an explanation for why some countries get so much more out of their inputs. To paraphrase the title of a recent paper by Prescott (1997), we will need a theory of productivity differences.

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