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New Estimates of Total Factor Productivity Growth for Developing and Industrial Countries

Vikram Nehru
Ashok Dhareshwar

An error correction model, using new data on human and physical capital stock, is used to estimate the growth of total factor productivity for 83 countries for 1960–87. The results show that human capital accumulation explains more cross-country variations in growth than previously thought. And cross-country differences in total factor productivity growth can be attributed mostly to differences in initial conditions and political stability.

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Summary findings

Nehru and Dhareshwar present new estimates of long-term total factor productivity (TFP) growth for 83 industrial and developing countries for 1960–87. These estimates are based on new data developed for the research project on total factor productivity growth (and available on diskette). Although based on the "old" growth theory, the estimates are derived from a cross-country production function using an error-correction model. This is more appropriate than the usual first-difference model for capturing long-term relations.

Nehru and Dhareshwar conclude the following:

- The estimated cross-country production function shows that human capital accumulation is far more important in explaining growth than several earlier studies have indicated. This conforms with recent studies that find raw labor's share in income to be much less than thought previously.
- Contrary to the results of other studies, TFP growth in high-income countries has been comparable to that in faster-growing low- and middle-income countries.
- The fastest growing developing economies have based their growth more on the rapidity with which they have accumulated physical and human capital than on high TFP growth.
- Cross-country differences in TFP growth are largely due to differences in the level of political stability and initial conditions (notably, initial per capita income and the initial level of human capital).
- Cross-country differences in TFP growth (once corrected for initial conditions and political stability) cannot be explained by structural and policy differences for which data are readily available (despite an exhaustive search for other explanations).
- Sub-Saharan Africa is the only region for which the actual TFP growth is significantly lower than the TFP growth predicted on the strength of initial conditions and political stability (by about 1.1 percentage points a year).

The cross-country profile of TFP growth and the role of initial conditions point toward the dual role played by human capital in the development process: as a standard factor of production to be accumulated and as a source of learning and entrepreneurship and hence of interesting growth dynamics. It may be necessary to rethink the concept of "TFP as the residual" in models with human capital.

And the relationship between policy variables and TFP growth is likely to be sensitive to the way human capital is incorporated in the production function. These substantive issues, along with a number of econometric refinements, are fruitful avenues for further research.

This paper — a product of the International Economics Department — is part of a departmental research project on total factor productivity growth and part of a broader Bank effort to understand how sources of economic growth in developing countries may be influenced by national policies and by global economic trends and events. The study was funded by the Bank's Research Support Budget under the research project, "The International Economic Environment and Productivity Growth in Industrial and Developing Countries" (RPO 676-67). Copies of this paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Moira Coleridge-Taylor, room S8-049, extension 33704 (36 pages). June 1994.

New Estimates of Total Factor Productivity Growth for Developing and Industrial Countries

Vikram Nehru and Ashok Dhareshwar

International Economics Department

This paper presents new estimates of long term total factor productivity growth for 83 industrial and developing countries at the economy-wide level for the period 1960-90. The research was undertaken as part of a broader effort by the World Bank to better understand the sources of economic growth in developing countries and how they may be influenced by national policies and economic trends and events in the global economy. The TFP growth estimates are "new" because they use data on physical and human capital that were prepared recently by the authors[1]. More important, although they are based on the "old" growth theory framework, they are derived from a cross-country production function using an error-correction model, which is more appropriate than the usual first-difference model for capturing long-term relations from the data, and which, to our knowledge, has not been used before for such a purpose.

The study reaches six conclusions. First, the estimated cross-country production function shows that human capital accumulation is far more important in explaining growth than several earlier studies have indicated. This is in conformity with some of the recent studies that find the share in income of raw labor to be much less than thought previously. Second, contrary to the results of other studies, TFP growth in high income countries has been comparable to the faster growing low- and middle-income economies. Third, and related to the above, the fastest growing developing economies have based their growth more on the rapidity with which they have accumulated physical and human capital than on high TFP growth. Fourth, cross-country differences in TFP growth are largely due to differences in the level of political stability and initial conditions (notably, initial per capita income and the initial level of human capital). Fifth, after an exhaustive search for other explanations, cross-country differences in TFP growth (once corrected for initial conditions and political stability) cannot be explained by structural and policy differences for which data are readily available. And sixth, Sub-Saharan Africa is the only region for which the actual TFP growth is significantly lower than the TFP growth predicted on the strength of initial conditions and political stability (by approximately 1.1 percentage points a year).

The cross-country profile of TFP growth and the role of initial conditions point toward the dual role played by human capital in the development process: as a standard factor of production to be accumulated and as a source of learning and entrepreneurship, and hence, of interesting growth dynamics. This may entail a rethinking of the concept of "TFP as the residual" in models with human capital. Further, the relationship between policy variables and TFP growth is likely to be sensitive to the way human capital is incorporated in the production function. These substantive issues, along with a number of econometric refinements, are fruitful avenues for further research.

[1] See Nehru, V., E. Swanson, and A. Dubey (1993) and Nehru, V. and A. Dhareshwar (1993). A diskette containing the data can be obtained by writing to Mr. Vikram Nehru, World Bank, 1818 H. Street, N.W., Washington D.C. 20433, U.S.A. or by calling (202)473-3887.

New Estimates of Total Factor Productivity Growth for Developing and Industrial Countries

Introduction

1. This paper presents new estimates of long-term growth in total factor productivity (TFP) for 93 industrial and developing countries at the economy-wide level for the period 1960-90. Of particular importance are estimates of TFP growth which incorporate human capital as a factor of production for 83 countries for the period 1960-87. The research was undertaken as part of a broader effort by the World Bank to better understand the sources of economic growth in developing countries and how they may be influenced by national policies and economic trends and events in the global economy. In the first phase of the project, time-series estimates of human capital stock were prepared for 83 countries (see Nehru, Swanson, and Dubey, 1994). In the second phase, we estimated a physical capital stock series for 93 countries (see Nehru and Dhareshwar, 1993). In the present paper, we use these data to derive total factor productivity growth estimates from cross-country production function analysis using error correction models, which to our knowledge have not been used before for such a purpose. The results from this analysis are compared to TFP estimates derived from more traditional methodological techniques and with results from other studies. One important conclusion of the study is that human capital accumulation plays a much larger role in explaining output growth than previous studies have found. In addition, unlike previous studies, the analysis in this paper finds that TFP growth in the high income countries is comparable to that of the better-performing low- and middle-income countries. Finally, cross-country variations in TFP growth can be largely explained by a combination of initial conditions and political stability; policy and structural variables that may be thought to be important, such as trade and macroecnonomic and financial environment, do not appear to be influential in a robust way.

2. The basic approach taken in this paper uses the same concepts as the neoclassical models of economic growth developed during the 1950s and 1960s by, among others, Abramovitz (1956), Solow

(1957), Fabricant (1959), , and Kendrick (1961). Since then, a long line of researchers have further developed and refined various econometric techniques to estimate TFP growth at the economy-wide level as well as at the sectoral and the firm level. [2] The most recent economy-wide estimates can be found in World Bank (1991), Elias (1992) and Fischer (1993). The current fashion is to describe these models as belonging to the "old growth theory" framework, to be distinguished from endogenous or "new" growth theories. The innovations in the present paper consist of incorporating of human capital stock as a factor of production in the "old" growth model, using new data on factors of production, and applying cross-country cointegration models for estimating the parameters of long-run production relations. We start with a brief account of the neoclassical model and its limitations.

3. The standard model of economic growth seeks to explain the long-term trend in the potential output of an economy by breaking it down into two parts: that part which can be explained by the growth in inputs used in production and that which can be explained by improvements in the efficiency with which these inputs are used. The latter is called total factor productivity (TFP) growth. Total or multi-factor productivity extends the concept of single factor productivity, such as output per unit labor or capital, to more than one factor. Thus, total factor productivity can be defined simply as:

$$A = \frac{Q}{aL + bK} \tag{1}$$

where A is total factor productivity, Q is output, L and K are labor and capital, and a and b are appropriate weights. Kendrick's arithmetic measure of total factor productivity growth is consequently given by:

$$\frac{dA}{A} = \frac{Q_1 / Q_0}{(wL_1 + rK_1)/(wL_0 + rK_0)} - 1 \tag{2}$$

where the subscripts represent periods; and Solow's geometric index, based on a Cobb-Douglas production function with constant returns to scale and neutral technological progress, is expressed as:

[2] A full bibliography of these papers is given at the end of the paper.

$$\frac{dA}{A}=\frac{dQ}{Q}-\left(\alpha\frac{dL}{L}+\beta\frac{dK}{K}\right) \tag{3}$$

Under the assumption of competitive equilibrium and small changes in the quantity of inputs and outputs, the Kendrick measure is identical to the Solow measure.

4. One of the stylized facts that has emerged from the accumulation of empirical work on TFP growth at the economy-wide level has been that roughly one-third to one-half of output growth can be attributed to TFP change. TFP growth was often described as the rate of "technological progress," but it was well understood that this had to be interpreted broadly to include changes in health and education levels, allocation and x-efficiency, and factors affecting the motivation of workers. Put more succinctly by a noted pioneer in the field, it is really a "measure of our ignorance" (Abramovitz, 1956). Indeed, if inputs are measured properly and the function governing their interactions is correctly specified, the residual TFP growth (dA/A) should be zero (Nadiri, 1970). Naturally, the thrust of the empirical effort over the years has been toward better measurement of inputs and a more precise estimation of the production function itself.

5. Apart from finding it difficult to "account" fully for the sources of growth, the "old" model of economic growth had another disturbing consequence -- it led to a pessimistic conclusion about the role of policy. Theoretically, long run steady state growth could be expressed as the sum of the population growth rate and the rate of disembodied, Hicks-neutral, technological progress (TFP growth). The key assumption leading to this conclusion is that of diminishing returns to any one factor of production that can be accumulated, usually capital. The long-run upper limit to the growth of capital stock per worker is the rate of technological progress. Thus, sustained acceleration in the growth rate could only come about through a rise in the rate of technological progress (assuming population growth to be impervious to policy). For policymakers, then, the issue boiled down to what could raise TFP growth -- and since understanding of the process of technological innovation was limited, the implications for policy were not explored in great detail.

6. The "new" growth theory changed this. According to this theory, the growth rate is determined endogenously, rather than being the sum of the population growth rate and the rate of disembodied technological progress. Pioneered by Romer (1986) and Lucas (1988), many variants of endogenous growth theory have emerged in the last few years. But one common feature among them, and one that is central, is that they all suspend the operation of diminishing returns on at least one factor of production that can be accumulated (Solow, 1991). And usually this factor is physical capital, but it can also be human capital.

7. Consider a rise in the share of investment in GDP through tax, public expenditure,or financial sector policies. Both the old and the new growth theories would predict a rise in the growth rate over the short run -- often a decade or even two. But the old growth theory would predict a return to the steady state in the long run (say, three decades or more), whereas the new growth theory would predict a permanent increase in the growth rate.

8. But the key assumption that distinguishes the two models -- diminishing returns in at least one factor of production that can be accumulated -- is difficult to test empirically, whether for an industry, a sector, or the entire economy. Statistical analyses have not settled this issue conclusively. The data seem compatible with both theories. It is, therefore, important to remind ourselves that "skepticism -- genuine, open-minded skepticism -- seems like the right attitude" (Solow (1991), p. 12). It is in this spirit that we have approached the estimation of total factor productivity growth in this paper. At the same time, we recognize that our results may be pushing against the imposed theoretical framework and pointing toward other approaches (Romer, 1994).

9. The next section in the paper goes through the different techniques that were used to derive alternative estimates of TFP growth, starting with the simplest. We finally choose the error correction

model as the most appropriate technique, partly for its theoretical strengths but also for its economic use of information, and examine the results of this method in the third section of this paper.

Some Traditional Approaches to Calculating TFP Growth

10. The first and simplest specification that we adopt is derived from the Cobb-Douglas production function:

$$Y = A(0)e^{\lambda t}K^{\alpha}L^{\beta} \tag{4}$$

where Y is value added, K and L are the capital stock and labor, α and β are output elasticities, $A(0)$ represents initial conditions, and λ is the rate of technological progress. In this specification of the production function, intermediate inputs can be explicitly incorporated by relating gross output to labor, capital, and intermediate inputs. We have chosen to net out intermediate inputs, and consequently relate value added to primary inputs. Expressing equation (4) in log linear form gives:

$$\log Y = \log A(0) + \lambda\, t + \alpha\, \log K + \beta\, \log L \tag{5}$$

Differentiating with respect to time yields:

$$d\log Y = \lambda + \alpha\, d\log K + \beta\, d\log L \tag{6}$$

To estimate this equation, we use a panel data set for 93 countries covering the periods 1960-90, 1960-73, and 1973-90. To estimate TFP growth rates for each country, we employ a fixed effects model with the following specification:

$$d\log Y = \phi + \sum_i \lambda_i + \alpha d\log K + \beta d\log L \tag{7}$$

where ϕ is the TFP growth for the reference country, and the λs are the TFP growth rates (relative to the reference country) for the remaining 92 countries. Thus the TFP growth rate for country k would be

$\phi + \lambda_k$. This specification assumes that all countries have the same elasticities of output with respect to labor and capital and are subject to the same unitary elasticity of substitution between these two factors. However, by estimating the production function directly, we do not assume anything about the competitive behavior of the output, labor, or capital markets. Finally, we impose a restriction that $\alpha + \beta = 1$, which imposes constant returns to scale.

11. We subsequently tried two methods for adding a human capital component to the model. The first was the standard technique of adding another input to the production function:

$$d\log Y = \phi + \sum_i \lambda_i + \alpha d\log K + \beta d\log L + \gamma d\log H \quad (8)$$

where H represents average years of total education in each country.[3] This specification posits human capital as a factor of production that is accumulated and has diminishing marginal returns, just as physical capital and labor. As such, it ignores the possibility that the stock of knowledge and skills in an economy may condition the speed with which agents learn new and more efficient techniques of production.

12. The second technique for incorporating human capital into the production function was to create a quality-adjusted labor force series by amalgamating the labor series with some estimate of human capital. The human capital estimate used for this purpose was educational attainment, and it was assumed that the marginal product of labor for groups with different educational attainment is proportional to their wage. Using census data on the shares of the labor force that have different educational attainments (taken from Barro, 1993), and weighting these by the wage rate (relative to the wage rates of uneducated

[3] For the estimation of these data, see Nehru, Swanson, and Dubey (1994). The production function associated with this formulation is $Y = A(0)e^{\lambda t}K^{\alpha}L^{\beta}H^{\gamma}$. It should be noted that alternative approaches to including the human capital variable leads to a different specification of the growth equation. Thus, consider a production function of the form: $Y = A(0)e^{\lambda t}K^{\alpha}L^{\beta}E(0)e^{\gamma Ht}$. When log differences are taken, the equation becomes: $d\log Y = \lambda + \alpha d\log K + \beta d\log L + \gamma H$. This is different from equation (8) because it includes the *level* of H and not its growth rate. Such a specification was used in World Bank (1991), and we examine a similar specification in a later section of this paper.

labor), we were able to derive a Divisia index of human capital. Multiplying this with the labor force in each year gave us the series on quality-adjusted labor force. [4] Data on wage rates by educational attainment were obtained from various articles and papers on rates of return to education. Relative wage data from such sources were available for 42 of the 93 countries in our sample. For each of the remaining 51 countries, we found a geographically proximate country that matched its economic characteristics (the characteristics used were per capita income, level of industrialization and urbanization) and assumed the relative wage structure to be the same.

13. Table 1 presents the estimates of these Cobb-Douglas specifications. Detailed country-by-country estimates are available in Annex 1. To make the comparisons simple, we have estimated the different production functions for the entire period 1960-90, first for the entire sample of countries for which data are available, and then segregating the sample into high income, and low and middle income economies. [5]

14. A number of conclusions emerge from these results. First, the *F*-statistics for all the regressions indicate that the postulated null hypothesis that there is no relationship between the growth rate of output and the growth rates of capital and labor (and human capital stock) can be rejected. In most of the equations, less than a quarter, and in most cases less than a tenth of the variation in output growth is explained by the variation in input growth and TFP growth. But the low R^2 values are not surprising given the noisy nature of annual data (when expressed in percentage changes). Second, in the regressions where the human capital variable is excluded, the elasticity of value-added to the physical capital stock varies between 0.33 and 0.38. But when the human capital variable is included, the elasticity declines for low and middle income countries (as well as for the entire sample of countries) but rises for high income

[4] The quality adjusted labor force derived for this paper is a much simpler version of the one used by Scott (1989). In addition to adjusting the labor force numbers for marginal product by educational attainment, Scott also corrects for marginal product by age, gender, sector (agriculture vs. manufacturing and services), and labor efficiency (which he assumes, like Denison, to be proportional to the numbers of hours worked).

[5] Definitions of country classification by high, middle and low income can be found in World Bank (1993).

Table 1: First difference regressions

Model	Coverage	Countries & observations	Estimate and t-statistic for: dln K	dln L	dln H	Lagrangian	F-statistic & RMSE	R^2 & adj.R^2
Without human capital	All income groups	93 2769	0.37 (12.5)	0.63 (20.9)	..	-4.2 (-7.5)	4.2 0.22	0.13 0.10
	LMICs	67 1991	0.38 (10.7)	0.62 (17.1)	..	-3.9 (-7.1)	3.0 0.23	0.10 0.06
	HICs	26 778	0.33 (6.3)	0.67 (12.7)	..	0 (-1.7)	9.5 0.17	0.25 0.22
With human capital	All income groups	83 2230	0.32 (9.5)	0.20 (3.7)	0.48 (8.7)	-2.1 (-5.5)	3.5 0.22	0.12 0.09
	LMICs	60 1610	0.27 (6.7)	0.16 (2.7)	0.57 (9.0)	-1.8 (-4.7)	3.0 0.23	0.11 0.07
	HICs	23 620	0.44 (7.8)	0.59 (4.4)	-0.03 (-0.3)	-0.2 (-2.3)	7.1 0.16	0.22 0.19
With quality adjusted labor	All income groups	82 2440	0.48 (16.2)	0.52 (17.8)	..	-8.8 (-10.4)	3.9 0.22	0.12 0.09
	LMICs	58 1726	0.48 (13.6)	0.52 (14.7)	..	-7.4 (-9.8)	2.2 0.23	0.07 0.04
	HICs	24 714	0.47 (8.9)	0.53 (10.2)	..	-1.4 (-3.9)	10.9 0.18	0.28 0.25

HICs – High income economies; LMICs – Low and middle income economies (see World Bank, 1993).
Note 1: Labor Force proxied by population in the age group 15-64
Note 2: The Lagrangian associated with the constant-returns-to-scale restriction; a positive value indicates that in the unrestricted model the parameters would sum to more than one, and vice versa. The associated t-statistic measures the significance of the restriction.
Note 3: The period of observations for all regressions is 1960-90 (annual data).

Source: Authors' estimates

countries (although in the latter case, the coefficient for human capital is of the wrong sign and not significantly different from zero). Third, as in Makiw, Romer, and Weil (1992), the output elasticity of raw labor is much smaller than the values typically found by studies that do not incorporate human capital. But, unlike the results of Mankiw, *et al*, the human capital variable is considerably more important than both physical capital and raw labor. In the case of developing countries, its coefficient is twice as large as that for capital stock and thrice as large as that for raw labor. In the case of industrial countries, however, the coefficient for the human capital variable is not significantly different from zero; this could be because the measure of human capital stock we use captures years of formal education only, and is therefore bounded at the upper end, resulting in very little variation in growth rates across different high-income countries.[6] Fourth, in most instances, the Lagrangian parameter is significant, indicating that the constant-returns-to-scale restriction is binding.

Table 2: Correlation coefficients of TFP growth rates when calculated from alternative specifications of first difference regressions 1/

		Without human capital			With human capital			With quality adjusted labor		
		All	LMIC	HIC	All	LMIC	HIC	All	LMIC	HIC
Without human capital	All	1.00								
	LMIC	1.00	1.00							
	HIC	0.99	..	1.00						
With human capital	All	0.84	0.80	0.76	1.00					
	LMIC	0.76	0.76	..	1.00	1.00				
	HIC	0.89	..	0.85	0.78	..	1.00			
With quality adjusted labor	All	0.94	0.93	0.91	0.80	0.69	0.89	1.00		
	LMIC	0.93	0.93	..	0.74	0.69	..	1.00	1.00	
	HIC	0.94	..	0.91	0.78	..	0.88	1.00	..	1.00

1/ The estimates without human capital are for 1960-90 and the estimates that include human capital are for 1960-87.

HICs -- High income economies; LMICs -- Low and middle income economies (see World Bank, 1993).

Source: Authors' estimates.

15. The country-by-country TFP growth rates that emerge from these alternative specifications tend to correlate relatively well with each other (Table 2).[7] But a few interesting points emerge from these correlation coefficients. First, the estimates of TFP growth from the equation using the quality-adjusted labor force series are highly correlated with those derived from the equation that does not

[6] See Nehru, Swanson, and Dubey, ibid.

[7] It should be noted that these correlation coefficients are significantly lower than those reported by Fischer (1993), who finds that the time series TFP growth rate for each country under the three methods used by him had correlation coefficients exceeding 0.98. This is not surprising. Our TFP growth rates are a *single* estimate for each country for the period 1960-90. Therefore, our correlation coefficients measure the cross-country variation in TFP growth estimates generated by alternative specifications of the production function. Fischer's correlation estimates measure the correlation between the residuals generated each year by applying different specifications. Given that these specifications explain a small amount of the variation in output growth (usually less than 10 percent), the bulk of the variation is placed in the residual. Thus, measuring the correlation of the annual residual across different specifications almost amounts to measuring the correlation of the annual growth rate for each country across the different specifications -- which is of course 1.0. To argue then, as he appears to argue, that it does not matter which specification one uses to estimate TFP growth rates, is incorrect in our view.

include human capital at all. This suggests that our procedure for adjusting the labor force for quality (using relative wage rates) does not add much additional information to the labor force series.[8] Second, the TFP growth estimates, when an independent human capital variable is included, are not as highly correlated with those calculated from the basic equation that includes no human capital or the one with the quality adjusted series. One interpretation of this result is that new information is indeed being added here, especially since the coefficient of the human capital variable in the regression equation are highly significant. Finally, there is usually little difference in the correlation estimates between the results for LMICs only and those for the entire group of countries in the sample. This is not surprising, because LMICs dominate the broader sample (67 out of a total of 93 countries) and LMIC data probably contain greater cross-country variation.

16. In addition to the Cobb-Douglas specifications given above, we also attempted to use less restrictive functional forms such as CES and translog production functions. Recall that the CES production function is of the form:

$$Y = A(0)e^{\lambda t}\left[\delta L^{-\rho} + (1-\delta)K^{-\rho}\right]^{-\nu/\rho} \tag{9}$$

where *d*, *r*, and *m* are the distribution, substitution, and returns to scale parameters respectively. Using the technique developed in Kmenta (1967), this was linearized and the actual equation estimated was:

$$\log\frac{Y}{L} \approx \log A(0) + \sum_i \lambda_i t + (\mu - 1)\log L + \mu(1-\delta)\log\left(\frac{K}{L}\right) - \frac{1}{2}\rho\mu\delta(1-\delta)\left(\log\frac{K}{L}\right)^2 \tag{10}$$

For each country, a separate time trend λ_{it} was included representing its total factor productivity growth. Similarly, we also estimated a translog production function of the form:

$$\begin{aligned}\log Y_t = {} & \alpha_0 + \alpha_k \log K_t + \alpha_l \log L_t + \sum_i \alpha_{it} t \\ & + \frac{1}{2}\beta_{kk}(\log K_t)^2 + \beta_{kl}\log K_t \log L_t + \frac{1}{2}\beta_{ll}(\log L_t)^2 + \beta_{lt}\log L_t t + \beta_{kt}\log K_t t + \frac{1}{2}\beta_{tt} t^2\end{aligned} \tag{11}$$

[8] It is worth noting that our database includes the requisite data only for a subset of 41 countries, as discussed earlier in paragraph 12.

where $$\frac{\partial \log Y_t}{\partial t} = \alpha_{tt} + + \beta_{lt} \log L_t + \beta_{kt} \log K_t + \beta_{tt} t \qquad (12)$$

is the growth rate of total factor productivity in country *i*.

17. Unfortunately both techniques yielded results that were unsatisfactory. [9] This was hardly surprising, because although these production functions can be calculated using single equation methods, it is more appropriate to estimate the production function and the factor share equations jointly to obtain precise estimates. Joint estimation techniques were not possible because of the lack of data on factor shares on such a wide range of countries. Researchers that have used such techniques have normally focused on one or two countries or have used data at the level of the firm where factor shares are relatively more easily available. [10]

An Error Correction Model

18. The regression results described above of production functions expressed in terms of growth rates have one serious shortcoming; they measure only the short-run responses of output to changes in inputs. But the production function is an expression that models a long-term relationship between the level of output and the level of inputs. This long-run relationship has not been explored because of the dangers of spurious regression results between non-stationary variables (Yule, 1926; Granger and Newbold, 1974). As a result, analysts have not used a considerable amount of information contained in data on levels of output and inputs that can inform productivity growth analysis.

19. This potentially valuable information on the relationship between levels can, however, be fruitfully used if error correction models are employed. Such models provide a way of separating the long-run relationship between economic variables from their short-run responses to each other. If the

[9] Interested readers can contact the authors should they be interested in the detailed results.
[10] See Young (1992), Nishimizu and Page (1982), and Ahluwalia (1991).

variables in the log-linear production function (log of value added, log of capital stock, and log of labor) are cointegrated, an OLS regression of log output on log inputs would yield consistent estimates of the regressors (Engle and Granger, 1987).

20. Consequently, we estimate the log-linear version of the Cobb-Douglas production function:

$$\log Y = \log A(0) + \sum_i \phi_i D_i + \sum_i \lambda_i t + \alpha \log K + \beta \log L + u_t \qquad (13)$$

and apply the Engle-Granger test for cointegration using the equation:

$$\Delta u_t = \mu + \pi \Delta u_{t-1} + \psi u_{t-1} \qquad (14)$$

The procedure we adopted consisted of three steps. First, equation (13) was estimated using OLS. Second, the variance of the predicted errors were then used to weight the variables to correct for heteroskedasticity, and the equation was run again. And third, the predicted errors from this second run were used for the Engle-Granger test in equation (14). If the hypothesis can be rejected that Ψ=0, then it can be concluded that the errors from the homoskedastic cointegrating regression are stationary and the cointegrating vectors describe a non-spurious relationship. To test the hypothesis, critical values were taken from Engle and Yoo (1987) since critical values from the standard Dickey-Fuller tables would not be appropriate (Muscatelli and Hurn, 1992).

21. The results are given in Table 3. [11] In all the specifications that were tested, the Engle-Granger test clearly shows that the time series of outputs and inputs are cointegrated and that the cointegrating vectors therefore can be interpreted as the elasticities of output with respect to inputs. [12] Moreover, the F-statistics and the adjusted R^2s are very high in each case, as one would expect in regressions in log levels.

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[11] We did not estimate a separate set of regressions using the quality adjusted labor force series because we had come to the conclusion earlier that the series did not add sufficiently additional information to warrant separate analysis (see para. 15).

[12] Unfortunately, the probability distribution of these estimates are not known, and so significance and other tests cannot be conducted. The size of the model precluded the use of the Johansen procedure.

22. Comparing the results in Table 3 with those in Table 1 reveals differences and similarities. The most important difference is that the elasticity of output with respect to physical capital is higher in the error correction model specifications than in the first difference regressions. Where human capital is not included, for example, this elasticity is over 0.5 whereas it is below 0.4 in the first difference regressions; and where human capital is included, it is close to 0.4 compared to 0.3 in the first difference regressions (we ignore the regression results for the high income countries sample because the coefficient for the human capital variable is not significant in both of the models). But the similarities in the results are equally striking. First, the coefficient of the human capital variable is three to four times as large as the raw labor variable in both the models. And second, the constant returns to scale restriction is binding in all the equations except the one for the high income countries, where in any case the human capital coefficient is not significant.

23. We subsequently estimated the correlation coefficients of the TFP growth results that emerged from the error correction model when human capital was excluded and when it was included. We also tested to see if the error correction model results were highly correlated with the results from the first difference regressions. The correlation coefficient estimates are given in Table 4. A careful look at them yields the finding that the inclusion or exclusion of the human capital variable is of greater importance than the specification of the estimating equation. To illustrate this, consider the numbers for LMICs only. In the error correction model, the correlation coefficient between the TFP growth estimates when human capital is included and when it is not is 0.79 (see the shaded numbers in Table 4); in the first difference regressions, the similar correlation coefficient is 0.73. Yet, in the case when human capital is not included, the results from the error correction model and the first difference regressions have a correlation coefficient of 0.92; similarly, when human capital is included, the TFP growth results from the two alternative techniques have a correlation coefficient of 0.97. Quite clearly, the inclusion of the human

Table 3: Results of Error Correction Model Applied to Panel Data 1/

Model	Coverage	Countries & observations	Estimate of coefficient for : LnK	LnL	LnH	Lagrangian	Fit of cointegrating regression: F-stat and Prob>F	R2 and Adj. R2	Co-integration tests Engle-Granger test: estimate of lagged residual and t-stat	CRDW
Without human capital	All countries	93	0.54	0.46	..	-8.80	30859	0.99	-0.22	0.47
		2862	(36.57)	(30.56)		(-6.59)	0.0001	0.99	(-20.02)	
	LMICs	67	0.52	0.48	..	-8.22	22821	0.99	-0.21	0.46
		2058	(26.74)	(24.38)		(-7.03)	0.0001	0.99	(-16.53)	
	HICs	26	0.59	0.41	..	-8.28	58284	0.99	-0.28	0.53
		804	(29.60)	20.74		(-1.42)	0.0001	0.99	(-13.00)	
With human capital	All countries	83	0.49	0.11	0.39	-3.43	33409	0.99	-0.26	0.52
		2313	(29.6)	3.23	(12.0)	(-3.50)	0.0001	0.99	(-18.9)	
	LMICs	60	0.41	0.10	0.49	-3.45	26861	0.99	-0.25	0.55
		1670	(19.67)	(2.56)	(12.95)	(-3.80)	0.0001	0.99	(-15.53)	
	HICs	23	0.74	0.34	-0.08	-0.61	74162	0.99	-0.39	0.67
		643	(34.75)	(5.67)	(-1.43)	(-1.69)	0.0001	0.99	(-14.18)	

1/ The estimates without human capital are for 1960-90 and the estimates that include human capital are for 1960-87.

Note 1: Labor force proxied by population aged 15 to 64. The Lagrangian parameter is associated with the constant returns to scale restriction. A positive value indicates that in the unrestricted model, the parameters would add to more than one,and vice-versa. Its t-statistic measures the significance of the restriction.

Note 2: t-statistics in parentheses.

capital variable tends to have a more important effect on the TFP growth estimates than the switch from the first difference regressions to the error correction model.

24. So far, we have analyzed five different specifications of the production function from which we have calculated TFP growth estimates for the period 1960-90. Add to that the separate estimations when the original sample of countries were divided into LMICs and HICs. All in all, then, we have 15 estimates of TFP growth for each country in our sample. These alternative estimates were useful in understanding the sensitivity of the results to various specifications and different country groups. But to discuss the TFP growth results in some detail and to understand their relationship to other variables, we need to choose one set on which to focus the discussion.

25. We have, therefore, chosen as our most preferred set of TFP growth results the one that emerges from the error correction model which incorporates human capital as a separate variable and which is based on the entire sample of countries. We do this for a practical reason that has been implicit in our discussion so far -- this particular set of results uses the most information compared to any of the other approaches that we have tried. The error correction model uses information not only on log differences but also on levels of the different variables; and the inclusion of the human capital variable adds important information to the production function, which is highlighted by the fact that its coefficient is found to be considerably more important than the coefficient for raw labor. Finally, we chose to use the results from the regression that includes all countries because the distinction between high income and low and middle income economies is somewhat arbitrary for the purposes of our analysis. Moreover, the number of countries in the sample of high income economies was only 23 -- and the TFP growth estimates from the alternative specifications were sufficiently different for us to be concerned that the sample was not large enough to provide robust estimates. Finally, the data on low and middle income countries contain greater cross-country variation in the independent variables, especially human capital.

Table 4: Correlation coefficients of TFP growth rates when calculated from the error correction model and from the first difference regressions 1/

			Error correction model						First difference regressions					
			Without human capital			With human capital			Without human capital			With human capital		
			All	LMIC	HIC	All	LMIC	HIC	All	LMIC	HIC	All	LMIC	HIC
Error correction model	Without human capital	All	1.00											
		LMIC	0.99	1.00										
		HIC	0.99	..	1.00									
	With human capital	All	0.86	0.85	0.88	1.00								
		LMIC	0.78	0.79	..	0.99	1.00							
		HIC	0.91	..	0.95	0.81	..	1.00						
First difference regressions	Without human capital	All	0.93	0.92	0.96	0.78	0.72	0.52	1.00					
		LMIC	0.78	0.92	..	0.75	0.72	..	0.99	1.00				
		HIC	0.96	..	0.95	0.61	..	0.42	0.99	..	1.00			
	With human capital	All	0.78	0.76	0.71	0.95	0.97	0.53	0.82	0.78	0.77	1.00		
		LMIC	0.71	0.72	..	0.94	0.97	..	0.74	0.73	..	0.99	1.00	
		HIC	0.95	..	0.93	0.79	..	0.80	0.90	..	0.85	0.79	..	1.00

1/ The estimates without human capital are for 1960-90 and the estimates that include human capital are for 1960-87.

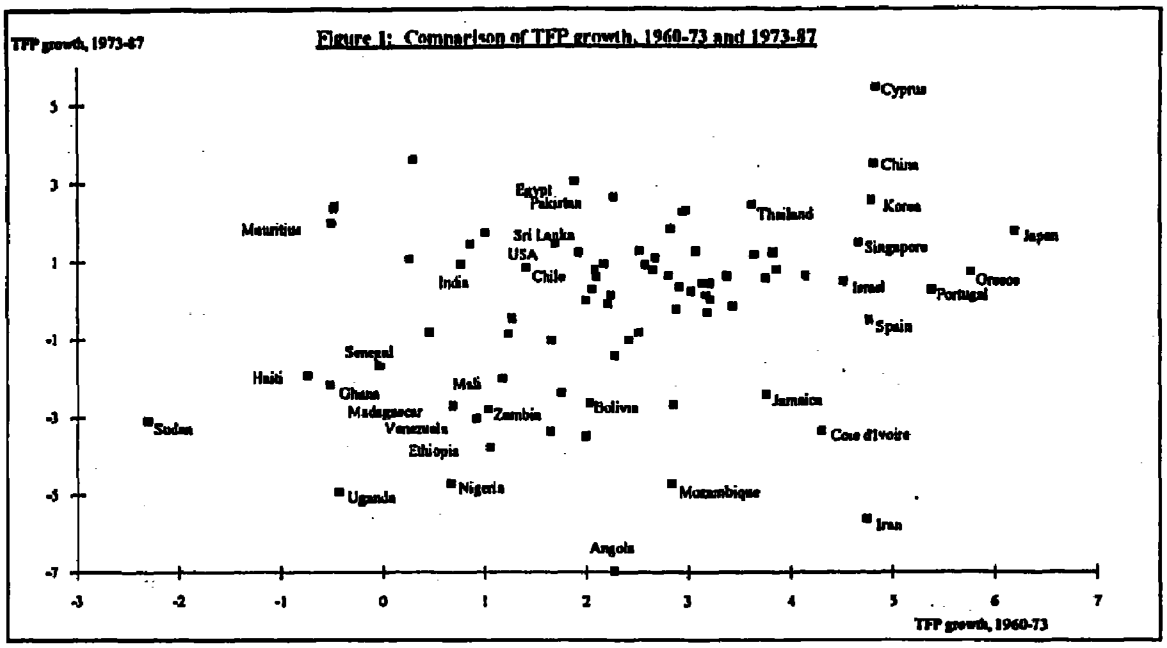
Source: Authors' estimates

An Analysis of the TFP Growth Estimates

26. On the strength of the reasons presented in the previous paragraphs, the following analysis of our TFP growth estimates rests on the results that emerge from the error correction model that includes the human capital variable and uses data on all the 83 countries in the sample. In addition to estimating TFP growth for 1960-87, we use the same techniques to estimate the TFP growth for two sub-periods, 1960-73 and 1973-87. Comparing TFP estimates between the two sub-periods, 1960-73 and 1973-87, confirms the view that countries with the best TFP growth performance in both periods have tended to be in East Asia and those with the worst have tended to be in Sub-Saharan Africa (see Figure 1). [13] Of the six economies which were higher than the 80th percentile of the TFP growth distribution in both periods, five were from East Asia. And of the five which had a TFP growth less than the 20th percentile in both periods, four were in Saharan Africa.

27. In most countries, the TFP growth rate slowed during the sample period, being much lower in 1973-87 than in 1960-73. Indeed, the correlation coefficient of TFP growth rates between the two periods is as low as 0.22, confirming earlier observations of the low level of persistence in GDP growth across different time periods. [14] Countries which underwent a significant improvement between the first sub-period and the second included such economies as Jordan, Egypt, Mauritius, India, and Pakistan. Economies which faced a significant worsening in their performance included such wartorn economies as Iran and Iraq, economies which experienced serious civil wars as Angola, Mozambique, Ethiopia, and Uganda, and countries which introduced severely distorted polices in the 1970s and 1980s such as Cote d'Ivoire, Nigeria, Zaire, and Tanzania.

[13] This confirms the results of several studies including the recent Bank study on East Asia.
[14] See Easterly et. al., 1993.

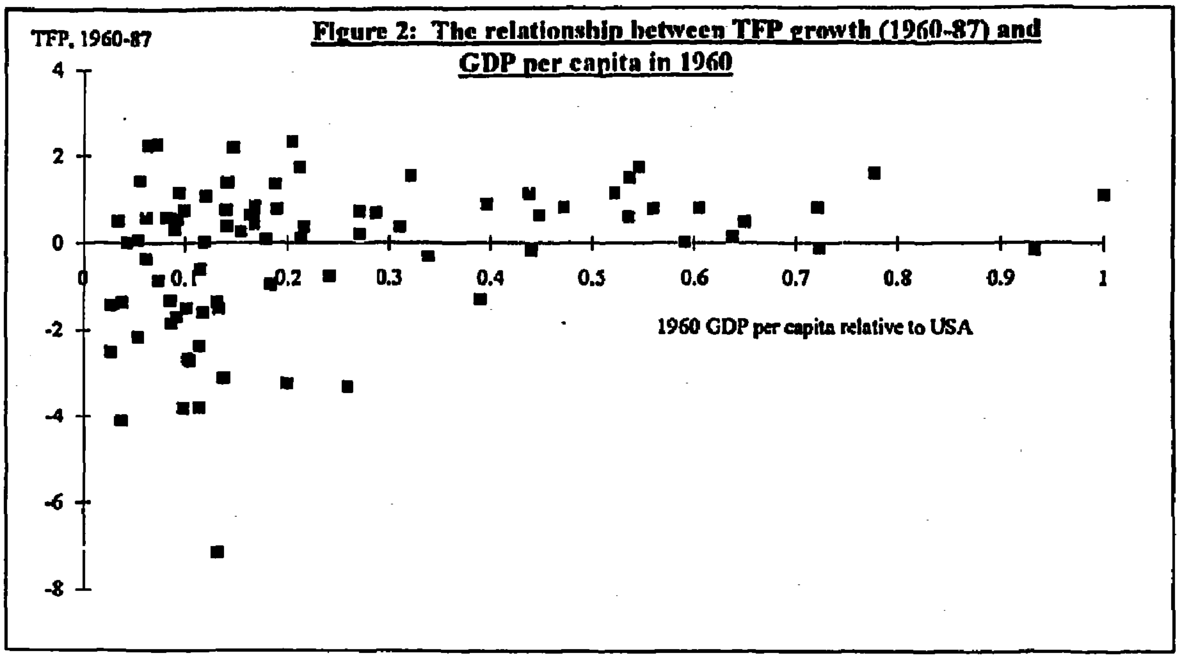


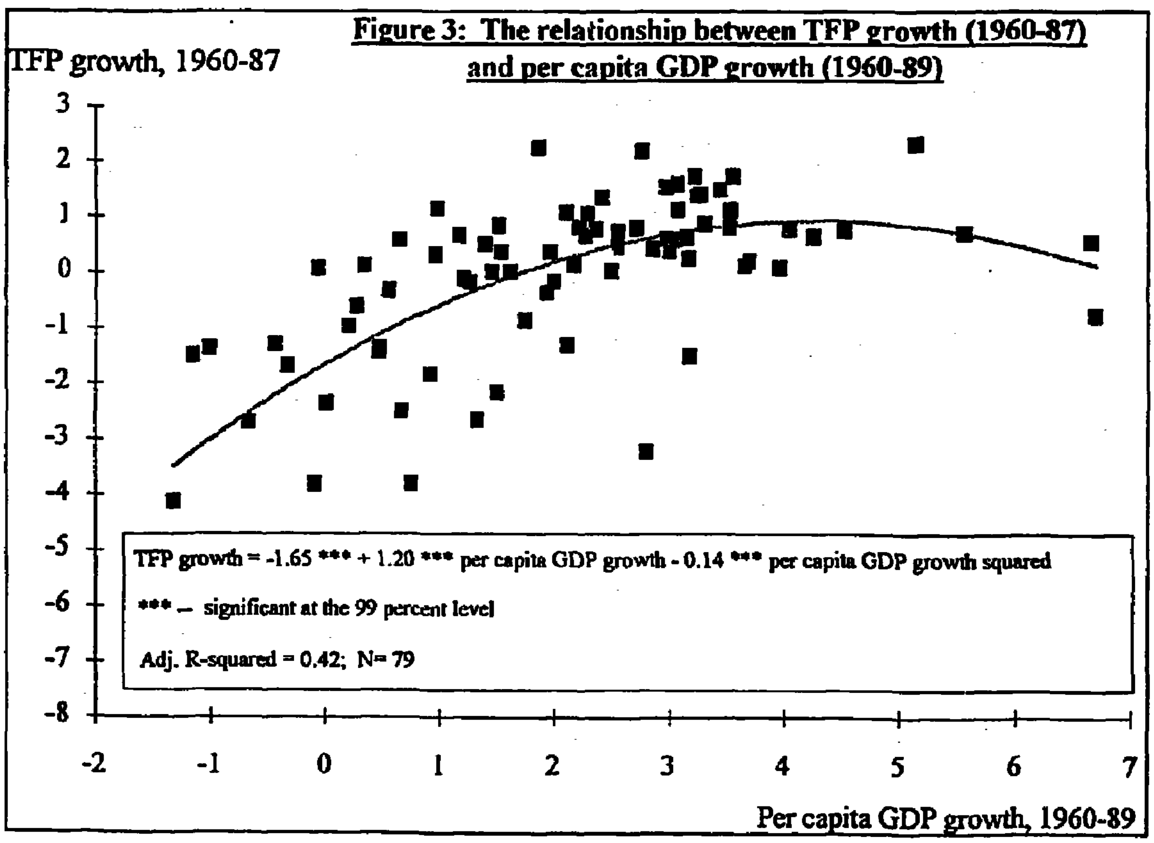
28. But the TFP estimates for individual sub-periods need to be interpreted with considerable caution. It should be noted that in a few cases, the TFP growth estimate for the full sample period 1960-87 is not within the range demarcated by the TFP estimates for the two sub-periods. Indeed, East Asian economies are top TFP growth performers in each sub-period, yet are quite average when the period is taken as a whole. Singapore, an extreme example, has a TFP growth estimate which is negative (-0.8 percent per year) for the entire period 1960-87; yet it is significantly positive (4.7 and 1.5 percent per year respectively) for the two sub-periods. Such anomalies are not unknown in the regression analysis of time series, and are all the more frequent in the analysis of panel data. Three reasons could possibly account for this in the current instance. First, the output series in several countries show a structural break around 1973, reflecting large adjustments in the wake of the first oil shock; this tends to lead to a low estimated output growth for the period from 1960 to 1987, but a high estimated output growth for the two sub-periods, 1960-73 and 1973-87. Second, the panel regression results are based on a combination of cross-country variation and inter-temporal variation. The longer the time series, the more important becomes the inter-temporal variation in shaping the trend and the estimated coefficients of the production function. The shorter the time series, the more important becomes the cross-country variation. Since

economic performance varied considerably between the two periods for most countries (see Easterly et. al., 1993), the inter-temporal variation predominates in the regressions covering the entire period, 1960-87. But when the sub-periods are analyzed, the cross-country variations dominate. Since East Asia's GDP growth performance was comparatively good in relation to other countries during both periods, this is amplified in the regression analysis of the sub-periods. The third possible reason for such anomalous results could be the differential weights accorded to different observations in a time series regression. As is well known, central observations in a time series have a larger influence on a fitted regression line than the observations at either end. Thus, observations around 1973 (the central observations) would be relatively more important in determining the coefficients in the 1960-87 regression, whereas they would be less important in determining the coefficients of the regressions for the sub-periods. The performance of the East Asian economies was not distinctively higher than other countries in the 1970s, but did perform better in the 1980s (especially Korea, Indonesia, China) and the 1960s (Japan, the Philippines). Thus, the weighting system implicit in time series regression could partly explain the seeming contradictions in the results. Clearly, the choice of the time period could materially affect the results and, a fortiori, our interpretation of the causes behind cross-country differences in TFP growth performance.

29. We have, therefore, opted to place less faith in the TFP growth estimates for the individual sub-periods, preferring to focus on the longest possible time period for which we have data. Thus, the rest of the discussion in this paper analyses the differences in TFP growth across countries for the period 1960-87. Figure 2 starts by examining the relationship between TFP growth between 1960 and 1987 and GDP per capita in 1960 (relative to the United States). Two features of the graph are of interest. First, the lower the relative GDP per capita, the higher seems to be the variation in TFP growth performance. The variation in TFP growth performance is comparatively small among the high income countries. Second, TFP growth in the better performing high income countries was not all that much worse than the better performing low and middle income countries. This finding stands in contrast to some earlier studies which have found higher TFP growth rates among developing countries compared to high income countries and have pointed to the possibility that technological "catch-up" may account for the difference.

The evidence in the graph indicates that once the more rapid growth in human capital in the developing world is taken into account, the difference in TFP growth with the industrial countries tends to diminish.





30. A similar comparison was made between TFP growth and per capita GDP growth (see Figure 3). The relationship is clearly non-linear, and a simple polynomial expression fits reasonably well, explaining over 42 percent of the variation in TFP growth. Countries at the lower end of the per capita GDP growth spectrum have also had low TFP growth. But countries that have experienced the fastest per capita GDP growth (Japan, Korea, Singapore, Thailand) appear to have done so more on the basis of the rapidity of their factor accumulation than on their TFP growth. [15] It is countries that have maintained per capita growth rates of 3.5-4.5 per cent per year that have tended to have the highest TFP growth rates.

Table 5: Correlation coefficients of alternative estimates of TFP growth

	This study	World Bank (1993b)	Fischer (1993)	Elias (1990)
This study	1.00			
World Bank (1993b)	0.80	1.00		
Fischer (1993)	0.67	0.83	1.00	
Elias (1990)	0.44	0.67	0.59	1.00

Sources: Authors' estimates, based on World Bank (1993b); Fischer (1993); and Elias (1990).

31. We compared our TFP growth results with those from three other studies which also estimated TFP growth for a wide range of countries over similar periods (World Bank, 1993b; Fischer, 1993; and Elias, 1990). The study by Fischer (1993) used Summers-Heston income data to estimate TFP growth for each country as the Solow residuals after imposing factor shares of 0.4 for capital and 0.6 for labor; Elias's estimates used World Bank real product data for some 73 economies and adopted a very similar technique to that of Fischer. In World Bank (1993b), human capital (proxied by educational attainment) was explicitly used, and TFP growth was estimated as a residual after fitting the standard log differences model discussed in the earlier part of this paper.

[15] Similar to Young (1992), we also find Singapore's TFP growth to be negative for the period 1960-87; its high per capita growth rate can be more than adequately explained by the growth of its physical and human capital.

32. The estimates presented in this paper and the ones given in these independent studies appear to be well correlated (Table 5). The only exception seems to be Elias (1990) which is less well correlated with the results of this study compared to the other two. A graphical representation of the comparison is given in Annex 2.

Empirical Regularities Between TFP Growth and Other Variables

33. We noted in the beginning of this paper that TFP growth needs to be interpreted broadly to include all aspects of the country that bear upon improvements in the technical efficiency with which input factors of production (physical capital, labor, and human capital) are transformed into output, such as the depth of a country's institutions, its political stability, the quality of its governance, the nature of its economic policies, its initial conditions, and so on. This section explores this issue further, asking whether the estimates of TFP growth for 1960-90 presented in this paper possess any striking statistical association with variables that describe these factors. We used the vast warehouse of data on policy and structural variables that has been generated by the explosion of endogenous growth literature, and have added a few variables of our own. [16]

34. We take as our starting point three independent variables that have become almost ubiquitous in cross-country growth regressions, particularly in the endogenous growth literature -- log of the initial stock of human capital, log of initial income per capita relative to the United States (the World Bank Atlas figures), and the numbers of revolutions and coups. [17] The results are given in the middle column of Table 6.

[16] We would like to thank William Easterly and Ross Levine for making this data available to us.
[17] Note that we have used here initial human capital stock based on estimates provided in Nehru, Swanson, and Dubey (1993) rather than initial primary or secondary enrollment rates which is more cusomary in the literature; moreover, we have normalized the initial per capita GDP of each country with that of the United States.

35. All the coefficients in the equation are significant at the 99 percent level of confidence. What is more, the overall goodness-of-fit is impressive, higher than it normally is for similar cross-section growth equations in which the dependent variable is per capita GDP growth (that is, in endogenous growth models). We found these three variables to be remarkably robust, remaining significant (at least at, but often above, the 90 percent level of confidence) in most cases when new policy or structural variables were introduced into the model.

Table 6: Regression results using "base" variables

	When dependent variable is: TFP growth rate, 1960-87	When dependent variable is: Growth of physical capital stock, 1960-90
Independent variables:		
constant	-1.75 (-3.95) ***	0.047 (4.34) ***
log of human capital	1.11 (7.44) ***	-0.0005 (-0.12)
number of revolutions and coups	-1.72 (-3.62) ***	-0.0125 (-1.09)
log of per capita GDP	-0.56 (-2.96) ***	-0.0064 (-1.40)
F-statistic (Prob>F)	32.63 (0.00)	1.36 (0.26)
R-squared	0.56	0.06
adj. R-squared	0.54	0.02
Number of observations	81	81

Note: t-ratios in parentheses.
*** Significant at the 99 percent level.

Source: Authors' estimates.

36. Equally important is the finding that there is little association between the growth of the physical capital stock and the same independent variables (see the third column in Table 6). None of the coefficients are significant in this equation, nor is the overall regression.

37. From these two equations, one can reach the tentative conclusion that initial conditions and political stability are associated less with the process of physical capital accumulation than with the efficiency with which factors of production are transformed into output. This finding was further confirmed by regressing the average share of investment in GDP over the period on the same set of independent variables; the coefficients were once again not significant (except for the number of revolutions and coups) at the 90 percent level.

Table 7: Regression tests for robust effect on TFP growth (Dependent variable: TFP growth)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Base variables a/									
constant	-3.01 ***	-1.97 ***	-1.88 ***	-1.07 ***	-1.27 ***	-1.78 ***	-2.08 ***	-1.92 ***	-1.99 **
lnthc60	1.15 ***	1.18 ***	1.17 ***	1.24 ***	0.89 ***	0.95 ***	1.27 ***	1.01 ***	0.91 ***
revc	-1.80 ***	-1.27 **	-1.13 **	-1.57	-1.88 ***	-1.78 ***	-1.59 ***	-1.64 ***	-1.06
lgdp60us	-0.64 ***	-0.69 ***	-0.61 ***	-0.60 **	-0.44 **	-0.31	-0.52 ***	-0.42 **	-0.30
Test variables a/									
aveqpshr	3.11 *								
bmp		-0.004 **							
bms			-0.003 **						
dcpt60				-1.50 *					
gdcpt					13.9 ***				
gm						0.11 **			
gqlly							4.83 **		
gx								0.08 **	
index1									0.02 **
Diagnostics									
R-squared	0.56	0.57	0.58	0.51	0.60	0.57	0.57	0.58	0.54
adj. R-squared	0.52	0.55	0.56	0.46	0.58	0.55	0.54	0.55	0.49
F-stat.	14.04	24.45	25.46	10.05	27.03	24.17	23.12	24.74	12.69
Prob>F	0.0000	0.000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
No. of obs.	50	78	78	43	77	77	76	78	49
Fragile? b/	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Which variables? c/	bmp share60 sury60 +others	gov sury60 gx +others	gov tot eqpshr +others	tot trd sury60 +others	index1 tot gsg +others	sury60	bmp gov pi +others	sury60 aveqpshr	tot sury60 aveqpshr +others

a/ lnthc60=log of human capital in 1960; revc=numbers of revolutions and coups; lgdp60us=log of GDP relative to U.S.; aveqpshr=average share of machinery and equipment in GDI; bmp=black market premium; bms=standard deviation of black market premium; dcpt60= ratio of private domestic asset to total domestic assets in 1960; gdcpt=growth of the ratio of private domestic assets to total domestic assets; gm=growth of imports; gqlly=growth of quasi-liquid liabilities of the banking system; gx=growth of exports; index1=composite index measuring macroeconomic stability and the incentive structure (Thomas and Wang, 1983). For the list of variables from which these acronyms are drawn, please see Annex 3.

b/ The test variable is considered fragile when its coefficient turns insignificant if another variable is added to the regression.

c/ See Annex 3 for a list of these variables.

* - significant at the 90 percent level;
** - significant at the 95 percent level;
*** - significant at the 99 percent level.

Source: Authors' estimates.

38. In addition to these base variables, we investigated a range of policy and structural variables (much in the same vein as Levine and Renelt, 1991, and Levine and Zervos, 1993) to see if they held any association with TFP growth after the latter was conditioned by these three base variables indicated in Table 6. Each of these 60 policy and structural variables was added, one at a time, to the base regression. [18] Nine of them turned out to have coefficients which were significant at the 90 percent level or higher (see Table 7). In virtually all the instances when these test variables were added, the base variables maintained their significance. In particular, the initial level of human capital in 1960 is highly significant in each of the nine cases, underscoring its robustness. As far as the test variables are concerned, further testing showed them to be fragile. In each case, their coefficients turned insignificant when certain other variables were added (see Table 7). Perhaps the most robust of these nine variable were the growth of imports (gm) and the growth of exports (gx). The addition to an extra variable does not affect the significance of the coefficient for gm except in one case -- the case when sury60 (the budget surplus, or deficit, in 1960) is added to the regression. Similarly, the growth of exports remains a strong explanatory variable for TFP growth except when either sury60 or aveqpshr (the average share of machinery and equipment in GDI) is added to the regression equation. These results confirm yet again the observation that open trade policies and strong export performance appear to be associated with rapid improvements in total factor productivity but, of course, say nothing about the causal direction.

Table 8: Regression results with regional dummies

Dependent variable: TFP growth	Coefficient
Base variables a/	
constant	-1.78 ***
lnthc60	1.03 ***
revc	-1.95 ***
lgdp60us	0.83 ***
Regional dummies	
East Asia	-0.27
South Asia	-0.00
Middle East & North Africa	-0.35
Sub-Saharan Africa	-1.11 *
Latin America	-0.15
North America	0.69
Diagnostics	
R-squared	0.67
adj. R-squared	0.63
F-stat.	16.13
Prob>F	0.0000

a/ lnthc60=log of human capital in 1960; revc=numbers of revolutions and coups; lgdp60us=log of GDP relative to U.S.
* - significant at the 90 percent level;
*** - significant at the 99 percent level.
Source: Authors' estimates

[18] For the list of variables, please Annex 3.

39. Finally, we added regional dummy variables to the basic regression to see if differences in location can be important in explaining differences in TFP growth (see Table 8). Other than in the case of Sub-Saharan Africa, all the coefficients of the regional dummies are not significant at the 90 percent level of confidence. In other words, differences in initial conditions and political stability by themselves are not adequate in explaining the poor TFP growth rates of the countries in the Sub-Saharan African region. In fact, by virtue of belonging to the region, the predicted TFP growth rate would be 1.1 percent below what would otherwise be expected on the strength of initial per capita income, initial education stock, and the numbers of revolutions and coups alone (see Table 8).

Conclusion

40. This paper presents a new set of TFP growth measures for a wide range of industrial and developing countries for the period 1960 to 1987. After exploring various alternatives, we decided to use an error correction mechanism to model the production function that includes a human capital stock variable and uses data on all the 83 countries in the sample. An analysis of the results led to six findings.

- First, human capital accumulation is three to four times as important as raw labor in explaining output growth, and its contribution to growth is larger than estimated in previous studies.

- Second, TFP growth among the high income countries was not all that much lower than in the better-performing low and middle income countries; this also contrasts with findings in earlier studies.

- Third, the relationship between the per capita GDP growth rate and the TFP growth rate is non-linear; countries with the fastest per capita GDP growth rates, most of which are in East Asia, appeared to have based their performance more on the speed of factor accumulation than on the pace of TFP growth.

- Fourth, TFP growth between 1960 and 1987 is strongly associated with the initial level of human capital, the initial level of per capita income, and the number of revolutions and coups. This was not the case when physical capital accumulation was made the dependent variable, suggesting that initial conditions and political stability are associated less with factor accumulation than with the efficiency with which inputs are transformed into output.

- Fifth, regressions showed that the TFP growth rate of Sub-Saharan countries tends to be 1.1 percent below what would otherwise be predicted on the basis of initial conditions and political stability alone.

- Sixth, apart from initial conditions and political stability, virtually no other policy and structural variables are associated with TFP growth. Over sixty policy and structural variables were included one by one in a regression to see whether they exhibit any association with a set of TFP growth estimates pre-conditioned by the initial level of human capital, the initial per capita GDP, and the number of revolutions and coups. Nine were found to be significant at the 90 percent confidence level or higher. Of these, not even one was considered robust, because the addition of one or more variables rendered them insignificant. The growth of imports and the growth of exports were considered the least fragile of these nine variables, confirming the widely held view that, over long periods, openness in trade tends to be associated with economy-wide efficiency improvements. But it does not provide any basis for the belief that trade openness causes efficiency improvements.

A number of avenues for future research suggest themselves. They range from econometric refinements through richer datasets and disaggregated modeling to alternative approaches that accommodate the concerns of "new" growth theories:

- In the estimation results presented in this paper, the constant returns restriction was rejected by the data both in the traditional and the error correction models. Before concluding that diminishing returns to scale prevail in the cross-country aggregate data, it is imperative to refine the econometric procedures used to arrive at the result. For example, the estimation can benefit from a fuller treatment of heteroskedasticity and autocorrelation. Perhaps more important, estimation techniques that can yield statistical inferences, such as the Johansen procedure or joint estimation of level and first-difference equations (Muscatelli and Hurn, 1992), should be tried although the large dataset and complicated heteroscedastic effects present a particularly difficult computational challenge.

- The modeling framework that we use--the single-sector growth model--is a limitation imposed by the dearth of disaggregated data. This is an area where further research would pay rich dividends; the availability of dissaggregated data on factor inputs and income shares would permit better estimates of productivity growth and a better understanding of the growth process. This would be true from the points of view of both "old" and "new" growth theories.
- The cross-country profile of TFP growth, together with the role of human capital (both its growth and its initial stock), point toward the dual role played by human capital in the development process: as a standard factor of production, which is accumulated and has diminishing marginal returns, and as a source of learning and entrepreneurship, which gives rise to interesting growth dynamics. This may entail a rethinking of the concept of TFP as the residual in models with human capital. Further, the relationships between growth of productivity and policy and environmental variables are more fruitfully modeled causally; they are also likely to be sensitive to the way human capital is incorporated in the production function.

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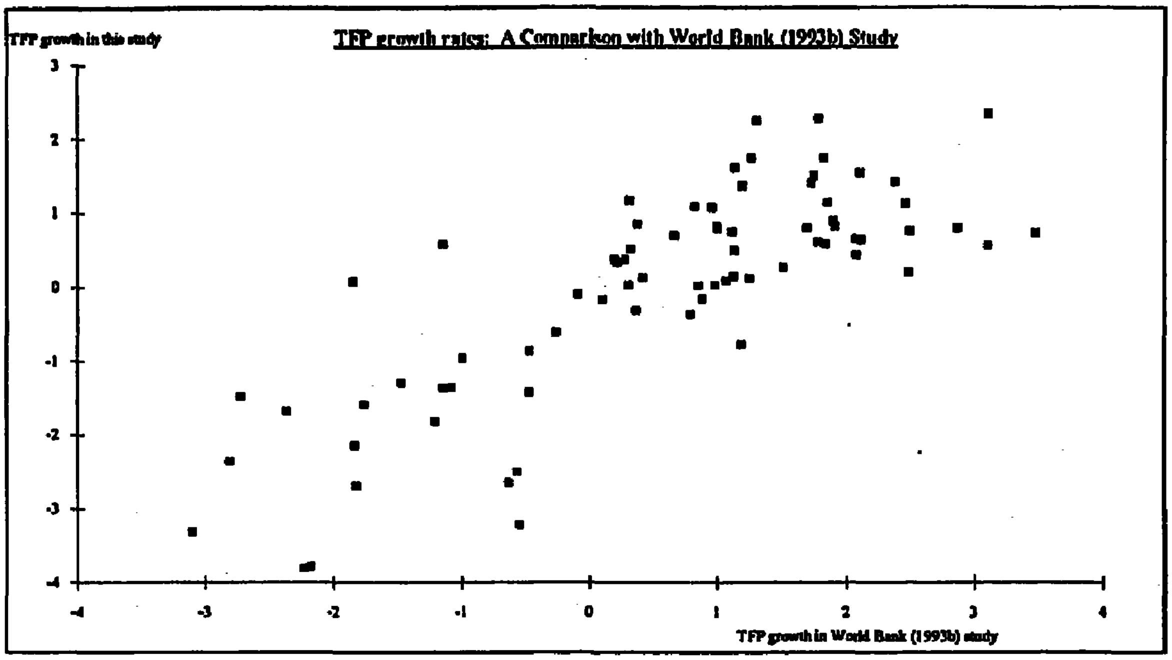
Annex 1: Estimates of TFP Growth Rates from Alternative Models, 1960-90
(annual percentage changes)

	Error-Correction Model		First-Difference Model	
	Without human capital	With human capital	Without human capital	With human capital
High-Income OECD				
Australia	0.28	0.81	0.78	1.59
Austria	0.18	0.63	1.18	1.46
Belgium	0.87	1.13	1.67	1.78
Canada	0.82	1.60	1.35	2.26
Switzerland	-0.62	-0.16	0.33	0.98
Germany	0.00	0.79	0.69	1.42
Denmark	-0.11	0.02	0.73	1.08
Spain	0.02	0.20	1.57	1.74
Finland	1.05	0.81	1.71	1.47
France	0.08	0.60	1.05	1.64
United Kingdom	0.06	0.15	0.76	1.07
Ireland	0.53	1.54	1.61	2.39
Iceland	1.11	1.49	1.52	2.32
Italy	0.96	1.12	1.71	1.85
Japan	0.03	0.72	1.82	2.68
Luxemburg	1.01	...	1.56	...
Netherlands	0.12	0.78	0.77	1.39
Norway	1.32	1.74	1.72	2.46
New Zealand	-0.29	-0.11	0.14	0.43
Sweden	0.36	0.48	1.09	1.38
United States	0.56	1.08	1.07	1.74
Other High-Income				
Cyprus	2.26	2.33	3.23	3.27
Israel	1.29	0.88	1.97	1.57
Kuwait	-8.51	...	-6.86	...
Taiwan, China	0.41	...	2.21	...
Singapore	-0.61	-0.77	1.22	0.61
Africa				
Angola	-3.12	-7.14	-1.08	-5.98
Cote dIvoire	-0.93	-2.66	-0.10	-2.04
Cameroon	-0.12	-0.86	-0.16	-0.76
Ethiopia	-1.35	-2.51	-1.04	-2.21
Ghana	-1.45	-2.70	-1.21	-2.43
Kenya	2.38	2.24	2.25	1.91
Madagascar	-1.37	-1.48	-1.02	-1.20
Mali	0.77	-2.15	0.78	-2.54
Mozambique	-2.51	-3.11	-1.55	-2.82
Mauritius	1.68	1.73	2.32	2.51
Malawi	-1.27	0.01	-0.14	1.23
Nigeria	-2.86	-3.78	-1.42	-3.30
Rwanda	-0.72	0.07	-1.16	-0.28
Sudan	-2.42	-3.81	-2.32	-3.99
Senegal	-0.08	-2.37	0.14	-2.39
Sierra Leone	-0.65	-1.83	0.09	-1.33
Tanzania	-0.10	-1.43	0.52	-1.48
Uganda	-4.05	-4.11	-2.48	-2.39
South Africa	-0.87	...	-0.15	...
Zaire	-1.10	-1.37	-0.91	-1.22
Zambia	-0.46	-1.60	-0.39	-1.59
Zimbabwe	0.74	1.15	0.92	1.26

Continued.

Annex 1: Estimates of TFP Growth Rates for Alternative Models, 1960-90 (Continued)
(annual percentage changes)

	Error-Correction Model		First-Difference Model	
	Without human capital	With human capital	Without human capital	With human capital
East Asia & Pacific				
Myanmar	0.45	0.51	0.10	0.15
China	2.76	2.27	2.23	1.64
Indonesia	0.19	0.12	1.05	0.55
Korea	0.71	0.55	2.43	2.21
Malaysia	-0.18	0.09	1.11	0.96
Philippines	-0.84	0.02	-0.14	0.44
Thailand	0.09	0.75	1.73	2.21
South Asia				
Bangladesh	0.34	0.58	0.55	0.98
India	0.22	-0.36	0.83	0.14
Srilanka	0.10	0.74	0.75	1.31
Pakistan	0.43	0.58	0.98	1.32
Middle East & North Africa				
Algeria	0.52	0.84	-0.06	0.04
Egypt	0.80	1.41	1.49	2.11
Iran	-2.86	-3.23	-1.24	-2.06
Iraq	-2.67	-3.32	-2.67	-3.46
Jordan	-0.56	-1.50	0.57	0.03
Libya	-4.61	...	-1.79	...
Morocco	0.03	-1.32	1.64	-0.05
Tunisia	0.83	0.38	1.47	0.77
Europe & Central Asia				
Greece	0.50	0.78	1.62	1.84
Malta	3.98	...	3.64	...
Portugal	0.85	0.65	1.92	1.48
Turkey	0.46	0.43	1.31	1.28
Americas				
Argentina	-0.63	-0.32	-0.27	0.22
Bolivia	-0.60	-0.61	-0.02	-0.23
Brazil	0.72	1.39	1.05	1.98
Chile	0.11	0.37	0.69	0.96
Colombia	0.87	1.36	1.10	1.60
Costa Rica	-0.55	0.37	0.15	1.06
Dominican Rep.	-0.36	...	0.07	...
Ecuador	1.36	2.20	1.23	1.81
Guatemala	-0.02	0.67	0.43	1.03
Guyana	-1.32	...	-1.35	..
Honduras	-0.08	0.32	0.21	0.72
Haiti	-1.97	-1.69	-1.53	-1.23
Jamaica	-1.07	-0.96	-0.20	-0.32
Mexico	-0.28	0.68	0.41	1.26
Nicaragua	-3.03	...	-2.24	...
Panama	-0.70	0.26	0.08	1.51
Peru	-0.53	0.12	-0.63	0.83
Paraguay	-0.53	1.07	0.21	1.63
El Salvador	-1.53	-1.36	-0.58	-0.48
Trinidad-Tobago	-1.84	...	-1.12	...
Uruguay	0.46	-0.17	0.59	-0.04
Venezuela	-1.45	-1.30	-0.85	-0.78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TFP growth rates: A Comparison with World Bank (1993b) Study
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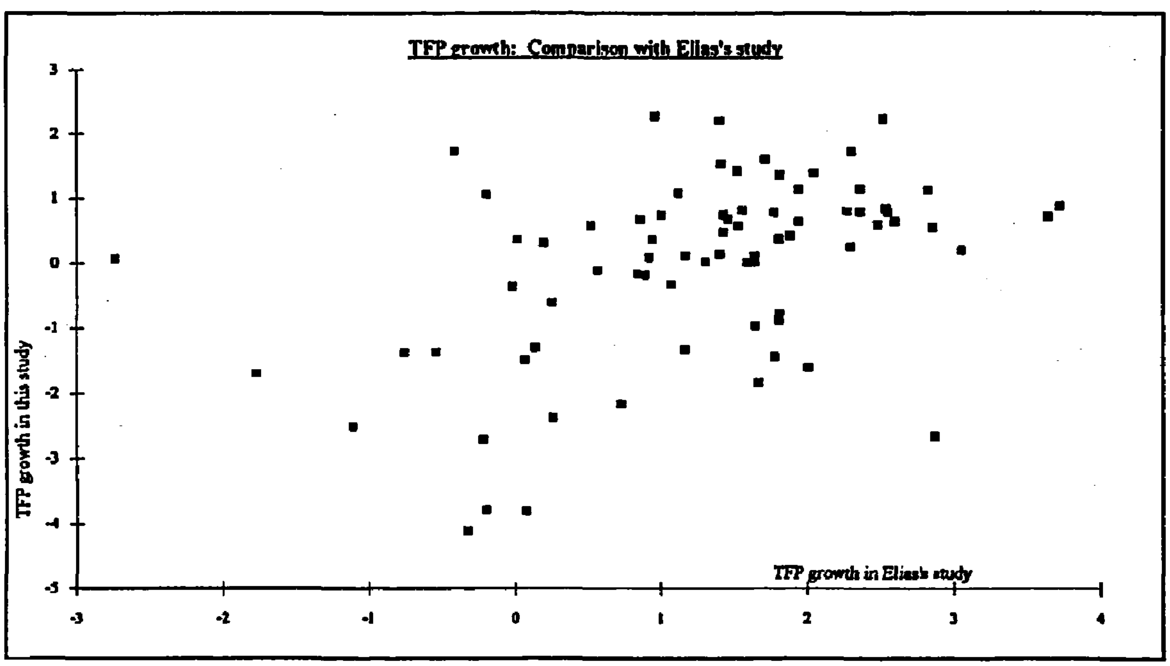
TFP growth in World Bank (1993b) study


TFP growth: Comparison with Elias's study
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TFP growth in this study
TFP growth in Elias's study
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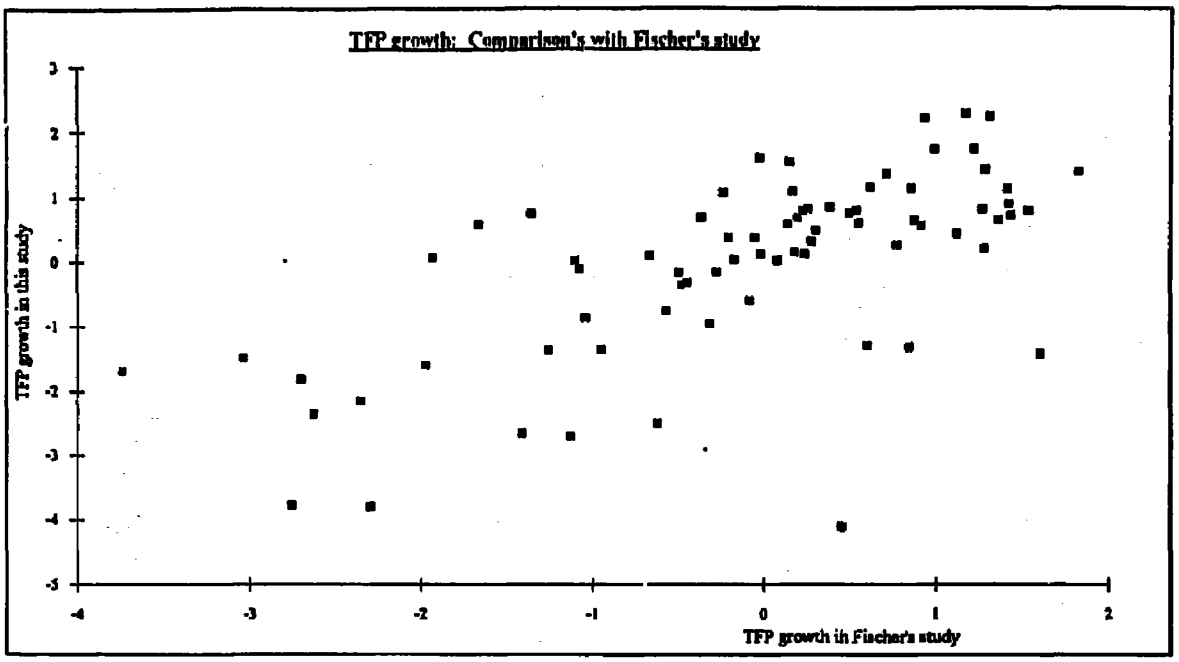
TFP growth: Comparison's with Fischer's study
TFP growth in this study
TFP growth in Fischer's study
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ANNEX 3: List of policy and structural variables used in testing for robust effect on TFP growth

Variable	*Description of variable*
aveqshr	share of capital equipment in gross domestic investment
bmp	black market premium
bmpl	black market premium (calculated by Jong-Wha Lee)
bms	standard deviation of the black market premium
btot	ratio of deposit banks' domestic assets to the sum of deposit banks' and central bank's domestic assets
civl	index of civil liberties
curo	currency outside the banking system as a share of GDP
dcpt	ratio of private domestic assets to total domestic assets
dcpy	ratio of gross claims on the private sector by the central bank
gbtot	growth of btot
gcuro	growth of curo
gdc	growth rate of domestic credit
gdcpt	growth of dcpt
ggov	growth of gov
glly	growth of lly
gm	growth of imports
gov	share of government consumption in GDP
gpi	growth of the price index
gpo	growth rate of the population
gqlly	growth of qlly
gsg	growth rate of share of government consumption in GDP
gtot	growth of tot
gtrd	growth of trd
gx	growth rate of exports
gyp	growth rate of per capita GDP
index1	composite index including variables measuring macroeconomic stability and the incentive structure (Thomas and Wang, 1993).
index2	composite index including public various public sector variables (from Thomas and Wang, 1993)
inv	share of investment in GDP
lit	literacy rate
lly	share of liquid liabilities of the banking system to GDP
m	share of imports in GDP
msg	growth of m
pi	average price index

List of policy and structural variables used in testing for robust effects (cont.)

pop	population
pri	primary enrollment rate
qlly	share of quasi-liquid liabilities of the banking system to GDP
revc	number of revolutions and coups per year
sec	enrollment rate in secondary schools
share	share of primary commodities in total exports
stgd	standard deviation of gross domestic credit
stpi	standard deviation of inflation
sury	share of government surplus (deficit) in GDP
tot	terms of trade
trd	ratio of trade (exports and imports) to GDP
x	share of exports to GDP
xsg	growth of x

Where the variable is a ratio, the simple average of the annual ratio was calculated for the period as a whole (usually 1960-89). In addition, the initial 1960 value of most variables was used to determine if initial conditions affected subsequent TFP growth performance (this denoted with the suffix "60"). In all, over 60 structural and policy variables were investigated for their relationship with TFP growth performance. The shaded variables were significant when entered singly along with the base variables.

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