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Total Factor Productivity Revisited: A Dual Approach to Development Accounting

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This paper tackles a number of issues that are central to cross-country comparisons of productivity. We develop a "dual" method to compare levels of total factor productivity (TFP) across nations that relies on factor price data rather than the data on stocks of factors required by standard "primal" estimates. Consistent with the development accounting literature based on primal estimates, we find that TFP accounts for much of the differences in income per worker across countries. However, we also find that there are significant differences between TFP series calculated using the two approaches. We trace the reason for this divergence to inconsistencies between the data on user costs of capital and physical stocks of capital. In addition, we establish that the standard Cobb-Douglas methodology of assuming a constant capital share of one-third for all countries is a very good approximation to a more general formulation under which countries have different aggregate production functions that do not require a constant elasticity of substitution among factors. [JEL O47, O57]

Recent studies suggest that differences in total factor productivity (TFP) explain most of the variation in per capita income observed across countries (Islam, 1995; Klenow and Rodriguez-Clare, 1997; Hall and Jones, 1999; Aiyar and Feyrer,

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2001; Easterly and Levine, 2001). If this is indeed the case, or if the role of TFP is even a fraction as important as the consensus suggests, a closer look at how TFP is measured merits considerable attention.

Several contributions have stressed the problems associated with measuring, in particular, the stock of physical capital. Pritchett (2000) argues that the standard procedure for calculating the stock of capital—the perpetual inventory method—is likely to severely mismeasure the actual stock of capital and thus its growth contribution. Hsieh (1999, 2002) voices similar concerns in his work on the seemingly miraculous growth experience of a set of East Asian countries. Hsieh notes that if capital accumulation has been as important to East Asian growth as the influential studies by Young (1992, 1995) suggest, one should have observed a secular decline in the real return to capital investment in these countries. He documents that this did not occur, and proceeds to calculate "dual" TFP growth estimates. This approach relies on factor prices rather than physical stocks of inputs, thereby extending a literature that dates back to Griliches and Jorgenson (1967). The result is a marked upward correction of TFP growth in almost all of the East Asian countries Young examined.

Hsieh's approach allows the calculation of only *growth rates*—not levels—of TFP for a single country. Our central contribution is to extend this growth-accounting methodology to the field of development accounting, by showing how a dual approach can be used to calculate the level of TFP at a single point in time for a cross section of countries. We use the dual approach to calculate TFP levels for 22 OECD countries.

Empirically, our key result is a confirmation of the consensus view of the development-accounting literature: a large part of cross-country differences in income can be attributed to differences in TFP, not factors of production. In fact, our dual TFP estimates exhibit even greater variance across countries than do their primal counterparts.

Although both primal and dual methodologies confirm the importance of TFP, we find that the TFP series calculated by the primal and dual methods are far from identical (the correlation between them is 0.46), and are significantly different in their ranking of countries. We examine different possible sources for the divergence between the two series and find that it can be accounted for by inconsistencies between our data on the user costs of capital and our data on capital stocks. Using particular country examples, we discuss how these inconsistencies lead to systematic movements in the relative magnitude of primal and dual estimates. The inconsistencies we find are noteworthy in that they arise from empirical sources that are commonly and extensively used by researchers in a number of economic fields. Moreover, they arise for a sample of the richest countries in the world, which may be expected to have the most reliable data. One of the most useful roles of dual TFP estimates should therefore be to alert a researcher about inconsistencies in the data for countries in which divergence between primal and dual estimates is large.

To carry out our development-accounting exercise, we need make minimal assumptions about the production function. In particular, we do not have to assume a Cobb-Douglas formulation, or even a constant elasticity of substitution among factors of production. This allows us to employ different factor shares for different countries. We use national accounts data to obtain factor shares for different countries, rather than assuming a capital share of one-third for all countries, as is standard in the literature. This enables us to test whether the Cobb-Douglas production function is a good approximation of the real world; if it were not, we would expect our TFP series (calculated on the basis of a generalized production function) to diverge considerably from the series obtained by assuming Cobb-Douglas for all countries in the world. In fact our results strongly validate the use of Cobb-Douglas production functions; the correlation between the two series is 0.99 for both primal and dual estimates.

I. Theory

The Solow growth-accounting technique (Solow, 1957) requires only the assumptions of constant returns to scale (CRS) in the production function and perfect competition. Denoting output by Y, the production function for a country may be written as

$$Y = AF(K, H), \tag{1}$$

where A represents TFP, K is the stock of physical capital in that country, and F is a function that is homogeneous of degree one in its two arguments. H is the country's stock of human capital, defined by $H = hL$, where h is the average level of education and L is the country's labor force. Solow showed that the production function above yields the following growth-accounting identity:

$$\hat{A} = \hat{y} - \alpha_K \hat{k} - \alpha_H \hat{h}, \tag{2}$$

where $y = Y / L$, $k = K / L$, and $h = H / L$; α_K and α_H refer to the share of physical capital and human capital, respectively, in national output;[1] and hats above variables denote growth rates.

With constant returns to scale and perfect competition, there are no aggregate profits in the economy, so we have the national accounts identity $Y = rK + w_H H$, where r and w_H are the returns to physical and human capital, respectively. Griliches and Jorgenson (1967) showed that this identity in conjunction with equation (2) implies

$$\alpha_K \hat{r} + \alpha_H \hat{w} = \hat{A} = \hat{y} - \alpha_K \hat{k} - \alpha_H \hat{h}. \tag{3}$$

Equation (3) shows us how to obtain both dual (left side) and primal (right side) estimates of TFP growth, using only the assumptions of CRS and perfect competition. This is the identity popularized by Hsieh in his work on East Asia.

Equation (3) is a differential equation whose discrete version may be used to calculate growth rates of TFP over time. However, following Hall and Jones (1996), we consider a cross-sectional interpretation of the equation. Imagine that

[1] Strictly speaking, $\alpha_K = AF_K / Y$ and $\alpha_H = AF_H / Y$. But the assumption of perfect competition ensures that factors are paid their marginal products, so that α_K and α_H may be treated as factor shares that sum to unity.

all the countries in the world are ranked along a continuum, with i denoting the country index. We can reinterpret the hats above variables as denoting the proportional difference in a particular variable between two adjacent countries along the continuum. For example, $\hat{r} = \frac{d \log r_i}{di}$. The factor shares are functions of the country index i, not constants.

To employ the above derivation, we must rank countries so that similar ones are close to each other, because the cross-sectional formulation assumes that factor inputs, factor prices, and factor shares are differentiable functions of the country index. Our ranking system uses an index that combines countries' capital shares, capital-labor ratios, and human capital–labor ratios (for the primal estimates), and an index that combines countries' capital shares, returns to human capital, and returns to physical capital (for the dual estimates).[2] Once the countries have been sorted by this index, the TFP level for country i is recovered as

$$\log A_i = \int_0^i \hat{A}_j dj + \log A_0, \tag{4}$$

or, in discrete terms,

$$\log A_i = \sum_{j=2}^{i} \Delta \log A_j + \log A_1. \tag{5}$$

Finally, discretizing equation (3) allows us to obtain

$$\bar{\alpha}_{K_i} \Delta\log r_i + \bar{\alpha}_{H_i} \Delta\log w_i = \Delta\log A_i = \Delta\log y_i - \bar{\alpha}_{K_i} \Delta\log k_i - \bar{\alpha}_{H_i} \Delta\log h_i, \tag{6}$$

where $\bar{\alpha}_{H_i} = 0.5(\alpha_{H_i} + \alpha_{H_{i+1}})$ and $\bar{\alpha}_{K_i} = 0.5(\alpha_{K_i} + \alpha_{K_{i+1}})$. To summarize our procedure, we use the data we have on factor prices, factor shares, and factor stocks to calculate primal and dual estimates of $\Delta\log A_i$ using equation (6). Equation (5) is then used to convert the two series of $\Delta\log A_i$ into levels of $\log A_i$. Because of the normalization implicit in equation (5), our TFP estimates are valid only up to a constant term.[3]

II. Data

To make equation (6) operational, data on the real stocks of capital, GDP per worker, income shares, and factor prices are required. We obtained such data on 22 OECD countries for 1980 and 21 for 1990.[4] Because the cross-sectional

[2] For the primal rankings, we use an index z, which equals $z_{\log k} + z_{\alpha_K} + z_{\log h}$, where $z_x = (x - mean(x)) / std(x)$. For the dual rankings we use $z_{\log w} + z_{\alpha_K} + z_{\log r}$.

[3] In fact when we calculate TFP for a sample of n countries, we are able to obtain only the series for $n - 2$ of them. We lose one observation in the calculation of labor's share, and another when we perform the discrete version of integrating over the continuum of countries.

[4] This discrepancy is due to lack of necessary labor data on Switzerland for 1990.

methodology outlined above requires that the countries under consideration be sufficiently "similar," we pool the data to get a denser clustering of countries. Hence, we treat our selection of countries as a set of 43 distinct observations, effectively assuming that, say, the United States in 1980 is a different country from the United States in 1990.

Stocks of physical capital and output per worker are taken directly from the Penn World Tables 5.6 (PWT).[5] To compute the aggregate stock of human capital, we need data on human capital per worker, h, and total employment. Human capital is estimated in a way that has become fairly standard. We use Mincerian coefficients estimated by Psacharopoulos (1994) to weight the average years of primary (*pyr*), secondary (*syr*), and higher (*hyr*) education in a country. Assuming that the log of human capital per person is piecewise linear, we get that[6]

$$\log h = .134 * pyr + .101 * syr + .068 * hyr. \tag{7}$$

Data on total employment are obtained from the *Yearbook of Labour Statistics* (ILO, 1998) for L in 1990, and the OECD Statistical Compendium (OECD, 1996) for L in 1980. Note that these numbers include both paid employees and the self-employed.

Both the primal and dual methods require data on factor shares. To compute the share of human capital in total income, we use data on GDP and on the compensation of employees from the National Accounts Statistics (United Nations, 1993). One problem with estimating the share of human capital as the total compensation of employees divided by GDP is that total compensation excludes the self-employed. Hence, following Gollin (2002), we adjust for the wage income of the self-employed by assuming that the wage share in the unincorporated sector is equal to its share in the corporate sector. The correction requires a few simple steps. First, we obtain both total employment and the number of self-employed workers (classified as "Employers and own account workers") from the *Yearbook of Labour Statistics* (ILO, 1981, 1992), allowing us to compute the ratio of self-employed workers to paid employees. Second, we estimate the (adjusted) share of human capital as

$$\alpha_H = \frac{(\text{compensation of employees})\left(1 + \dfrac{\text{self-employed workers}}{\text{paid employees}}\right)}{\text{GDP}}. \tag{8}$$

[5]The PWT make data available on five categories of capital. We use all of them to calculate the aggregate stock of physical capital.

[6]The basic idea that this is the appropriate way to introduce human capital into an aggregate production function comes from Bils and Klenow (2000). Here we duplicate Hall and Jones (1999) in using Mincerian coefficients estimated by Psacharopoulos; that is, we use the average Psacharopoulos reports for sub-Saharan Africa to weight primary education, the average for the world as a whole to weight secondary education, and the OECD average to weight higher education. An alternative approach would be to allow for variation in the return to education, using micro estimates for individual countries with respect to primary, secondary, and tertiary years of schooling. Such data are not available for the countries in our sample, which is why we employ the standard approach.

Assuming CRS, the capital share is then given by $\alpha_K = 1 - \alpha_H$. To achieve an accurate estimate for the annual wage itself, we divide the total compensation of employees by an estimate of the total number of paid employees. Specifically,

$$w = \frac{\text{compensation of employees}}{(\text{total employment})\left(1 - \dfrac{\text{self-employed workers}}{\text{total employment}}\right)}. \tag{9}$$

These wages are then converted into 1980 international dollars for comparability. Note that the wage rate calculated above is the compensation per unit of (raw) labor, which we may denote as w_L, whereas what we need for the exercise we have outlined is w_H, the compensation per unit of human capital. From the production function in equation (1) and our assumption of perfect competition, it follows that

$$w_H = AF_H \tag{10}$$

and

$$w_L = AF_H h. \tag{11}$$

Therefore, $w_H = w_L / h$, and $\log w_H = \log w_L - \log h$. Finally, we need an estimate of the real user cost of physical capital, r. Following Hall and Jorgenson (1967), we apply the following formula:

$$r = \frac{P_I}{P_y}(i - \pi_I + \delta), \tag{12}$$

where P_I is the price of a new unit of capital, P_y is the product price, i is the relevant nominal interest rate, π_I is the (expected) increase in the investment price, and δ is the (geometric) rate of depreciation. The right-hand side of equation (12) simply quantifies the marginal cost of capital, assuming competitive markets along with the absence of convex costs of installation and investment irreversibility. To see this, note that since profit maximizing behavior implies $F_K = r$, equation (12) can be rewritten to yield $F_K \frac{P_y}{P_I} = \left(i - \pi_y + \delta - (\pi_I - \pi_y)\right)$, where π_y is the rate of inflation. Thus, the equation states that, in units of output, the marginal product of capital $\left(F_K \frac{P_y}{P_I}\right)$, net of depreciation plus capital gains $(\delta - (\pi_I - \pi_y))$, equals the real rate of interest $(i - \pi_y)$.[7] To apply this formula, we use data from the PWT for P_I (the aggregate investment price index) and P_y (the GDP deflator).[8] In measuring i, we use lending rates taken from the *International Financial Statistics Yearbook* (IMF, 1995). π_I is derived as the

[7] In the case of a one-good economy, where $p_y = p_I$ (thus, $\pi_I = \pi_y$), equation (12) simply states that the marginal product of capital equals the real rate of return plus depreciation.

[8] We would prefer to estimate separate user costs for each category of capital in the PWT, but the individual investment prices are not available.

Table 1

	$\frac{\text{COV}(\log y, \log A)}{\text{VAR}(\log y)}$	$\frac{\text{COV}(\log y, \log Z)}{\text{VAR}(\log y)}$	$\frac{\text{VAR}(\log A)}{\text{VAR}(\log y)}$
Primal	0.32	0.68	0.44
Dual	0.35	0.65	0.76

lagged percentage increase in the aggregate investment price index. The depreciation rates on the five categories of capital available in the PWT are taken from Hulten and Wyckoff (1981). The depreciation rate ultimately used in our user-cost expression is then computed as a weighted average of these five depreciation rates, the weights being the relative sizes of the individual categories of capital in the total stock of capital. The resulting series for α_H, w, and r are reported in the appendix.

III. Results: Primal vs. Dual

Following Klenow and Rodriguez-Clare (1997) it is possible to decompose the variation in per capita output levels in our sample into that explained by variation in factors of production (or factor returns) and that explained by variation in TFP, calculated by both the primal and dual methods. Formally,

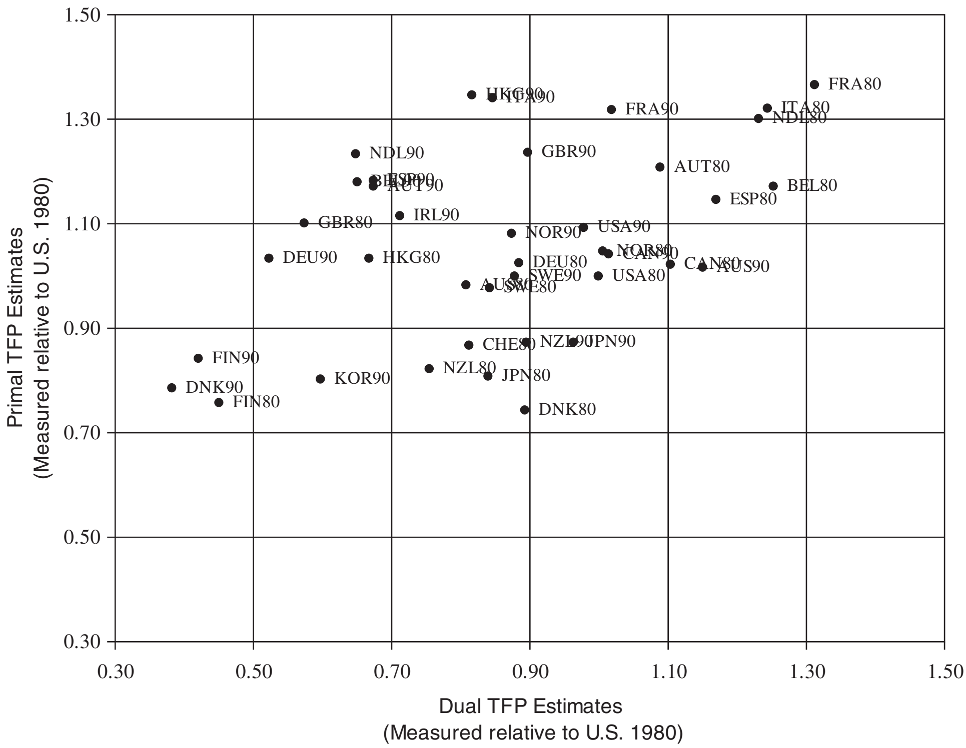
$$\frac{\text{Var}(\log y)}{\text{Var}(\log y)} = 1 = \frac{\text{Cov}(\log A, \log y)}{\text{Var}(\log y)} + \frac{\text{Cov}(\log Z, \log y)}{\text{Var}(\log y)}, \tag{13}$$

where $Z \equiv F(K / L, h)$. The important question is whether there are significant differences in the share of the variation accounted for by our two methodologies. The answer is provided in Table 1.

Columns 1 and 2 reveal that the share of the variation in output attributable to TFP is of the same order of magnitude whether dual or primal estimates are used. However, as the third column makes clear, dual TFP estimates vary much more across the sampled countries than do their primal counterparts. This phenomenon is also clear in Figure 1, which shows a cross-plot of the primal and dual estimates. The size of this TFP variation is all the more striking considering that we are examining a group of relatively homogeneous OECD countries. The primal and dual decompositions yield similar results only because the implicit covariance between calculated TFP levels and log Z is different in magnitude. In general, the variance of log y is given by the sum of the variances of log A and log Z plus twice the covariance between the two—the Klenow and Rodriguez-Clare decomposition distributes the covariance evenly between log A and log Z. Accordingly, both primal and dual TFP estimates are negatively correlated with the factor index log Z, but dual estimates are more so.[9]

[9]A similar negative covariance between levels (and growth rates) of factor stocks and levels (and growth rates) of TFP is present in the Klenow and Rodriguez-Clare study. A possible explanation is that standard calculations omit capital utilization (Dalgaard, 2003).

Figure 1



The key conclusion we draw from this exercise is that the dual TFP calculations support previous studies (based on primal calculations) that show that TFP differences, not differences in physical stocks of capital, are paramount in accounting for cross-country productivity differences.

At a more detailed level, Table 2 shows the ranking of all the sampled countries using both primal and dual approaches.[10] It is immediately apparent that there are significant differences in the ranking of countries using the two different sets of TFP estimates. In fact, the correlation between the TFP series is only 0.46. The United States (1990) moves up from rank 16 in the primal series to rank 13 in the dual series, and the United States (1980) moves up 13 places, from 25 to 12. Hong Kong[11] in 1990 moves from being the second most productive country to position 24.

It is interesting to note that by both primal and dual methodologies, a number of countries move down in the productivity rankings in 1990 compared with their

[10] For this exercise, we are using national accounts data to estimate factor shares, as described in the previous section. Recall also that we are treating a country in 1980 and a country in 1990 as different points along the continuum, so that we have a "cross section" of 43 countries (we lack data for Switzerland in 1990). We have to drop two observations in both the primal and dual estimation procedures, but there is an overlap of one country. Thus, for purposes of comparison the final sample size is 40.

[11] This territory was referred to as Hong Kong before July 1, 1997.

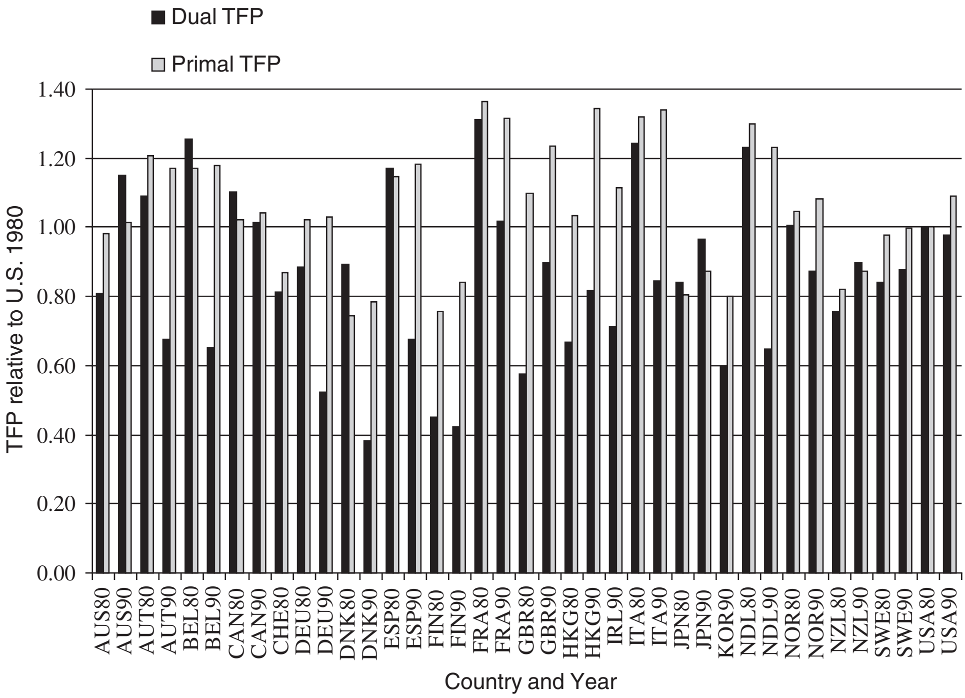
Table 2

Year	Primal Approach	Rank	Year	Dual Approach
1980	FRA	1	1980	FRA
1990	HKG	2	1980	BEL
1990	ITA	3	1980	ITA
1980	ITA	4	1980	NDL
1990	FRA	5	1980	ESP
1980	NDL	6	1990	AUS
1990	GBR	7	1980	CAN
1990	NDL	8	1980	AUT
1980	AUT	9	1990	FRA
1990	ESP	10	1990	CAN
1990	BEL	11	1980	NOR
1980	BEL	12	1980	USA
1990	AUT	13	1990	USA
1980	ESP	14	1990	JPN
1990	IRL	15	1990	GBR
1990	USA	16	1990	NZL
1990	NOR	17	1980	DNK
1980	NOR	18	1980	DEU
1990	CAN	19	1990	SWE
1980	HKG	20	1990	NOR
1990	DEU	21	1990	ITA
1980	DEU	22	1980	SWE
1980	CAN	23	1980	JPN
1990	AUS	24	1990	HKG
1980	USA	25	1980	CHE
1990	SWE	26	1980	AUS
1980	AUS	27	1980	NZL
1980	SWE	28	1990	IRL
1990	NZL	29	1990	AUT
1990	JPN	30	1990	ESP
1980	CHE	31	1980	HKG
1990	FIN	32	1990	BEL
1980	NZL	33	1990	NDL
1980	JPN	34	1990	KOR
1990	KOR	35	1980	GBR
1990	DNK	36	1990	DEU
1980	FIN	37	1980	FIN
1980	DNK	38	1990	FIN
1980	KOR	39	1990	DNK

position in 1980. However, the number of such “switches” is greater in the dual rankings (12 switches) than in the primal rankings (6 switches).

Figure 2 shows a histogram of all the observations in which TFP levels are measured relative to the TFP level for the United States in 1980. For each country, the first two bars represent TFP in 1980 and the second two represent TFP in 1990. The black bars represent dual estimates, while the gray ones represent the

Figure 2



primal series. The most visually arresting aspect of the histogram is the shortness of the black bars relative to the gray ones; this disparity is largely due to the fact that the United States in 1980 moves up 13 places in the dual series rankings. In only 8 observations out of 40 is the productivity relative to the United States in 1980 higher according to the dual method compared with the primal method.[12]

Among the observations for which the differences between primal and dual estimates are most stark are Hong Kong, Britain, Denmark, and Finland in both years, and West Germany, Austria, Belgium, Spain, and the Netherlands in 1990. The contrast is clear from the discrepancy between the heights of the black and gray bars for these observations. In each of these cases the black bar is shorter than the gray one; measured productivity is greater by the primal method than by the dual method. Belgium, Canada, Denmark and Spain are interesting because they are the only countries in which the relative heights of the black and gray bars switch from 1980 to 1990; for each of these countries, dual TFP was higher than primal TFP in 1980, while the opposite held in 1990. Japan is the only country in the sample for which dual TFP was higher than primal TFP in both years.

What accounts for the striking divergence between the two TFP series? In the subsequent section we attempt to pinpoint the sources of the divergence. But first,

[12] These observations are Australia (1990), Belgium (1980), Canada (1980), Denmark (1980), Spain (1980), Japan (1980), Japan (1990), and New Zealand (1990).

it is worth noting that the divergence is not caused by any measurement issues regarding the stock of human capital. The reason is that w_H was calculated using data on human capital stocks.[13] Thus the dual estimates for TFP are not based only on factor returns but also on average educational levels. Since both dual and primal TFP estimates make use of the same measure of human capital, measurement error in human capital is not causing the observed divergence.

IV. Accounting for the Divergence in TFP Estimates

The poor correlation between dual and primal TFP estimates may arise for two reasons. The first possibility is that the theory on which the equality of dual and primal estimates is founded is wrong. This option is decidedly unattractive. All we need for the identity of primal and dual estimates is a production function with constant returns to scale in rival inputs and perfect competition. If these assumptions are not a good approximation to reality, then we must abandon not just the comparison between dual and primal but also growth- and development-accounting exercises altogether, since the standard primal estimates presented in the literature typically employ at least these assumptions and usually additional ones.

The second possibility is that the data on factor inputs and the data on factor prices are inconsistent with one another. To investigate to what extent this is the case, one can compare the factor price data used for the dual estimates with the wage and rental rates implied by our data on factor stocks and our theoretical assumptions. It is straightforward to obtain imputed series for rental rates and wage rates that are consistent with our data on factor shares, output per worker, and stocks of capital. Specifically, the imputed wage rate for raw labor in country i, w_{Li}, is obtained by multiplying the share of human capital by output per worker:

$$\tilde{w}_{Li} = \alpha_{Hi} \frac{Y_i}{L_i}. \tag{14}$$

Similarly, the imputed rental rate in country i, r_i, is given by

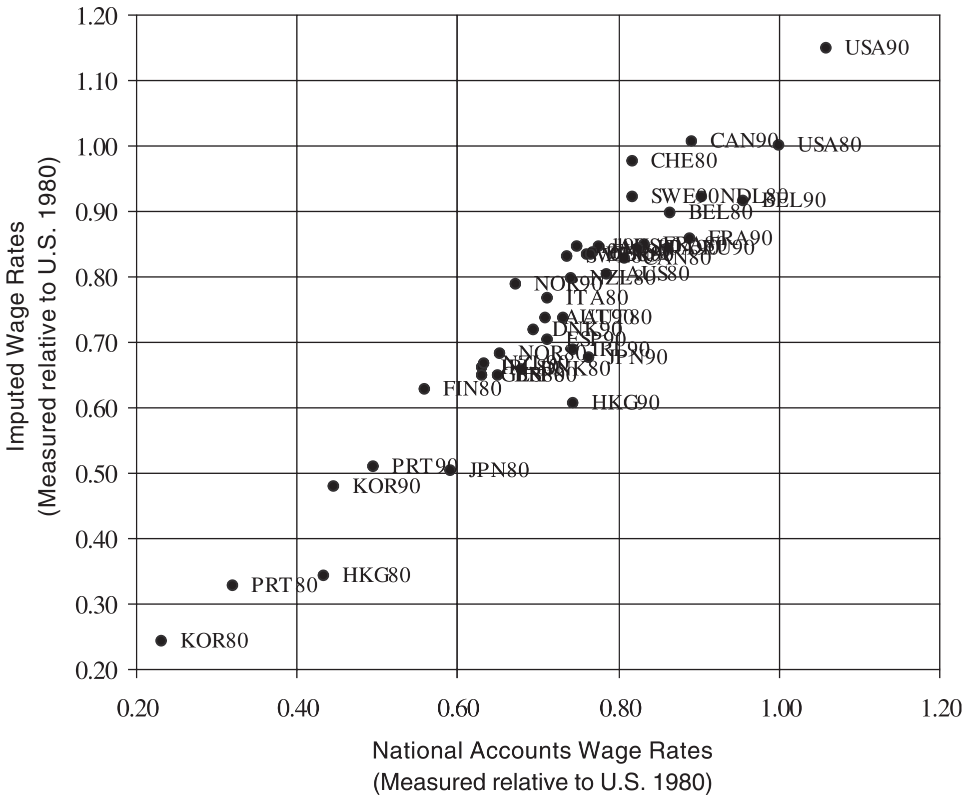
$$\tilde{r}_{Li} = \alpha_{Ki} \frac{Y_i}{K_i}. \tag{15}$$

Calculating the imputed wage and rental rates implied by our primal estimates allows us to pinpoint the source of divergence between primal and dual estimates (alternatively, we could have calculated the factor stocks consistent with our dual estimates).

Figure 3 measures the wage rates obtained from national accounts data (which we use for our dual estimates) on the horizontal axis; the vertical axis measures the wage rates imputed from our data on factor stocks (equation (14)). Both series are normalized by the U.S. wage rate in 1980. It is obvious that the two series are nearly identical; the correlation between them is 0.95. It follows that the wage data

[13] $\log w_H = \log w - \log h$.

Figure 3

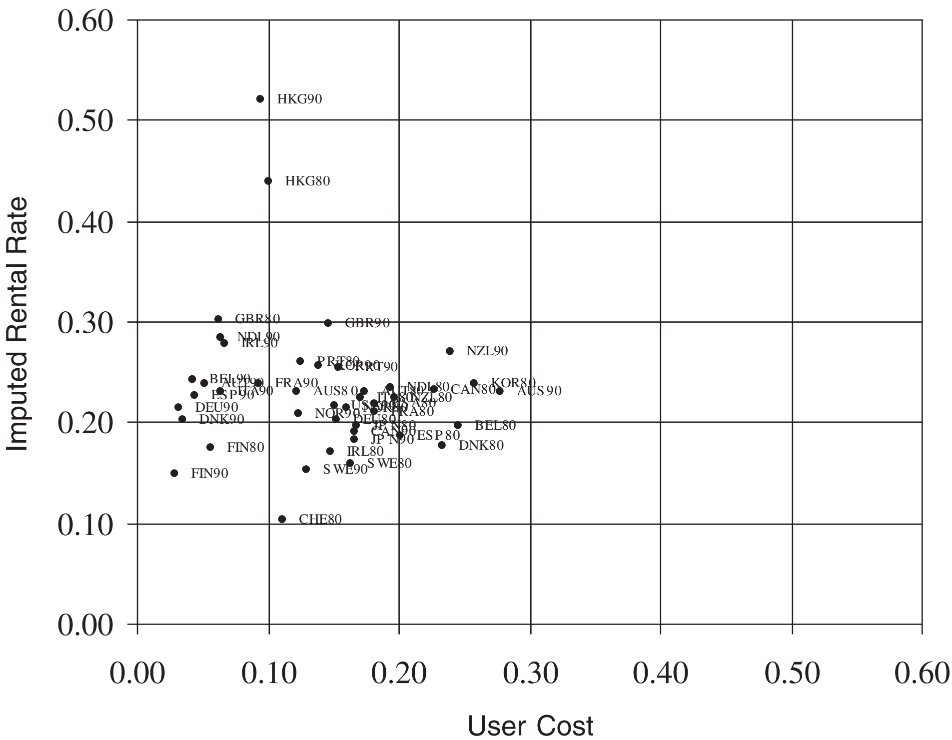


from the national accounts are consistent with perfect competition and our estimates of the labor force; the source of discrepancy between primal and dual estimates does not lie here.

By a process of elimination, therefore, it seems that the discrepancy must arise because our data on the user costs of capital are inconsistent with our data on capital stocks from the PWT. This hypothesis is confirmed when we calculate the rental rates implied by our data on capital stocks using equation (15). Figure 4 plots the imputed rental rates against the actual user costs of capital, and Table 3 (p. 96) lists them. It is clear that the two series have no discernable relationship to one another. The correlation coefficient is actually negative, at –0.14. In general, the imputed rates tend to be higher than the actual user costs. This is spectacularly evidenced by Hong Kong, whose imputed rate is 44 percent in 1980 and 52 percent in 1990.

So which data are more reliable: our series on the user costs of capital or our series on the capital stocks (which imply the rental rates on the vertical axis in Figure 4)? This question may not have a general answer. Countries and international institutions may differ in their ability to measure one or the other series correctly. An investigator must draw on detailed knowledge of the specific country under examination when deciding whether to trust dual or primal estimates of productivity. However, it is worth commenting on some specific characteristics of our

Figure 4



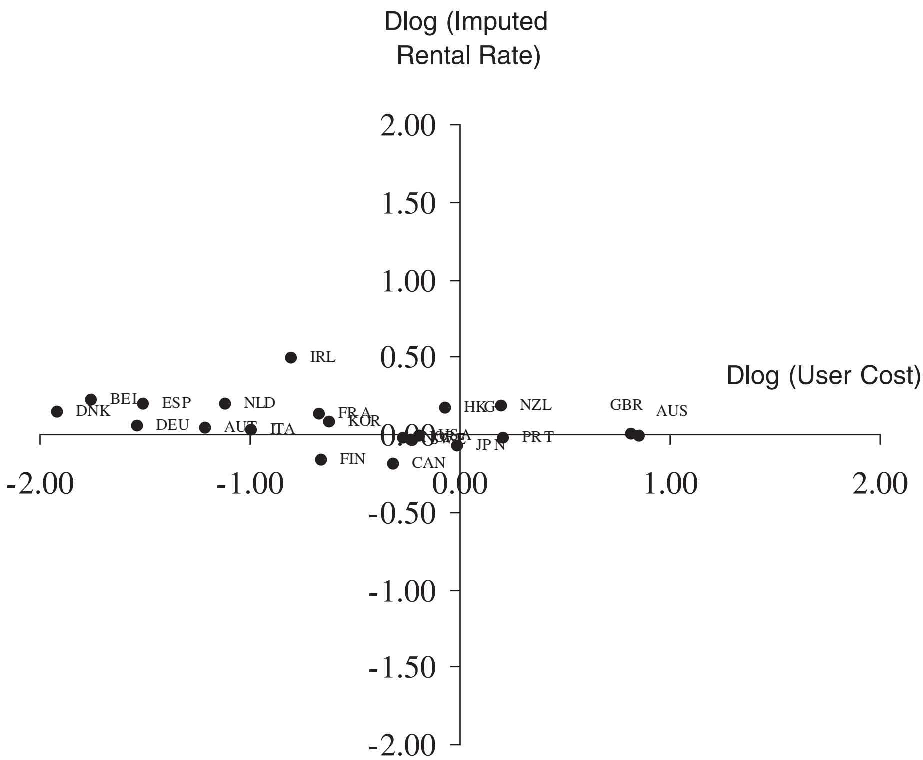
data on user costs that contrast with our imputed series and showing how these characteristics affect the comparison between primal and dual TFP for certain countries in our sample.

Figure 5 shows the proportionate changes in rental rates over the decade for all the countries in our sample, for both the actual series and the imputed series. The figure reveals a systematic difference between the two. While the imputed rental rates have tended to remain stable or increase slightly over the decade, the actual user costs in almost all countries seem to have fallen considerably. The appendix contains our complete series for the user costs of capital and documents this decline in user costs. This pattern sheds some light on the divergence between primal and dual TFP estimates.

We noted above that measured productivity declined over the 1980s in 12 countries by the dual measure, compared with 6 countries by the primal measure. This is directly attributable to the fall in user costs over the decade for these countries.

Figure 2 documented primal and dual TFP estimates for all the countries in our sample. The differences between the gray bars and black bars in this figure can be explained in terms of the divergence between user costs and imputed rental rates. For example, in Britain and Finland, the dual estimate is below the primal estimate in both years; Table 3 shows that this is because user costs are well below the level implied by capital stocks in both years. The imputed rental rate in Britain in both 1980 and 1990 was 30 percent. The corresponding actual user costs were 6 per-

Figure 5



cent and 15 percent, respectively. The imputed rental rates in Finland in 1980 and 1990 were 17 percent and 15 percent; the corresponding user costs were only 6 percent and 3 percent. We commented above that only Japan showed higher dual TFP than primal TFP for both years. Table 3 documents that for Japan the user costs in both years are fairly similar to the imputed rental rates. But because the latter are in general so much higher than the former, Japan's ranking among countries is much higher in the user costs series, which explains why its ranking is higher in the dual estimates.

Hong Kong shows the most glaring discrepancy between user costs and imputed rates. While its actual user costs in 1980 and 1990 are 10 percent and 9 percent, respectively, the imputed rental rates implied by its capital stocks are entirely unreasonable, at 44 percent and 52 percent, respectively. Unsurprisingly, its primal TFP estimates tower above its dual estimates.

What is one to make of the differences documented here? One approach would be to argue that capital is not being paid its marginal product, and, in particular, capital is being paid less than its marginal product (because in general the imputed rates are higher than the user costs). While this is a tenable interpretation of our results, it should be noted that such an argument would constitute an indictment of not just our dual estimates of productivity but also of most primal estimates that are standard in the literature. For if such imperfections are significant,

Table 3

Year	Country	Imputed Rental Rates	User Cost
1980	AUS	0.23	0.12
1990	AUS	0.23	0.28
1980	AUT	0.23	0.17
1990	AUT	0.24	0.05
1980	BEL	0.20	0.25
1990	BEL	0.24	0.04
1980	CAN	0.23	0.23
1990	CAN	0.19	0.17
1980	CHE	0.10	0.11
1980	DEU	0.20	0.15
1990	DEU	0.21	0.03
1980	DNK	0.18	0.23
1990	DNK	0.20	0.03
1980	ESP	0.19	0.20
1990	ESP	0.23	0.04
1980	FIN	0.17	0.06
1990	FIN	0.15	0.03
1980	FRA	0.21	0.18
1990	FRA	0.24	0.09
1980	GBR	0.30	0.06
1990	GBR	0.30	0.15
1980	HKG	0.44	0.10
1990	HKG	0.52	0.09
1980	IRL	0.17	0.15
1990	IRL	0.28	0.07
1980	ITA	0.22	0.17
1990	ITA	0.23	0.06
1980	JPN	0.20	0.17
1990	JPN	0.18	0.17
1980	KOR	0.24	0.26
1990	KOR	0.26	0.14
1980	NDL	0.23	0.19
1990	NDL	0.28	0.06
1980	NOR	0.22	0.16
1990	NOR	0.21	0.12
1980	NZL	0.22	0.20
1990	NZL	0.27	0.24
1980	PRT	0.26	0.12
1990	PRT	0.25	0.15
1980	SWE	0.16	0.16
1990	SWE	0.15	0.13
1980	USA	0.22	0.18
1990	USA	0.22	0.15
Average		**0.23**	**0.14**
Standard Deviation		**0.07**	**0.07**

then α_k no longer equals KF_K / Y, and standard growth- and development-accounting exercises lose all meaning.

The other interpretation of our results is that either capital stocks or user costs or both are being badly measured; certainly, they are not consistent if minimal theoretical requirements are satisfied. Are there then any grounds for suspecting that one series is measured more poorly than the other? This question, as we have stated before, seems answerable only in the context of detailed knowledge of particular countries. For example, we would be inclined to argue that in the case of Hong Kong, capital stocks have been mismeasured, simply on the grounds that an implied rental rate in excess of 40 percent is thoroughly implausible.

Whatever the particular circumstances of particular nations, it seems that the dual methodology that we have presented here provides a useful way for researchers to double-check the plausibility of their standard primal estimates of productivity. A large divergence among the estimates should alert the researcher to potential data problems, especially with regard to the measurement of capital stocks or user costs.

V. Income Shares and the Cobb-Douglas Hypothesis

As we mentioned above, all the results presented thus far have relied on estimating factor shares from national accounts data. We were able to do this because our minimal assumptions about the production function allowed us to use both country- and time-varying factor shares. We turn now to the issue of how well the standard Cobb-Douglas formulation holds up when compared with our more general method for estimating TFP. This question is of obvious interest and importance to empirical researchers. If the strong assumption of an identical Cobb-Douglas technology with a capital share of one-third for every country in the world leads to TFP estimates that are indistinguishable from ours, that is welcome news from both the perspective of validating recent research in the growth literature and the perspective of making future research less cumbersome.[14] If the Cobb-Douglas formulation is indeed valid, there is a very simple formula that may be used to obtain dual estimates of TFP. Suppose the production function takes the form

$$Y = AK^{\alpha_K} H^{\alpha_H}, \tag{16}$$

[14] Hall and Jones (1996) also use factor shares that vary across countries, but they obtain their factor shares by means of a calibration exercise rather than from the national accounts. In particular, they work with the identities $\alpha_{Ki} = r_i K_i / Y_i$ and $\alpha_{Hi} = 1 - \alpha_{Ki}$. Armed with data on capital stocks and national output, they calibrate the return on capital such that $\alpha_K = 1/3$ for the United States. They then assume that the return to capital in all nations is equal to that of the United States, and this assumption allows them to calibrate different factor shares for all nations. But they find that using this calibrated approach leads to TFP estimates that are extremely similar to TFP from a simple Cobb-Douglas methodology. The close correlation between the two series leads them to be satisfied with a Cobb-Douglas framework in subsequent work (Hall and Jones, 1999). Although the calibrated approach described above does allow one to employ different factor shares for each country, it is clearly a more restrictive approach than our methodology of using national accounts data. In particular, its assumption of equal rates of return to capital in all countries of the world appears to be contradicted by our data on factor prices (see Appendix).

where $\alpha_K = 1 - \alpha_H = 1/3$. Then, noting that by the assumption of perfect competition, $K = \alpha_K Y / r$ and $H = \alpha_H Y / w_H$, it follows that

$$A = Y / \left[\left(\frac{\alpha_K Y}{r} \right)^{\alpha_K} \bullet \left(\frac{\alpha_H Y}{w_H} \right)^{\alpha_K} \right] = \left(\frac{r}{\alpha_K} \right)^{\alpha_K} \bullet \left(\frac{w_H}{\alpha_H} \right)^{\alpha_K}. \tag{17}$$

Taking logs then gives us

$$\log A = \alpha_K \log r + \alpha_H \log w_H - \alpha_K \log \alpha_K - \alpha_H \log \alpha_H, \tag{18}$$

where the last two terms are constants that are equal for all countries. Equation (18) allows us to obtain dual estimates for the Cobb-Douglas approach; neither ranking countries along a continuum nor any process of integration to get from growth rates to levels is necessary under such a formulation.[15] Figures 6 and 7 show Cobb-Douglas estimates and our generalized estimates. It is immediately obvious that the data points cluster tightly around a 45-degree line from the origin. The correlation between the two series is very close to unity for the dual approach as well as for the primal approach. In both cases, the correlation is 0.99.[16] The great similarity of the Cobb-Douglas estimates to our generalized estimates leads us to conclude that, for the purposes of measuring TFP, assuming a fixed capital share of one-third is a convenient and accurate shortcut.

VI. Concluding Remarks

In this paper we developed a dual approach to development accounting. Comparing the results from this approach with the standard primal approach reveals significant differences between the two sets of TFP estimates for a group of 22 OECD countries. Our analysis reveals that the divergence between primal and dual TFP estimates is caused by data inconsistencies between the user costs of capital and physical stocks of capital. This finding suggests that even in rich countries with rigorously researched statistics, researchers should be aware that significant discrepancies may exist in the data. We have argued that there is no general rule that would identify which TFP estimates are preferable; what is needed is detailed knowledge of the particular country under consideration. Such knowledge may enable a researcher to determine whether data on user costs or data on capital stocks are more reliable on a case-by-case basis. The usefulness of having two methods of constructing productivity estimates is that their comparison can serve as a warning signal: a substantial divergence between the two should alert the researcher that the data on physical stocks and factor prices are inconsistent with each other or with the assumptions of growth accounting.

[15] Primal estimates of TFP under the Cobb-Douglas assumption are based on the familiar equation $\log A = \log Y - \alpha_K \log K - \alpha_H \log L - \alpha_H \log h$.

[16] When we compare the primal and dual estimates of TFP under the Cobb-Douglas formulation, we find the correlation to be 0.53, which is comparable to, albeit slightly higher than, the correlation we found between primal and dual series using our more general approach (0.46). This result mirrors the fact that the divergence between dual and primal TFP estimates is due to data inconsistencies.

Figure 6

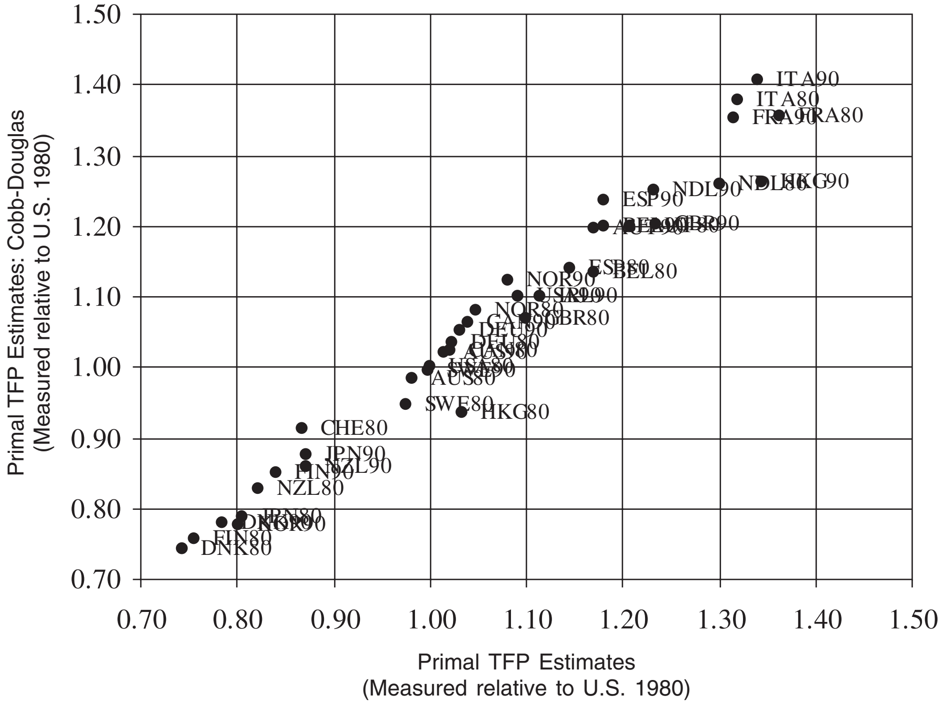
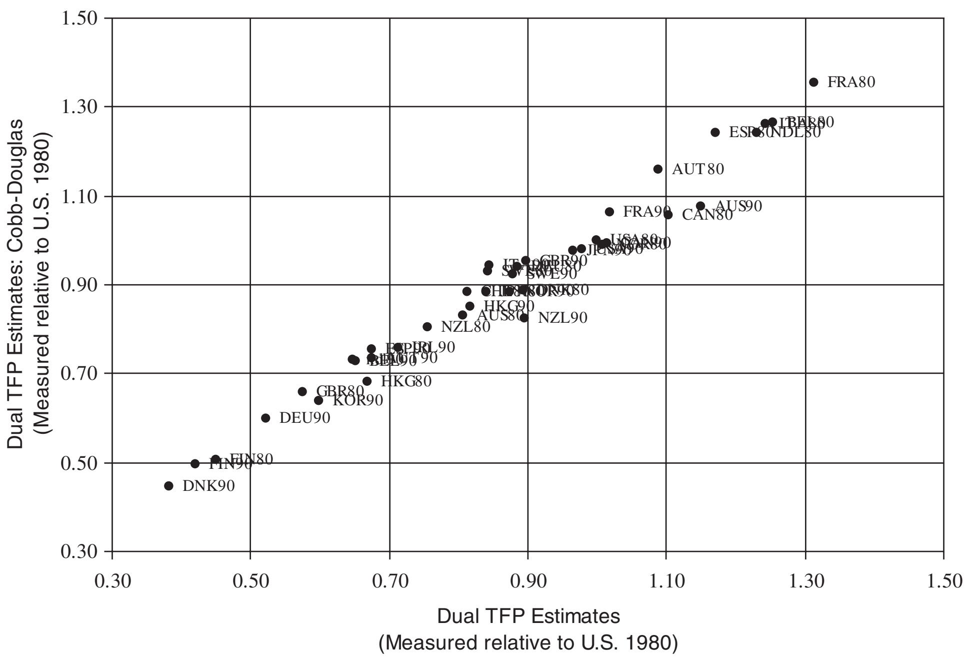


Figure 7



Whether one a priori has more faith in primal or dual estimates, one important conclusion is robust: the importance of TFP in accounting for cross-country income differences. Our dual estimates strongly support standard primal estimates of the relative importance of TFP and factor stocks. The variance in TFP levels is even greater under the dual methodology than under the traditional primal approach to development accounting.

Finally, we found evidence to suggest that the Cobb-Douglas formulation with a constant capital share of one-third is a very good approximation to a world in which countries have different production functions satisfying more general conditions. This is good news for growth researchers both in terms of increasing our confidence in previous work using the Cobb-Douglas formulation and in terms of allowing an accurate simplification of reality in future productivity studies.

APPENDIX

Year	Country	Human Capital Share	Annual Wage[1]	Log h	User Cost
1980	AUS	0.62	142.2	1.20	0.122
1990	AUS	0.59	140.7	1.21	0.277
1980	AUT	0.66	132.5	0.81	0.174
1990	AUT	0.58	128.6	0.86	0.052
1980	BEL	0.68	156.4	1.01	0.245
1990	BEL	0.61	173.0	1.07	0.042
1980	CAN	0.61	146.1	1.18	0.228
1990	CAN	0.61	161.7	1.22	0.166
1980	CHE	0.70	148.0	1.10	0.112
1980	DEU	0.64	137.8	1.09	0.152
1990	DEU	0.59	156.2	1.13	0.033
1980	DNK	0.64	123.2	1.29	0.234
1990	DNK	0.60	125.6	1.38	0.034
1980	ESP	0.64	117.8	0.66	0.202
1990	ESP	0.56	129.0	0.75	0.045
1980	FIN	0.61	101.3	1.22	0.056
1990	FIN	0.64	139.0	1.24	0.029
1980	FRA	0.67	150.9	0.73	0.181
1990	FRA	0.59	161.2	0.82	0.093
1980	GBR	0.64	114.3	1.00	0.062
1990	GBR	0.66	138.6	1.06	0.147
1980	HKG	0.51	78.3	0.81	0.101
1990	HKG	0.56	134.6	0.99	0.095
1980	IRL	0.75	114.4	0.93	0.148
1990	IRL	0.60	134.6	0.98	0.067
1980	ITA	0.60	129.1	0.65	0.171
1990	ITA	0.58	149.4	0.73	0.063
1980	JPN	0.65	107.1	0.98	0.167
1990	JPN	0.63	138.4	1.08	0.166
1980	KOR	0.63	41.8	0.82	0.259

Year	Country	Human Capital Share	Annual Wage[1]	Log h	User Cost
1990	KOR	0.63	80.9	1.10	0.139
1980	NDL	0.66	163.8	0.97	0.194
1990	NDL	0.57	135.8	1.02	0.064
1980	NOR	0.57	118.1	0.89	0.160
1990	NOR	0.57	121.9	0.96	0.123
1980	NZL	0.68	134.5	1.43	0.197
1990	NZL	0.55	114.8	1.33	0.239
1980	PRT	0.61	57.9	0.40	0.125
1990	PRT	0.64	89.9	0.44	0.154
1980	SWE	0.70	133.4	1.11	0.163
1990	SWE	0.68	148.1	1.11	0.129
1980	USA	0.66	181.0	1.36	0.182
1990	USA	0.66	191.6	1.35	0.151
Average		0.62	130.8	1.01	0.138
Standard Deviation		0.05	29.8	0.24	0.067

[1] Thousands of 1980 international U.S. dollars.

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