IS A THEORY OF TOTAL FACTOR PRODUCTIVITY REALLY NEEDED?

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ABSTRACT

This paper addresses the question of whether or not a theory of total factor productivity (TFP) is needed in order to explain the observed large per capita income differences across countries. As the argument that it is needed has been reached by calculating TFP empirically, we show that the way the estimates of TFP have been computed is not an innocuous issue. To illustrate our point, we discuss how two well-known textbooks on growth theory present the arguments and the problems associated with these expositions. We conclude that the tautological nature of the estimates of TFP lies at the heart of an important question that the empirical literature on economic growth has been dealing with during recent years. Hence, our arguments cast doubt on the need for a theory of TFP.

1. INTRODUCTION

Macroeconomics consists of identities and opinions

Orley Ashenfelter[1]

With the revival of the interest in growth theory since the 1980s, and, in particular, the interest in applied work in this area, economists have returned to the important question of why some countries are richer than others. A crucial development has been the availability of large databases that allow comparisons across countries to be carried out. While some researchers would claim that the profession has advanced and that neoclassical growth analysis has provided useful answers to this question (Mankiw *et al.*, 1992; Jones, 1998, 2002), others take the opposite view or are more skeptical (Nelson, 1998; Kenny and Williams, 2000; Easterly, 2001).

Solow's (1956, 1957) seminal growth model is still generally viewed today as the starting point for almost all analyses of growth, and even models that depart significantly from this model are often best understood through a comparison with it. This model, augmented by human capital, is seen by some as providing a satisfactory explanation of disparities in per capita income growth, or at least a useful starting point (Mankiw *et al.*, 1992; Mankiw, 1995, 1997). What does Solow's model say about why some countries are richer than others? His model predicts that countries with high savings/investment rates will tend to have high levels of income per capita; and countries that have high population growth rates will tend to be poor. But savings rates and population growth do not affect the steady-state growth rates of per capita output. Therefore, the model does not provide an adequate explanation of the determinants of long-run per capita growth, which are merely captured by the rate of exogenously given technical progress. The model, however, shows how an economy's per capita income converges towards its own steady-state value, and in this way it provides an explanation for the observed differences in growth rates across countries. In simple terms, this explanation is that poorer countries tend to grow faster than the richer countries as they are generally farther away below their conditional steady-state growth rates.

An important assumption of Solow's growth model is that countries have identical technologies (production functions). Some authors have argued, however, that this model cannot account for the large observed variations across countries in total factor productivity (TFP) precisely because it assumes identical technologies (Durlauf and Johnson, 1995; Jorgenson, 1995;

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[1] Cited by Lewis (2004, p. 7).

Jones, 1997a, 1998, 2002; Hall and Jones, 1999; Islam, 1999; Parente and Prescott, 2000).[2,3] The productivity and per capita income of the world's richest country (the USA) is presently some 30–35 times that of the poorest country (Prichett, 1997). To what extent can such differences in productivity be explained by differences in the rate of savings (which we shall assume equals the investment–output ratio) over a long period? In other words, can the fact that the more advanced countries have generally had higher savings rates in the past than the poorer countries explain why some countries are rich and others poor? The conclusion of a number of economists (Romer, 1990, 1994; Prescott, 1998) is that within the Solow model differences in these ratios (and, hence, in the capital–output ratios) can explain very little of the differences in per capita income.

One response to the issue at hand has been that employment is not the appropriate proxy to measure the flow of labor services, but rather that this should be augmented by the quality of the labor input, which varies across countries. Mankiw *et al.* (1992) concluded, under the assumption that technology is the same in all countries, that exogenous differences in saving and education cause the observed differences in levels of income. (See Felipe and McCombie (2005a) for a survey of this literature, and also for an assessment of the Mankiw *et al.* (1992) procedure to test Solow's (1956) growth model). However, Jones (2002) has shown that education can only account for a factor of two in the differences between the richest and poorest countries.[4] Likewise, Prescott (1998, p. 541), following Lucas (1988), used an explicit equation for the production of human capital. For various values of the parameters of the human capital production sector, Prescott used US data to calibrate the model, and found that either the implied values of time were so implausibly large, or else the implied rates of return to education were so high in the poorest countries that he was led to 'reject this model as a theory of international income differences' (Prescott, 1998, p. 543).

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[2] Productivity is a ratio of some measure of output to some index of input use. TFP, therefore, is one measure of productivity where the denominator of the ratio is not one input (e.g. labor) but includes other factors of production, such as a capital. The most important issue in constructing this index refers to the precise form it takes and, related to this, to the way the different inputs are weighted. The neoclassical growth model solves this problem by relating the concept of TFP to a production function and to the conditions for producer equilibrium.

[3] Strictly speaking, the TFPG is not the same as the rate of technical progress as the former is a 'catch all' and will include measurement errors, productivity gains from the intersectoral shift of resources etc. But ever since Solow (1957), the two terms have been used loosely as synonyms.

[4] One year of schooling in an advanced country surely increases human capital by more than one year of schooling in a less developed country. It is not just a question of the number of years spent in school, but the quality of that education.

Consequently, if differences in investment ratios and human capital cannot explain very much of the international differences in the levels of productivity, the answer in the neoclassical approach must lie, by definition, in disparities in TFP. Authors such as Jones or Prescott, therefore, argue for a version of Solow's growth model that incorporates differences in technology levels. Prescott (1998), for example, has made a case that a separate, or distinct, theory of TFP differences is needed. In a similar vein, Meier (2001, p. 25), in suggesting a series of research topics for the new generation of development economists, argues 'Because of the importance of total factor productivity [. . .] future research will have to increase our understanding of the "unexplained residual factor" in aggregate production functions.'

This paper addresses the question of the need to develop a theory of TFP by taking one step back. As the conclusion that a theory of TFP is needed in order to explain the observed large income differences across countries has been reached empirically (i.e. by calculating TFP), it is shown that the way the estimates of TFP have been computed is not an innocuous issue. In this way, we highlight some important, but neglected, issues.

The rest of the paper is structured as follows. We first discuss in section 2 how the arguments regarding the importance of TFP are presented in Jones's (1998, 2002) textbooks (Jones (1997a) also uses similar arguments).[5] To this purpose, we consider first Jones (1998), the first edition of his well-known economic growth textbook. Jones argues that the neoclassical model describes 'the distribution of per capita income across countries fairly well' (Jones, 1998, p. 53). We argue that this conclusion results from the tautological way TFP is calculated. Jones's view has somewhat changed by the second edition of the book (Jones, 2002), where the tautological nature of the argument is conceded to some extent, but the problem still remains.

Perhaps more importantly, we show in section 3 that the same results will be achieved even though there is no underlying aggregate production function, in which case the Solow model is incoherent. The problem arises due to the existence of an underlying identity, which is responsible for the observed relationships and enables the results to be predicted *a priori* with only the knowledge of the Kaldorian 'stylized facts' of economic growth (Kaldor, 1961; Valdés, 1999, pp. 10–12). Section 4 elaborates upon the previous arguments and questions Barro's (1999) and Hsieh's (1999, 2002) argument that growth-accounting exercises, whose purpose is to estimate the rate of TFP

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[5] It is perhaps unusual to concentrate on a textbook. However, as Kuhn (1962) pointed out, textbooks are crucial in the propagation of a paradigm, and are important as they are seen as presenting generally agreed-upon and uncontroversial views. Moreover, often textbooks set the agenda for future research problems or 'puzzles'.

growth (TFPG)—not its level—can be directly carried out from the accounting identity.

In section 5, we provide another example of the problems posed by the accounting identity and analyze Valdés's (1999) simple test of one of the first endogenous growth models, the linear-in-K, or AK, model. We also show that the model in question cannot be tested because the data cannot refute it.

We conclude in section 6 by arguing that, given the empirical problems with the notion of TFP, we feel skeptical about the need for a theory of TFP, and offer a series of suggestions to open more fruitful lines of research for understanding economic growth.

2. SOLOW'S MODEL AND THE RELATIONSHIP BETWEEN ACTUAL AND STEADY-STATE LEVELS OF PRODUCTIVITY

Jones (1998) putatively tested the Solow model, augmented by human capital, by calculating the steady-state levels of labor productivity of a number of countries relative to that of the USA (y_i^*/y_{US}^*), where the subscript i denotes the ith country and the superscript * denotes the steady-state value. These values were then compared with the actual, or observed, relative values of labor productivity (y_i/y_{US}). When the two ratios were found to be sufficiently close, Jones concluded that the steady-state augmented Solow growth model provided a good explanation of economic growth. Assuming a constant level of technology, he found that the relationship between $\ln(y_i^*/y_{US}^*)$ and $\ln(y_i/y_{US})$ gave a slope of less than unity, but he nevertheless concluded that 'the neoclassical model still describes the distribution of per capita income across countries fairly well' (Jones, 1998, p. 53). After allowing for differences in technology and human capital, the correspondence improved and was very close: 'The model broadly predicts which countries will be rich and which will be poor' (Jones, 1998, p. 54). He concluded, 'the Solow framework is extremely successful in helping us to understand the wide variation in the wealth of nations' (Jones, 1998, p. 56).

However, in the second edition of the book, Jones (2002) omits this last piece of analysis between the actual and steady-state levels of productivity. After noting that the predictive correspondence between the relative steady state and the actual levels of productivity is poor, he again allows for differences in technology. But the analysis showing the much improved fit between the two variables $\ln(y_i^*/y_{US}^*)$ and $\ln(y_i/y_{US})$ is dropped, and instead the Cobb–Douglas production function $Y_{it} = (A_t L_{it})^{(1-\alpha)} K_{it}^{\alpha}$ is used to show the range of values of A necessary to fit the model to the data. Y is the level of

output, A is the level of technology,[6] L is employment, K is the capital stock, and $(1 - \alpha)$ and α are the output elasticities of labor and capital, respectively. He examines the relationship between the relative A's and the actual (and not the steady-state) relative levels of productivity and finds that there is a close relationship. 'Rich countries generally have high levels of A and poor countries generally have low levels' (Jones, 2002, p. 61). This analysis is also found in Jones (1998), where the estimates for A, the actual and the steady-state values of the relative productivity levels are all reported (Jones, 1998, table 3.1, p. 55). It is shown there that the actual and the steady-state relative levels of productivity are very close. The table is subsequently omitted from the second edition.

Jones's (1998) argument is as follows. The production function for country i, expressed in intensive form, is given by

$$y_i = \left(A_i' h_i\right)^{(1-\alpha)} k_i^{\alpha} \tag{1}$$

where y, k and h are output per worker, capital per worker and a measure of human capital per worker (proxied by the level of schooling). A' is the level of technology when human capital is included in the production function. (The time subscript is dropped for notational convenience for equation (1) and the remainder of this section.)

Jones derives the steady-state level of productivity from equation (1) by assuming that $\hat{Y} = \hat{K}$, where $^{\wedge}$ denotes a growth rate, and that the rate of technical progress is the same for all countries (i.e. $g_i = g$). (For notational ease, g is the growth of either A or A', depending upon the context.) The steady-state level of productivity is given by

$$y_i^* = \left(\frac{s_{K_i}}{n_i + g + \delta}\right)^{\alpha/(1-\alpha)} A_i' h_i \tag{2}$$

where s_K is the share of physical investment in output, n is the growth rate of employment (alternatively denoted by $\hat{L}$ below) and δ is the rate of depreciation.

Equation (2) is used to calculate the ratio of the steady-state levels of productivity of various countries to that of the USA:

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[6] $A^{(1-\alpha)}$ is the level of TFP where, under the usual neoclassical assumptions, $(1 - a)$, labor's share in output, is equal to $(1 - \alpha)$.

$$\frac{y_i^*}{y_{US}^*} = \frac{\left(\dfrac{s'_{K_i}}{n_i + g}\right)^{\alpha/(1-\alpha)}}{\left(\dfrac{s'_{US}}{n_{US} + g}\right)^{\alpha/(1-\alpha)}} \cdot \frac{A_i'}{A_{US}'} \cdot \frac{h_i}{h_{US}} \qquad (3)$$

For simplicity, we define s'_K as the share of *net*—rather than *gross* —investment in output and so δ is not now an explicit argument of the equation.

Jones first assumes that the level of technology does not vary across countries. Under these circumstances $A_i'/A_{US}' = 1$. A comparison of $\ln(y_i^*/y_{US}^*)$ with $\ln(y_i/y_{US})$ provides a moderately close fit, but with the slope noticeably less than unity (see Jones, 1998, figure 3.1, p. 52).[7]

Jones next relaxes the assumption that the level of technology is constant. As Jones (1998, p. 51) puts it: 'differences in technology presumably explain to a great extent why some countries are richer than others'.[8] A_i' is defined as

$$A_i' \equiv \left(\frac{y_i}{k_i}\right)^{\alpha/(1-\alpha)} \left(\frac{y_i}{h_i}\right) \qquad (4)$$

The value of A' that is calculated from equation (4) is substituted into equation (3) to derive a value for (y_i^*/y_{US}^*). A visual comparison of (y_i^*/y_{US}^*) with $\ln(y_i/y_{US})$ now shows a closer fit with a slope of about unity (Jones, 1998, figure 3.2, p. 54). However, much of this good fit is merely a result of the method Jones adopts to calculate A_i'. To see this, let us first assume for expositional ease that the production function excludes human capital. Equation (4) is, in these circumstances, written as

$$A_i \equiv \left(\frac{y_i}{k_i}\right)^{\alpha/(1-\alpha)} y_i \qquad (5)$$

Substituting A for A' in equation (3) and omitting (h_i/h_{US}) gives the following equation:

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[7] The same figure is reproduced in Jones (2002, p. 59). No statistical diagnostics are reported.
[8] Jones (2002, p. 58) tones it down and the sentence becomes 'differences in technology presumably help to explain why some countries are richer than others'.

$$\frac{y_i^*}{y_{US}^*} = \frac{\left(\dfrac{s_{K_i}'}{n_i + g}\right)^{\alpha/(1-\alpha)}}{\left(\dfrac{s_{US}'}{n_{US} + g}\right)^{\alpha/(1-\alpha)}} \cdot \frac{\left(\dfrac{Y_i}{K_i}\right)^{\alpha/(1-\alpha)}}{\left(\dfrac{Y_{US}}{K_{US}}\right)^{\alpha/(1-\alpha)}} \cdot \frac{y_i}{y_{US}} \tag{6}$$

where, it will be recalled, g is the rate of technical progress.

Consider the expression $\left(\dfrac{s_{K_i}'}{n_i + g}\right)$. The net investment ratio can be written as $s_{K_i}' = I_i'/Y_i = \Delta K_i/Y_i = \hat{K}_i(K_i/Y_i)$, where I_i' is net investment. Hence

$$\left(\frac{s_{K_i}'}{n_i + g}\right)\left(\frac{Y_i}{K_i}\right) = \left(\frac{\hat{K}_i}{n_i + g}\right) \tag{7}$$

Equation (6) may therefore be expressed as

$$\frac{y_i^*}{y_{US}^*} = \frac{\left(\dfrac{K_i}{n_i + g}\right)^{\alpha/(1-\alpha)}}{\left(\dfrac{K_{US}}{n_{US} + g}\right)^{\alpha/(1-\alpha)}} \cdot \frac{y_i}{y_{US}} \tag{8}$$

or in logarithmic form as

$$\ln\left(\frac{y_i^*}{y_{US}^*}\right) = \frac{\alpha}{1-\alpha}\ln\left(\frac{x_i}{x_{US}}\right) + 1.0\ln\left(\frac{y_i}{y_{US}}\right) \tag{9}$$

where $x_i = \hat{K}_i/(n_i + g)$.

Consequently, we can see immediately that if we regress $\ln(y_i^*/y_{US}^*)$ on $\ln(y_i/y_{US})$ there will be a close statistical fit as (y_i/y_{US}) is, by definition, a component of (y_i^*/y_{US}^*), given the stylized fact that the growth of the capital–output ratio does not greatly vary between countries.[9] Moreover, if $\ln(x_i/x_{US})$ is orthogonal to $\ln(y_i/y_{US})$, then the coefficient of the latter must be equal to

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[9] This is a condition for steady-state growth in the neoclassical growth model, but is also one of Kaldor's (1961) stylized facts, which do not depend upon the existence of a neoclassical production function.

unity. In fact, plotting $\ln(y_i^*/y_{US}^*)$ against $\ln(y_i/y_{US})$ gives a slope that is less than unity, suggesting that $\ln(x_i/x_{US})$ is negatively correlated with $\ln(y_i/y_{US})$.

Ironically, if we now introduce human capital we get exactly the *same* relationship between the relative steady-state and the actual productivities. If we substitute equation (4) into equation (3), we obtain equation (8) again. This is because $A_i \equiv A_i'h_i$ or $A_i' \equiv A_i/h_i$. Due to the way A and A' are calculated, including a measure of human capital, no matter how it is calculated, will not improve the goodness of fit. Or to put it another way, excluding human capital and using Jones's procedure will not worsen the explanatory power of the model.

By introducing a more general (neoclassical) assumption, namely that the rate of technical progress is not constant across countries, we can improve the relationship by making it even more tautological. Assuming a well-behaved (aggregate) cost function and perfectly competitive markets, it can be shown that, using the aggregate marginal productivity conditions and Euler's theorem, the rate of technical progress is given by the dual (Chambers, 1988, ch. 6) as (for a Cobb–Douglas technology) $g_i = \hat{w}_i + [a/(1-a)]\hat{r}_i$ where a and $(1 - a)$ are the factor shares of capital and labor and $a = \alpha$ and $(1 - a) = (1 - \alpha)$. This is the standard result from the growth-accounting approach.

The underlying assumption is that if countries have different technologies, part of the differences in the growth rates of productivity will be accounted for by disparities in the rate of technical progress, as the benefits of the latest technology diffuse from the more to the less advanced countries.

Jones (1998), however, makes the assumption that the levels of technology differ among the countries; yet rather surprisingly, he assumes that all countries have the same common rate of technical progress (so that $g_i = g$). He justifies this as follows:

> If g varies across countries then the 'income gap' between countries eventually becomes infinite. This may not seem plausible if growth is driven entirely by technology. . . . It may be more plausible to think that technological transfer will keep even the poorest countries from falling too far behind, and one way to interpret this statement is that the growth rates of technology g are the same across countries. (Jones, 1998, p. 51)

A couple of observations are in order here.

First, Jones's model departs from the traditional augmented Solow model (e.g. Mankiw *et al.*, 1992), where all countries are assumed to have the same rate of technological progress because they all have access to the *same* level of technology. However, most diffusion of technology models which assume

differences in the levels of technology predict that, because of the technological catching-up phenomenon, the countries with the lower levels of technology will experience faster temporary productivity growth because of a faster rate of technical progress as they benefit from the inter-country transfer of technology (Fagerberg, 1987).[10] We should thus expect the rate of technical progress (or TFPG) to vary among countries, for this reason. This is precisely what the growth-accounting studies suggest—the rate of technical progress and TFPG do vary across countries.[11] It would be purely coincidental, and implausible, to expect the rate of technical progress in these circumstances to remain constant across countries. Thus, the usual assumptions made are either that all countries have access to the same level of technology and the rate of technological progress is constant across countries, or that countries differ in their level of technology, and because of this, the rate of technical progress differs between countries. The combined assumption of differing levels of technology and constant rates of technical change does not seem plausible.

Second, the relative income gap will be constant if g is the same for all countries, but this fails to explain the reasons for the initial disparities in technology. But even if the relative per capita income gap remains constant, the absolute differences in per capita income will widen.

If we adopt the more general assumption that the rate of technical progress varies between counties, as we have already noted, neoclassical theory shows that the rate of technical progress is equal to the dual, i.e. $g_i = \hat{w}_i + [a/(1-a)]\hat{r}_i$. It is straightforward to see that in these circumstances the whole exercise reduces to nothing more than a tautology. It can be seen that equation (8) becomes

$$\frac{y_i^*}{y_{US}^*} = \frac{\left(\dfrac{K_i}{n_i + g_i}\right)^{\alpha/(1-\alpha)}}{\left(\dfrac{K_{US}}{n_{US} + g_{US}}\right)^{\alpha/(1-\alpha)}} \cdot \frac{y_i}{y_{US}} \tag{10a}$$

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[10] Gomulka (1971) has suggested that there is likely to be a hat-shaped relationship between the growth of productivity and the level of productivity (a proxy for the level of technology). Very underdeveloped countries are unlikely to have the social and human capital and infrastructure to take advantage of the diffusion of technology from the advanced countries. As development occurs so the absorptive capability for adopting for new technology increases with the result that productivity growth rates increase, until, after a point, a greater level of development leads to a decrease in productivity growth as the scope for catch-up decreases.

[11] Indeed, this is confirmed by Jones in his growth-accounting exercise, reported in Jones (1998, ch. 2).

or

$$\frac{y_i^*}{y_{US}^*} = \frac{x_i'}{x_{US}'} \cdot \frac{y_i}{y_{US}}$$

(10b)

Given that $\hat{Y}_i = \hat{K}_i$, it follows that $\hat{K}_i = n_i + g_i$ and hence $x_i' = x_{US}' = 1$.[12] Consequently, $\ln(y_i^*/y_{US}^*)$ *must* necessarily *equal* $\ln(y_i/y_{US})$. Hence, plotting $\ln(y_i^*/y_{US}^*)$ against $\ln(y_i/y_{US})$ would result in all the observations lying on the 45-degree line. But this does not convey any information beyond the growth of output must be equal to the growth of capital.

To the extent that g is assumed to be a constant in that it does not vary between countries, this will slightly weaken the fit between $\ln(y_i^*/y_{US}^*)$ and $\ln(y_i/y_{US})$, but we have seen above why the slope coefficient will be close to unity.

In Jones (2002), as we have mentioned, greater emphasis is placed on the relationship between the relative levels of technology (A_i/A_{US}) and the observed relative levels of productivity. There is no discussion of the steady-state values. The relationship for the production function including human capital is

$$\frac{A_i'}{A_{US}'} \equiv \frac{\left(\dfrac{Y_i}{K_i}\right)^{\alpha/(1-\alpha)} \dfrac{y_i}{h_i}}{\left(\dfrac{Y_{US}}{K_{US}}\right)^{\alpha/(1-\alpha)} \dfrac{y_{US}}{h_{US}}}$$

(11)

or, assuming that the capital–output ratios are constant, by

$$\frac{A_i'}{A_{US}'} = \frac{h_{US}}{h_i} \cdot \frac{y_i}{y_{US}}$$

(12)

Thus

$$\ln\left(\frac{A_i'}{A_{US}'}\right) = \ln\left(\frac{h_{US}}{h_i}\right) + \ln\left(\frac{y_i}{y_{US}}\right)$$

(13)

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[12] $\hat{Y}_i = (1-\alpha)\hat{w}_i + \alpha\hat{r}_i + (1-\alpha)n + \alpha\hat{K} = (1-\alpha)g_i + (1-\alpha)n + \hat{\alpha}K$. If $\hat{Y}_i = \hat{K}_i$, then $\hat{K}_i = n_i + g_i = \hat{Y}$.

It should be emphasized that equation (13) is also true by construction and therefore cannot be used to *test* the Solow model. If a different proxy for *h* is used, the calculated value of A' will alter to preserve the equation. This is analogous to the growth-accounting approach, as Jones (2002) admits, although in terms of relative levels. As such, while this method can give quantitative estimates of the various components, given the usual neoclassical assumptions, it cannot give any idea of whether the components of equation (13) (i.e. A' and *h*) are causally significant in the growth process.

3. THE PROBLEMS POSED BY THE ACCOUNTING IDENTITY

A further problem of the interpretation of these relationships is that they will occur even if we assume that there is *no* underlying aggregate production function. The work of Fisher (1992), *inter alios*, has shown that the aggregation conditions for the existence of an aggregate production function are so severe that theoretically its existence cannot be justified (Felipe and Fisher, 2003). If this is the case, is it possible to derive a general and parsimonious explanation for why aggregate production functions seemingly work in empirical work *à la* Jones, or in econometric estimation. This is the purpose of this section.

The accounting definition of value-added according to the National Income and Product Accounts (NIPA), which must hold for every state of competition, and regardless of whether or not an aggregate production function exists, is

$$y_t^n \equiv P_t Y_t \equiv W_t^n + \Pi_t^n \equiv w_t^n L_t + r_t^n K_t \qquad (14)$$

where Y^n and Y are nominal and real value-added, respectively; P is the output deflator; W^n is the total (nominal) wage bill; and Π^n denotes total (nominal) profits (operating surplus in the NIPA terminology). The symbol $\equiv$ indicates that equation (14) is an accounting identity, not a behavioral model. Each of these two components can be rewritten as the product of the *average* factor price times the quantity of that factor. Thus w^n is average nominal wage rate, r^n is the average *ex post* nominal profit rate, L is the number of workers and K is the constant-price value of the stock of capital.[13]

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[13] It must be emphasized that K is not the 'quantity' of capital. It is measured in constant-price dollars. We remind the reader that this observation was one of the key points raised during the Cambridge Capital Theory debates, recently summarized by Cohen and Harcourt (2003).

It must be added that the NIPA does not provide the decomposition on the right-hand side of equation (14), but only the aggregate sum of the payments to the factors of production (wages and profits), i.e. $Y_t^n \equiv W_t^n + \Pi_t^n$. However, L and K can be readily obtained from other sources. The decomposition of the wage bill and total profits into the products of the factor prices times the 'quantities' is definitional, as it will always be true that the wage bill can be written as the product of the average wage rate times employment. Whether or not the wage rate equals the marginal product of labor is quite another matter. And the same argument applies to capital. The identity can also be defined in real terms as $Y_t \equiv w_t L_t + r_t K_t$ where $w_t = (w_t^n / P_t)$ the average real wage rate and $r_t = (r_t^n / P_t)$ the average *ex post* profit rate.

In proportionate growth rate form, equation (14) in real terms becomes[14]

$$
\begin{aligned}
\hat{Y}_t &\equiv (1-a_t)\hat{w}_t + a_t\hat{r}_t + (1-a_t)\hat{L}_t + a_t\hat{K}_t \\
&\equiv (1-a_t)g_t + (1-a_t)\hat{L}_t + a_t\hat{K}_t
\end{aligned}
\tag{15}
$$

where $(1-a)g_t \equiv (1-a_t)\hat{w}_t + a_t\hat{r}_t$; $(1-a_t) \equiv (w_t L_t)/Y_t$ is labor's share; and $a_t \equiv (r_t K_t)/Y_t$ is capital's share in value-added. Assuming that factor shares are constant, i.e. $a_t = a$ and $(1-a_t) = (1-a)$, integrating equation (15) and taking anti-logarithms, we obtain

$$
Y_t \equiv B_0 w_t^{(1-a)} r_t^a L_t^{(1-a)} K_t^a
\tag{16}
$$

where B_0 is the constant of integration; or

$$
Y_t \equiv (A_t L_t)^{(1-a)} K_t^a
\tag{17}
$$

where $A_t \equiv \left[B_0 w_t^{(1-a)} r_t^a \right]^{1/(1-a)}$. It is obvious that equation (17) *resembles* the Cobb–Douglas production function, where $A_t^{(1-a)}$ represents, in the tradi-

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[14] Constant factor shares are consistent with a Cobb–Douglas production function. However, Fisher (1971) showed using simulation experiments that constant factor shares will give rise to a putative aggregate Cobb–Douglas production function even though the aggregation conditions necessary for the existence of the latter are deliberately violated, so that it does not exist. As Fisher commented, the constant factor shares can equally give rise to a functional form that resembles a Cobb–Douglas just as a 'true' aggregate Cobb–Douglas production function gives rise to constant factor shares. Constant shares will occur, for example, if firms adopt a constant mark-up pricing policy on normal unit costs and the average mark-up does not greatly vary over time. This is consistent with *any* set of micro production functions and no aggregate production function.

tional nomenclature, the level of TFP. Moreover, suppose in this economy wage and profit rates grow at constant rates (or that the wage rate grows at a constant rate and the profit rate is constant), then equation (16) could be written as

$$Y_t \equiv \left(A_0 e^{gt} \right)^{(1-a)} L_t^{(1-a)} K_t^a \tag{18}$$

where $(1 - a)g$ is the weighted average of the rates of growth of the wage and profit rates, which is constant. However, equations (17) and (18) *are not* production functions. It should be emphasized that these equations have been merely derived as a transformation of the accounting identity, equation (14), using two hypotheses about the data (which can be tested), namely that factor shares and the weighted growth of the real wage rate and the rate of profit are constant over time. Therefore, if these two assumptions are roughly correct, equation (18) will be a very good approximation to the accounting identity.

If we next assume the stylized fact that the growth of output and capital are equal, we can derive, by the same procedure as in section 2, an equation for productivity (denoted here for convenience by y_i^*, although it is not the steady-state value in the neoclassical sense of the term) from the identity given by equation (15) as

$$y_i^* = \left(\frac{K_i}{n_i + g_i} \right)^{a/(1-a)} y_i. \tag{19}$$

The ratio y_i^*/y_{US}^* is the same as equation (10a), although the latter was derived using an aggregate production function and the usual neoclassical assumptions, including the aggregate marginal productivity theory of factor pricing and Euler's theorem. Here, however, we have not made use of any of them. Given the stylized facts that $\hat{Y} = \hat{K}$ and that factor shares are constant, then equation (19) is true by definition and $y_i^* = y_i$.

In the precise context of this paper, this derivation also implies that estimates of the level of TFP based on the Cobb–Douglas production function obtained as $A_t^{(1-a)} = Y_t / (L_t^{(1-a)} K_t^a)$ (compare equation (4)) are definitionally equal to $A_t^{(1-a)} = B_0 w_t^{(1-a)} r_t^a$.[15] Gollin (2002) has argued that factor shares are not significantly different between developed and developing countries once an allowance is made for the fact that the NIPA of the developing countries

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[15] In fact, it is easy to show that the constant of integration has to be $B_0 = 1/[a^a(1 - a)^{(1-a)}]$.

register a large part of what is in fact labor compensation of the self-employed as profits (capital compensation). When this is properly computed as labor compensation, the labor share of the developing countries comes out to be of similar magnitude to that of the developed countries. What probably accounts for the largest part of the differential in the observed levels of TFP across countries is differences in the real wage rates (w), given also that real profit rates (r) are probably not greatly different across countries. But this is a rather convoluted way of finding what we already know, namely that real wages are higher in the developed than in the developing countries.

The derivation of equation (18) has some other important implications for understanding what occurs when researchers try to tackle the problems that usually appear with the estimation of production functions. It means that it is not possible to test the existence of the aggregate production function, as the econometric estimates will basically pick up the identity. What this indicates is that if one obtains data for the economy in question and regresses the logarithm of output on that of labor and capital, together with a linear time trend (t), i.e. $\ln Y_t = c + \lambda t + \alpha \ln K_t + \beta \ln L_t + \varepsilon_t$, where ε_t is the random disturbance and c is a constant, and the two assumptions made happen to be roughly correct, it is obvious, by comparison with equation (18), that the statistical fit will be perfect with $\lambda \equiv a\hat{r} + (1-a)\hat{w} \equiv (1-a)g$, $\alpha \equiv a$ and $\beta \equiv (1-a)$. Under a neoclassical interpretation, the equality of the elasticities and the relevant factor shares would be interpreted as a failure to refute the neoclassical theory of factor pricing and, consequently, the assumption that markets are competitive. Moreover, the result indicates 'constant returns to scale'.[16] But this economy could well be, for example, a country with a command economy where factors are not paid their marginal products or a less developed country where there is disguised unemployment. All we have used in deriving equation (18) is the identity that output equals the payment to the factors of production, together with the two assumptions. The fact that the estimated 'output elasticities' closely approximate the factor shares does not imply that markets are competitive, and that there are constant returns to scale. This correspondence merely follows from the accounting identity.

In this context, Barro (1999, pp. 122–123) has argued that the econometric estimation of the production function suffers from some serious disadvantages (as opposed to growth accounting) as a method to estimate the rate of technological progress. In particular, he lists the following three problems: (1) the growth rates of capital and labor are not exogenous variables with

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[16] It follows that an incorrect approximation to the accounting identity through the estimation of an incorrect functional form may lead to, for example, estimates that suggest increasing returns to scale. For an evaluation of the literature on returns to scale see Felipe (2001).

respect to the growth of output, (2) the growth of capital is usually measured with errors, which often leads to low estimates of the contribution of capital accumulation, and (3) the regression framework must be extended to allow for variations in factor shares and the TFPG rate.

It is easy to relate the three problems that Barro mentions to the problems posed by the accounting identity discussed in this section, and thus show that they all reduce to the fact that most often researchers do not approximate the accounting identity adequately when they estimate the production function.[17] For example, to see that Barro's third 'problem' is not really a problem at all, one has to simply elaborate on the arguments above. Note that, in general, a production function of the form $Y_t = \tilde{A}_t f(K_t, L_t)$ can be expressed in growth rates and specified as $\hat{Y}_t = \lambda_t + \alpha_t \hat{K}_t + \beta_t \hat{L}_t + \mu_t$ where α_t and β_t are the output elasticities of capital and labor (which, in general, vary over time, as Barro notes), respectively, λ_t is the rate of technical progress and μ_t is the error term. The accounting identity in growth rates is given by equation (15). A comparison of both expressions indicates that any functional form (or estimation procedure, such as a time-varying parameter estimation method) that gives a good approximation to the identity could also be mistakenly interpreted as a production function.[18]

It is worth mentioning that it is the second assumption made (i.e. the one about the constancy of the growth rates of the wage and profit rates) that empirically causes most problems in the estimation of production functions using time-series data, as factor shares tend to be sufficiently constant empirically so that the Cobb–Douglas form with constant returns to scale works reasonably well. Why is this the case? From the identity, we know that $g_t \equiv \lambda_t / (1-a) \equiv \hat{w}_t + [a/(1-a)]\hat{r}_t$. Plots of the Solow residual typically show a pro-cyclical fluctuation around its mean growth rate (e.g. Solow, 1957).

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[17] Jones (1997b, p. 111) argues: 'With hindsight, estimating the parameters of the aggregate production function econometrically appears to be impossible. The required identifying assumption is that one can separate shifts of the production function from movements along the production function. In practice, I do not see how this can be done.' This argument explains *how* and *why* one can, in fact, estimate the coefficients of equation (18). However, they do not represent the parameters of an aggregate production function simply because such a construct does not exist (Felipe and Fisher, 2003).

[18] It can then be seen that if the assumptions about the factor shares and the wage and profit rates are empirically incorrect, estimation of equation (18)—in levels or in growth rates—will give a poor statistical fit, and the estimated coefficients will have large standard errors and will diverge significantly from the factor shares. But this problem is not insurmountable. What is needed is to determine the mathematical form of the empirical path of the shares. Once found, one simply has to proceed as above, i.e. substitute the expression for the path into equation (15) and proceed as above. This will give rise to forms that resemble the CES or the translog or other functional forms more flexible than the Cobb–Douglas. These issues are discussed in Felipe and McCombie (2003).

Consequently, in spite of the strong trend underlying the growth rate, using a linear time trend in the log-levels specification, or a constant in the growth-rate specification, will most likely not accurately explain the variation in this variable. In fact, the problem in the regression is akin to one of omitted variable bias. For all practical purposes, g_t is omitted from the regression, thus biasing the estimates of capital and labor. This is the problem to which Barro implicitly refers. What is the solution? Given the typical path of g_t, a complex trigonometric function, rather than a simple time trend, will do a much better job at tracking its fluctuations. But once this is done, we will revert to the identity, elasticities will equal the factor shares, and we will find putative constant returns to scale. Summing up: if the production function is estimated 'correctly' (i.e. if the functional form chosen correctly approximates the accounting identity), no data set can refute the null hypotheses that the elasticities equal the factor shares and constant returns to scale. The consequence is that it is not possible to test and potentially refute the existence of an aggregate production function.

There is a different solution to the problem, which Barro hints at when he mentions 'the capital stock is unlikely to correspond to the stock currently utilized in production' (Barro, 1999, p. 123). He refers to the use of a capital stock corrected for the rate of utilization. This does not matter for the accounting identity, but could potentially solve the 'problem' of estimating the production function. The issue is as follows: as we have noted, if one looks at the components of $g_t \equiv \hat{w}_t + [a/(1-a)]\hat{r}_t$, the one that varies the most is $\hat{r}$, and it does so pro-cyclically. As we are arguing that this variable is being omitted from the regression, the inclusion of any other variable that moves pro-cyclically, namely the capital stock adjusted for capacity utilization, will serve as a good proxy. If capital's share is roughly constant, imparting a pro-cyclical fluctuation in the capital stock will reduce that exhibited by the rate of profit. Barro is right, but for the wrong reason (McCombie, 2000–2001).[19]

The above arguments may be further elaborated upon with the use of Solow's (1957) data. In fact, as we have seen, Jones (1998) and Hall and Jones (1999) constructed the series of technical progress as in equation (4). This is similar to the method Solow (1957) used but Hall and Jones also include

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[19] The answers to Barro's first and second points follow from the above discussion. It does not matter whether the growth of capital and labor are exogenous or endogenous, if all that is being estimated is an identity. Moreover, at the theoretical level, these constructs do not satisfy Fisher's aggregation conditions (Felipe and Fisher, 2003), so it is dubious what empirical relevance they have. Econometrically, the issue is not one of instrumental variables or unit roots (with time-series data) as, once again, we are dealing with an accounting identity. Finally, the possibility of measurement error is potentially a serious issue, but it will affect both econometric estimation and growth accounting, and does not invalidate our argument.

human capital in the manner outlined above. In this context, Hall and Jones (1999, p. 94) asked: 'What do the measured differences in productivity across countries actually reflect?' They postulated, following Solow (1957), that the disparities in productivity reflect differences in the quality of human capital, on-the-job training, vintage capital effects and social institutions. As a corollary, they argued that a theory of productivity differences is needed. While they were correct in focusing on the determinants of productivity differences such as disparities in social infrastructure, their procedure for calculating technology is problematic since TFP is, by definition (derived above), a weighted average of the logarithm of the wage and profit rates.[20]

Solow (1957) constructed $\tilde{A}_t = Y_t / f(L_t, K_t)$ using the assumption that factor shares equal the output elasticities, and assigned $\tilde{A} = 1$ to the first year (i.e. he constructed an index of technology).[21] Then he divided output per worker ($y_t = Y_t/L_t$) by $\tilde{A}_t$ to generate the new series $q_t = y_t / \tilde{A}_t$ with a view to eliminating the effect of technical progress. Solow then regressed this new series q on the capital–labor ratio ($k_t = K_t/L_t$) using four different specifications. However, it should come as no surprise that the R^2s were in every case almost unity, a sign that he was dealing with an identity (since we are dealing with an accounting identity, unit roots and spurious regression problems are not an issue here). From equation (16), notice that $y_t = (Y_t/L_t) = B_0 w_t^{(1-a)} r_t^a L_t^{-a} K_t^a = B_0 w_t^{(1-a)} r_t^a k_t^a$, and that $\tilde{A}_t = w_t^{(1-a)} r_t^a$. This implies that $q_t \equiv B_0 k_t^a$. Therefore, regressing q on k must, by construction, yield an extremely good fit as long as factor shares are constant. For Solow's data set, the correlation between $k^{\bar{a}}$, where $\bar{a}$ is the average capital share and equals 0.341, and k is 0.99883. It is also obvious that the regression $\ln q_t = b_1 + b_2 \ln k_t$ (regression (4d) in Solow, 1957, pp. 318–319) must yield an estimate of $b_2 = \bar{a}$, the average capital share.[22] Indeed, the result is $b_2 = 0.347$ (20.43) with an $\bar{R}^2 = 0.912$. The difference with respect to the theoretical perfect fit lies in the fact that the capital share is not exactly a constant.[23] Our

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[20] Hall and Jones (1999) concluded that differences in institutions and government policies (social infrastructure in general) cause differences in productivity. This is a rather non-neoclassical and interesting explanation of differentials in wage and profit rates.

[21] Solow used the production function expressed in the form $Y_t = \tilde{A}_t f(L_t, K_t)$ rather than $Y_t = F(A_t L_t, K_t)$, i.e. in terms of the Cobb–Douglas expressed as $Y_t = \tilde{A}_t L_t^{(1-\alpha)} K_t^\alpha$ rather than as $Y_t = (A_t L_t)^{(1-\alpha)} K_t^\alpha$. This makes no difference to the substance of the argument and there is no conceptual difference between Harrod-neutral and Hicks-neutral technical change with the Cobb–Douglas production function.

[22] Solow, in error, omits the logarithm symbol.

[23] With regards to regression (4a) in Solow (1957, pp. 318–319), namely $q_t = b_3 + b_4 k_t$, it is also obvious that given the extremely high correlation between k_t^a and k_t, it must yield a very good fit. The result is $q_t = 0.445 + 0.0887 k_t$ with t-values 36.07 and 19.07, respectively, and $\bar{R}^2 = 0.90$. The coefficient of k is the average rate of profit, about 9 per cent.

analysis implies that we know, before estimating the equations, the coefficients of the regressions Solow (1957) estimated.

4. GROWTH ACCOUNTING REVISITED

We now discuss the most widely used methodology for estimating 'the rate of technical progress' (as opposed to the level) in the neoclassical framework. This is the growth-accounting approach. For practical purposes, this amounts to estimating the rate of TFPG. It is noteworthy that Barro (1999) and Hsieh (1999, 2002) have argued that growth-accounting exercises, specifically the derivation of the dual measure of TFPG (Jorgenson and Griliches, 1967), can be performed by simply differentiating the NIPA identity, equation (14) in real terms, to give equation (15). The purpose of this section is to provide an evaluation of this seemingly useful methodological simplification following the arguments in the previous section.

Hsieh argues 'It is useful to think about this [growth accounting] as an accounting identity' (Hsieh, 2002, p. 502) and reasons as follows:

> . . . with only the condition that output equals factor incomes, we have the result that the primal and dual measures of the Solow residual are equal. No other assumptions are needed for this result: we do not need any assumption about the form of the production function, bias of technological change, or relationship between factor prices and their social marginal products. We do not even need to assume that the data is correct. For example, if the capital stock data is wrong, the primal estimate of the Solow residual will clearly be a biased estimate of aggregate technological change. However, as long as the output and factor price data are consistently wrong, the dual measure of the Solow residual will be exactly equal to the primal measure, and consequently, equally biased.
>
> The two measures of the Solow residual can differ when national output exceeds the payments to capital and labor. (Hsieh, 2002, p. 505)

Barro (1999) concurs that: 'the dual approach can be derived readily from the equality between output and factor income' (Barro, 1999, p. 123). He writes the income-accounting identity, differentiates it and expresses it in terms of growth rates (Barro, 1999, equations (7) and (8)). Barro and Hsieh agree that (in Barro's words):

> . . . it is important to recognize that the derivation of equation (8) [the growth-accounting equation in his paper] uses only the condition $Y_t = r_t K_t + w_t L_t$. No

assumptions were made about the relations of factor prices to social marginal products or about the form of the production function. (Barro, 1999, p. 123)[24]

Y, r, K, w and *L* are again real value-added, the real rate of return, the value of the capital stock in constant prices, the real wage rate and the labor input. Barro (1999, pp. 123–124) continues:

If the condition $Y_t = r_t K_t + w_t L_t$ holds, then the primal and dual estimates of TFP growth inevitably coincide [...] If the condition $Y_t = r_t K_t + w_t L_t$ holds, then the discrepancy between the primal and dual estimates of TFP has to reflect the use of different data in the two calculations.

This rationale stands in marked contrast to the arguments in the previous section, an implication of which is that, precisely *because* of the existence of the accounting identity, growth-accounting exercises amount to no more than manipulations of the *ex post* national income accounting identity, and, as such, they are tautologies without necessarily any behavioral content. In the light of Barro's (1999) and Hsieh's (1999, 2002) papers, it is worth elaborating their argument and contrasting it with that of this paper. This is because while Hsieh acknowledges that he manipulates an identity, notwithstanding the quotation above, it is clear that there are neoclassical assumptions implicit in his analysis.[25] As we have seen, our argument is that because of the underlying accounting identity, it is not possible to test these assumptions. This implies that it is not possible to dichotomize, in a causal sense, the growth of output into that due to the (weighted) growth of the factors of production and a residual, which is interpreted as the rate of technical change or, more generally, as the rate of increase in efficiency of the economy.

It is important to note that Hsieh's quotation cited above that 'we do not need any assumption about the form of the production function, bias of technological change, or relationship between factor prices and their social marginal products' is misleading to the extent that it could be interpreted as implying that none of these conditions are required for growth accounting. What it simply means is that if we have an identity $X_t \equiv Y_t + Z_t$, then this may be expressed as $\phi_t \hat{Y}_t \equiv \hat{X}_t - (1 - \phi_t)\hat{Z}_t$, where $\phi_t \equiv Y_t / X_t$. If we term the right-hand side the 'primal', then, by definition, it must equal the left hand side, whether it is called the 'dual' or anything else. Consequently, any measurement error on either the right-hand side or the left-hand side of the equation

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[24] We have changed the notation to make it compatible with that in our paper.
[25] This is very clear in Hsieh (2002, p. 502), where he refers to the 'rental price of capital' and the 'marginal product of capital'. These concepts are theory dependent.

in growth rate form must lead to an absolute equal error on the opposite side. But this will lead to overlooking the necessary assumptions that underlie the growth-accounting approach, if either the dual or the primal is to be interpreted as a measure of technical progress.

Hsieh is also in error when he states that we do not need any assumption about the bias of technological change. Without the assumption of Hicks-neutral technical change, there is no way of providing unique estimates of TFPG. The estimates will depend upon the degree of biased technical change and the elasticity of substitution (Nelson, 1973). There is a contradiction here as steady-state growth when the elasticity of substitution is not equal to unity requires Harrod-neutral and not Hicks-neutral technical change (Barro and Sala-i-Martin, 1995, pp. 54–55). This is sometimes sidestepped by assuming that the underlying production function is a Cobb–Douglas. But even under the usual neoclassical assumptions, constant factor shares do not necessarily mean that the 'true' production function is a Cobb–Douglas. It is possible that biased technical change, together with an elasticity of substitution that is different from unity, could give stable factor shares (Nelson and Pack, 1999; Felipe and McCombie, 2001).

Equation (15) above can be rearranged to give

$$(1-a_t)g_t \equiv \lambda_t \equiv \hat{Y}_t - (1-a_t)\hat{L}_t - a_t\hat{K}_t \equiv (1-a_t)\hat{w}_t + a_t\hat{r}_t \tag{20}$$

Under the usual neoclassical assumptions, this equation is formally equivalent to the Solow residual or TFPG. The first part of equation (20), $\lambda_t \equiv \lambda_t^P \equiv \hat{Y}_t - (1-a_t)\hat{L}_t - a_t\hat{K}_t$, is identical to the growth-accounting equation derived from a neoclassical aggregate production function, imposing the conditions for producer equilibrium, and is referred to as the *primal* measure of TFPG. The second part of the equation, $\lambda_t \equiv \lambda_t^D \equiv (1-a_t)\hat{w}_t + a_t\hat{r}_t$, is the *dual* measure of TFPG, derived in neoclassical economics from the cost function. The latter is the expression Hsieh used in his empirical analysis.

On the one hand, implicit in the standard neoclassical approach to growth accounting is the assumption of the existence of an aggregate production function with Hicks-neutral technical change, i.e. $Y_t = \bar{A}_t f(L_t, K_t)$.[26]

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[26] Jorgenson (2001, p. 17) argues that the aggregate production function with a single output as a function of capital and labor inputs has been superseded by the production possibility frontier (PPF) as a tool for conducting growth-accounting exercises. The reason, Jorgenson argues, is that the PPF allows for a rich disaggregation of outputs (different types of investment and consumption goods) and inputs (different kinds of capital goods and services, and labor). We are grateful to Simon Zheng, of the Bureau of Australian Statistics, for bringing this issue to our attention. The use of the concept of PPF does not, however, solve the methodological problems

On the other hand, Euler's theorem implies that $Y_t = f_L L + f_{K_t} K_t$, where f_L and f_K are the corresponding marginal products, which are assumed to be equal to the factor prices, w and r, respectively. Then it follows that $Y_t = w_t L_t + r_t K_t$. This result, however, should not be confused with the identity, equation (14). It is important to appreciate that this equality, derived from the production function and Euler's theorem (Hulten, 2000, p. 11), is 'virtual', namely one that holds *if, and only if,* the theory under which it was built holds. On the other hand, the identity $Y_t \equiv W_t + \Pi_t \equiv w_t L_t + r_t K_t$ holds without recourse to any theory and does not require that wage and profit rates be equal to their respective marginal products.

The rate of TFPG obtained from the neoclassical production function with constant returns to scale equals

$$\lambda_t = \hat{Y}_t - (1 - \alpha_t)\hat{L}_t - \alpha_t \hat{K}_t \tag{21}$$

where $(1 - \alpha_t)$ and α_t are again the output elasticities of labor and capital, respectively; and λ_t is interpreted as the growth rate of technical progress (TFPG), or the *Solow residual*. Since usually there are no reliable estimates of the elasticities, by invoking the first-order conditions, the factor elasticities are taken to equal the appropriate factor shares, i.e. $(1 - \alpha_t) \equiv (1 - a_t)$ and $\alpha_t \equiv a_t$. Hence $\lambda_t = \hat{Y}_t - (1 - a_t)\hat{L}_t - a_t\hat{K}_t$.

These are not, however, innocuous assumptions. The interpretation of λ in equation (20) as the rate of technological progress *must* follow from a comparison with equation (21); otherwise, on what grounds is $(1 - a_t)g_t = \lambda_t$, which is just a term in an accounting identity, referred to as the rate of technical progress or TFPG? As we have noted above, the aggregate production function, together with the conditions for producer equilibrium (the first-order conditions), provides the underlying theory for the standard interpretation of the growth-accounting exercise. In fact, it is argued that the aggregate production function provides a theory of the income side of the NIPA (Prescott, 1998, p. 532).

From the accounting identity, if a consistent data set (i.e. one that makes the identity, equation (14), hold) is used for calculating the dual and the primal measures of TFPG, then, by definition, they must be equal. The identity consists of five variables, namely Y, w, L, r and K. If values of each are obtained 'independently' then it is possible that the identity will not hold

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that this paper addresses. This is because of the untestable assumptions that factor markets are competitive and constant returns are still needed. Moreover, the same results can be derived by considering the income- and demand-accounting identities.

because of measurement error. Thus, to ensure consistency, one of the variables will have to be obtained residually. The NIPA provides data on Y^n (as indicated above, it is deflated using the output deflator to obtain Y). Data on w^n (deflated with the output deflator to obtain w) and L can be obtained from wage and labor force statistics; and an estimate of K may be obtained by the perpetual inventory method. Hence, it is r that is often obtained residually. But if there were independent estimates of r published, one could equally obtain K (or any one of the other variables for that matter) residually.[27] However, the two approaches could differ if the identity is not consistent. For example, if r and K are calculated independently, it may well be that $r_t K_t \neq Y_t - w_t L_t$. This may be useful in terms of the growth-accounting approach to highlight possible measurement errors. However, the accounting identity must hold and so either r or K must be adjusted to ensure the identity is consistent.

In his calculations, Hsieh, however, did not use the accounting identity exactly as described above (i.e. by calculating residually one of the five variables). Instead, Hsieh calculated the five series in the identity independently, and instead of calculating r residually, he computed the rental price of capital (v) as $v_t = \varphi_t(\rho_t + \delta_t - \dot{\varphi}_t)$, where φ is the price of capital, ρ is a measure of the cost of capital, δ is the depreciation rate and $\dot{\varphi}_t = d\varphi/dt$ is the capital gain or loss. This amounts to writing the identity as

$$Y_t \equiv w_t L_t + v_t K_t + \pi_t \tag{22}$$

where π denotes pure profits. This differs from equation (14) in several respects.[28] First, writing the latter does not require any behavioral assumptions. However, in writing the equivalent to our equation (22), Hsieh assumed elements of neoclassical production theory, for example, that the factor prices (wage rate and rental price of capital) are indeed equal to their marginal products. The estimation of the rental price of capital in particular requires a number of neoclassical assumptions (Jorgenson, 1963). Second, if Hsieh had in mind equation (22) when he wrote equation (14), then he implicitly assumed that $\pi = 0$. This is consistent with long-run perfectly

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[27] Consider the following. From the NIPA we can obtain the labor share as $(1 - a_t) \equiv (W_t/Y_t)$. Now suppose we obtain independent data on the average wage rate (w) and employment (L), and find that $(1 - a_t) \neq (w_t L_t/Y_t)$. This would pose problems as there would be a statistical measurement error, similar to what happens with the measurement of GDP by the expenditure, output and income methods. It is obvious that residual adjustments would have to be made to preserve the labor-share identity. The same applies to the variables that make up the capital share.

[28] For an extensive discussion of these issues see Felipe and McCombie (2007).

competitive markets, but this again requires an assumption relating to the state of competition. (Hsieh confusingly used the same notation, r, in both equations (14) and (22), rather than distinguishing between r and v.)

It is in this case that the identity might not hold, i.e. Y may not equal the sum of $w_t L_t + v_t K_t$, if Y refers to (deflated) value-added as reported in the NIPA. The growth-accounting expression (15) captures the effects of monopoly profits included as part of π. If there is market power, for consistency under neoclassical assumptions, Hsieh should have calculated the 'true' Solow residual or TFPG after deducting monopoly profits from the recorded value-added in the national accounts. In other words, the identity should be given by $Y_t' \equiv w_t L_t + v_t K_t$, where $Y_t' \equiv Y_t - \pi_t$. This again makes the identity consistent. And finally, note that pure profits can be expressed as $\pi_t = \bar{v}_t K_t$, i.e. as the product of the rate of return due to market power (denoted by $\bar{v}$) multiplied by the value of the stock of capital. This implies that equation (22) can be rewritten as

$$Y_t \equiv w_t L_t + v_t K_t + \bar{v}_t K_t \equiv w_t L_t + (v_t + \bar{v}_t) K_t$$
$$\equiv w_t L_t + r_t K_t \tag{23}$$

which implies that $(v_t + \bar{v}_t) \equiv r_t$. In other words, one can decompose the *ex post* average profit rate r however one wishes. The problem is that, given that the rental price of capital is a theory-dependent concept, and that its calculation is not a straightforward issue (Mohr, 1986), there may be serious measurement errors involved in its calculation. No matter how the profit rate or rental price of capital is estimated, the exercise amounts to no more than the manipulation of an accounting identity.

All this leads us to conclude that the accounting identity 'stands on its own' as there is no theory behind it. So, what does the transformation of an accounting identity tell us about the growth of an economy? It certainly serves as an organizational device of relevant variables and data, but not as a theoretical construct. Can $(1-a_t)g_t \equiv (1-a_t)\hat{w}_t + a_t\hat{r}_t$ be interpreted as a measure of the change in technical progress in the way that it is done in growth-accounting exercises? It follows from the above arguments that g can be interpreted only as a measure of distributional changes (not in a zero-sum sense). To see what we mean by this, note that, as indicated above, the NIPA *do not* provide data as in equation (14), i.e. $Y_t \equiv w_t L_t + r_t K_t$, but as $Y_t \equiv W_t + \Pi_t$. The latter is an internally consistent identity; and to the extent that $W_t \equiv w_t L_t$ and $\Pi_t \equiv r_t K_t$, so must the former. Now note that, from equation (14), the growth rate of value-added equals

$$\hat{Y}_t \equiv (1-a_t)\hat{W}_t + a_t\hat{\Pi}_t \tag{24}$$

that is, the growth registered by any economy between two periods is, by definition, the sum of the growth of the total wage bill (i.e. the total contribution of the labor factor to output growth) plus the growth of total profits (i.e. the total contribution of capital to growth), each weighted by its share in value-added. These are, by definition, the sources of growth in any economy, but only in a classificatory sense. This, in itself, measures the overall distributional changes between the two classes that took place between two periods; and it is what growth is about in the classical Ricardian tradition, namely changes in the two components of value-added and how they are distributed.

From equation (24) it can be inferred that there is no residual in the sense that i.e. $\hat{Y}_t - (1-a_t)\hat{W}_t - a_t\hat{\Pi}_t \equiv 0$. This is an interesting point because Jorgenson and Griliches (1967) argued in their seminal growth-accounting exercise that the finding that the bulk of the rise in output per man was due to 'technical progress' resulted from the faulty measurement of the services of capital and labor when calculating $\hat{Y}_t - a_t\hat{K}_t - (1-a_t)\hat{L}_t$. Correcting for these measurement errors, they concluded that the rise in total output was mostly explained by the growth of total inputs.

Hence, the appropriate accounting identity is $\hat{Y}_t \equiv (1-a_t)\hat{w}_t'' + a_t\hat{r}_t'' + (1-a_t)\hat{L}_t'' + a_t\hat{K}_t''$. The superscript $''$ on the growth rates of capital and labor denote that the factor inputs have been adjusted to remove errors in aggregation, in investment goods prices and in relative utilization, and the superscript $''$ on the profit and wage rates denote that these are the returns to the 'corrected factors of production'. As Jorgenson and Griliches found that $\hat{Y}_t \cong (1-a_t)\hat{L}_t'' + a_t\hat{K}_t''$, it is tempting to conclude that the improvements in the efficiency of the factors of production had been subsumed within the inputs by correct measurement. This was Denison's (1961) view. But Jorgenson and Griliches (1967, p. 254, footnote 1) explicitly denied that this was the case.

This presents a conundrum, which may be seen by considering the definition of the growth rate of total output. Given that by definition $W_t \equiv w_t L_t$ and $\Pi_t \equiv r_t K_t$, and therefore, $\hat{W}_t \equiv (\hat{w}_t + \hat{L}_t)$ and $\hat{\Pi}_t \equiv (\hat{r}_t + \hat{K}_t)$, it follows that

$$\begin{aligned}\hat{Y}_t &\equiv (1-a_t)\hat{W}_t + a_t\hat{\Pi}_t \equiv (1-a_t)(\hat{w}_t + \hat{L}_t) + a_t(\hat{r}_t + \hat{K}_t)\\ &\equiv (1-a_t)(\hat{w}_t'' + \hat{L}_t'') + a_t(\hat{r}_t'' + \hat{K}_t'')\end{aligned} \tag{25}$$

The conundrum arises because if Denison was correct and the growth in efficiency of labor and capital (i.e. the growth rates of the marginal products which equal the growth rates of the wage rate and rental price of capital) was

merely included in the growth of the factor inputs, e.g. $\hat{L}_t'' = \left(\hat{w}_t + \hat{L}_t\right)$ then the explanation would be straightforward, but tautological.

However, Jorgenson and Griliches did not adopt this approach, as their careful statistical approach clearly shows—they were solely concerned with correcting measurement errors.[29] They found that measurement errors in the growth of the labor input were relatively minor compared with those found in the growth of the capital stock. The unadjusted TFPG (which we may take to be equivalent to the weighted growth of the real wage rate and the rate of profit) over this period was 1.60 per cent per annum (Jorgenson and Griliches, 1967, p. 260). The weighted growth of the wage rate is likely to be the more substantial component of this figure, given the relative constancy of the profit rate. Consequently, to reduce the annual rate of TFPG to 0.10 per cent, which was the adjusted growth rate that Jorgenson and Griliches calculated, implies that there must have been a substantial reduction in the rate of return, perhaps even a negative growth rate. However, this is likely to be most implausible. The incentive to invest would have declined rapidly and one would have expected the rate of capital accumulation to fall.[30]

Jorgenson and Griliches (1967, p. 274) reach the conclusion that 'it is not that advances in knowledge are negligible, but that accumulation of knowledge is governed by the same economic laws as any other process of capital accumulation.' However, under the neoclassical interpretation, according to Jorgenson and Griliches's figures, there was a negligible growth in 'economic efficiency' in the USA over the period 1945–65. In fact, Denison (1972a, 1972b) showed that the way Jorgenson and Griliches adjusted for changes in capacity utilization overestimated the growth of the capital input, and hence the adjusted TFPG was, in fact, higher than that which they had calculated (see Jorgenson and Griliches (1972) for a reply). But our main point is that by merely considering the accounting identity, it can be seen why this finding is not at all surprising.

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[29] Jorgenson and Griliches, for example, constructed the growth of the labor input index by weighting the growth of different types of labor by their share in the total value of the labor input. But this is not the tautological procedure that Denison (1961) accused them of.

[30] If there had been no errors in measurement in the growth of the labor force, then the adjusted growth of the real wage rate would have been the same as that observed, and the burden of adjustment of TFPG would have had to fall entirely on the growth rate of the profit rate.

5. VALDÉS'S TEST OF THE *AK* MODEL

The final case that we shall consider is Valdés's (1999, pp. 104–107) argument that the 'linear-in-*K*', or *AK*, model gives a very good fit to the data.[31] This case is instructive because the linear-in-*K* model is based on different assumptions from those of the augmented Solow model (notably the existence of constant returns to capital alone). It is also interesting to consider this example because, while Solow's growth model identifies technological progress (where TFPG is assumed to provide an estimate of it) with anything that raises factor efficiency, the endogenous growth models, by endogenizing technological progress, suggest specific mechanisms for how TFPG is produced within the framework of the model. Technical progress in the standard Solow growth model is exogenous, which implies that it is generated outside the economic realm of the private sector. For example, Romer (1990), the pioneer of this literature, has identified technological progress with increases in the stock of knowledge, determined by economic factors such as resources devoted to R&D. Another possibility is provided by the so-called Schumpeterian endogenous growth models built on the idea that each innovation affects one intermediate sector at a time, and involves winners and losers (Aghion and Howitt, 1998). What all these models have in common is that they provide specific explanations for how TFP is determined.

However, we shall see that the reason why the linear-in-*K* model putatively gives a good fit to the data is, again, that it just reflects the underlying accounting identity. Valdés considers the so-called Arrow–Romer model. At the macroeconomic level the production function is given by the traditional Cobb–Douglas:

$$Y_t = (A_t L_t)^{(1-\alpha)} K_t^\alpha \tag{26}$$

However, there are externalities to the capital–labor ratio resulting from learning-by-doing (this is the explanation of TFP in this model), so that[32]

$$A_t = \xi (K_t / L_t)^\theta \tag{27}$$

which means that *A* increases by θ per cent for each 1 per cent increase in the capital–labor ratio (*K/L*). If *A* were exogenous, this model would be the same

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[31] It should be noted that *A*—a constant—in the *AK* model is not the same as that in the Cobb–Douglas production function that we have used above.

[32] Note that equation (26) corresponds to the identity (16) with $A_t^{(1-a)} \equiv B_0 w_t^{(1-a)} r_t^a$.

as Solow's. But A is an endogenous variable in this model in that it depends upon the level of mechanization (K/L) that the firms choose. Assuming $\theta = 1$ (a necessary condition for the model to have a steady-state solution (see Valdés, 1999, p. 106) and substituting equation (27) into (26) we obtain

$$A_t = \xi^{(1-\alpha)} K_t = \Lambda K_t \tag{28}$$

where $\xi^{(1-\alpha)} = \Lambda$ is a constant.[33] The steady-state growth of productivity (assuming the rate of depreciation, δ, is constant) is given by

$$\hat{y} = \hat{k} = s_K \Lambda - (n_t + \delta) \tag{29}$$

and the growth of output and capital is given by

$$\hat{Y} = \hat{K} = s_K \Lambda - \delta \tag{30}$$

For the USA over the period from 1950 to the approximately 1990, Valdés (1999, p. 108) suggests the following values:

- The capital–output ratio (K/Y) is 2.5, which suggests $\Lambda = Y/K = 0.4$.
- The rate of depreciation is taken as a constant, so that $\delta = 0.04$.
- Population growth (strictly speaking it should be employment growth, $\hat{L}$) is $n = 0.015$.
- The gross investment ratio (s_K) is 0.187.

It follows from equation (29) that

$$\hat{y} = s_K \Lambda - (n + \delta) = 0.0198 = 1.98 \text{ per cent per annum}$$

and from equation (30) that

$$\hat{Y} = s_K \Lambda - \delta = 0.0348 = 3.48 \text{ per cent per annum}[34]$$

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[33] We use Λ to avoid confusion with A_t, the measure of technology in the Solow model.
[34] Valde's mistakenly reports 3.25 per cent per annum.

Valdés (1999, p. 108) asks, and answers, the question 'How good are these results? They are very accurate indeed.' In other words, the predicted growth rates of productivity and output given by the linear-in-K model for the USA are almost identical to the actual outcomes over the post-war period.

However, we can show that given the stylized facts that the growth of capital and output are equal and factor shares are constant, the data could not fail to give an accurate prediction. We start with the familiar accounting identity expressed in growth rate form:

$$\hat{Y}_t \equiv (1 - a_t)\hat{w}_t + a_t\hat{r} + (1 - a_t)\hat{L}_t + a_t\hat{K}_t \tag{31}$$

If factor shares are constant, $\hat{w}_t = \hat{Y}_t - \hat{L}_t$ and, given the stylized fact that $\hat{Y}_t = \hat{K}_t$, it follows that $\hat{r} = \hat{Y}_t - \hat{K}_t = 0$. Consequently, substituting for $\hat{w}$ and $\hat{r}$, the accounting identity becomes simply

$$\hat{Y}_t = \hat{K}_t \tag{32}$$

or, integrating

$$Y_t = \kappa K_t \tag{33}$$

where κ is the constant of integration.

Thus, the accounting identity with constant factor shares can be transformed into a form that resembles a Cobb–Douglas production function, or given the stylized fact of a constant capital–output ratio, into the linear-in-K model.[35]

Consequently, as $s_K \Lambda - \delta \equiv (I/Y)(Y/K) - \delta \equiv (I/K) - \delta \equiv \hat{K}$ (where I, it will be recalled, is gross investment) it follows that *if* the growth of output ($\hat{Y}$) is equal to the growth of the capital stock, then the definition $\hat{K} \equiv s_K \Lambda - \delta$ must also be equal to $\hat{Y}$, irrespective of whether the underlying production function is a Cobb–Douglas or 'linear-in-K'; or, more importantly for our purposes, even though an aggregate production function does not exist. A corollary is that $\hat{y}$ must also equal $\hat{k}$. Hence, equation (29) must give a growth rate of 1.98 per cent per annum and equation (30), 3.48 per cent per annum.

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[35] It should be obvious that the whole process is tautological. The stylized fact (assumption) that $\hat{Y}_t = \hat{K}_t$ itself implies that $Y_t = \kappa K_t$ (where κ is the constant of integration), the linear-in-K model!

Thus, the fact that the growth of productivity and the growth of output are closely approximated by equations (29) and (30) merely reflects the stylized fact that the growth of output equals the growth of the capital stock. It implies nothing about whether the 'linear-in-K' model out-performs the Solow model or, indeed, whether there exists an aggregate production function at all.

Alternatively, from equation (14) and these assumptions, we may also derive the relationship $Y_t \equiv \kappa K_t$, where $\kappa = \Lambda$ is a constant. Thus, the data are equally compatible with the conventional neoclassical model or the linear-in-K model. As Romer (1994, p. 10) commented in another context, 'if you are committed to the neoclassical model, the . . . data cannot be made to make you recant. They do not compel you to give up the convenience of a model in which markets are perfect.'

6. IS A THEORY OF TFP NEEDED?

A number of authors during the last decade have advocated models that allow for differences in technology across countries in order to explain differences in income per capita. This is because estimated levels of TFP across countries display substantial variations. This paper has shown that the procedure used to estimate TFP is tautological. Thus, asking whether a theory of TFP is needed begs the question. In our opinion, and for the reasons set out in this paper, the concepts of TFP and aggregate production function serve more to obfuscate than to illuminate the important problem of 'why growth rates differ'.

First, we have considered Jones's (1998, 2002) popular textbook. Jones argues that the neoclassical model describes the distribution of per capita income across countries fairly well. We have shown that this must be the case due to the tautological procedure used to calculate TFP. We have also shown that the same result is obtained even though there is no underlying aggregate production function, in which case the Solow model is incoherent. The problem arises due to the existence of the accounting identity that relates output to the sum of the wage bill plus total profits, which is responsible for the observed relationships and enables the results to be predicted *a priori* with only the knowledge of the Kaldorian 'stylized facts' of economic growth.

Second, we have discussed Barro's (1999) and Hsieh's (1999, 2002) argument that the rate of TFPG can be obtained by simply differentiating the income-accounting identity. We have shown that, while the procedure is correct, it is a tautology.

Finally, we have discussed Valdés's (1999) test in his textbook of one of the first endogenous growth models, the linear-in-K model, and also shown that it cannot be tested because the data cannot refute it.

Given the above conclusions, we are skeptical that this literature is advancing knowledge in the fields of economic growth and development in a particularly useful way. What neoclassical economics terms TFP is, *tautologically*, a weighted average of the wage and profit rates. Therefore, what this literature has discovered is that in order to explain the observed large income differences across countries, one needs a theory of this weighted average. Although neoclassical theory reaches this result through the so-called dual measure of TFP, we have shown that it follows simply from the income-accounting identity, and thus it is not testable because it cannot be refuted. As the well-behaved aggregate production function does not exist, then it is not possible to calculate separately the contribution to economic growth of technical change (or TFPG) and the growth of each factor input. This is equally true of both econometric techniques and the growth-accounting methodology (the endogenous growth theory also relies on the concept of the aggregate production function and takes us no further forward in understanding the determinants of growth). Acknowledgement of this obvious point might help in deciding if a theory of TFP is needed in order to explain income differences across countries. The critique does not deny that authors such as Parente and Prescott (2000) may be on the right track when they argue that one important reason why many developing countries do not perform well is that they erect barriers in order to protect industry insiders from outside competition, but which prevent the efficient use of available technologies in order to protect industry insiders from outside competition. However, arguing that the erection of these barriers *causes* differences in the level of aggregate TFP, which then *causes* differences in international income levels, is an altogether different proposition.

For purposes of measurement, efforts should be made towards improving the statistics of labor productivity. Moreover, when it comes to the analysis and understanding of growth, there are several paths that could yield useful results. Nelson (1998, p. 497) argued that 'the basic assumptions of the neoclassical growth theory inherently limit the ability of models within that theory to cast light on economic growth as we have experienced it. This holds for the "new growth theory" as well as the older growth theory of the 1950s and 1960s.' We fully agree with this statement. The question is how to proceed.

Nelson also argued that a useful theory of economic growth needs to consider the following: (1) technological advance as a disequilibrium process, (2) firms' capabilities and their differences as central elements, and (3) a richer body of institutions than the ones currently being considered by orthodox growth models. His approach (see also Nelson and Winter, 1982) has been to adopt an evolutionary approach to economic growth. By using simulation analysis, Nelson and Winter have shown how a distinctly non-neoclassical

approach (firms are satisficers and search for the new techniques only when their rate of profit falls below an 'acceptable' level) can yield an aggregate Cobb–Douglas production function even though each firm produces with a fixed coefficients technology. The outcome of their simulation exercise provides a very close approximation to Solow's (1957) data for the non-farm private business sector of the US economy. However, it is fair to say that this approach, while illuminating and of great potential, has not made a great impact on the growth literature.

At the macroeconomic level, one possibility is to revert to a research agenda based on the very fruitful classical approach, as shown by Salvadori (2003). Also, the neo-Keynesian theory of distribution and growth developed by the Cambridge, UK, school in the 1950s and 1960s (Pasinetti, 1962) starts by considering the income-accounting identity: after all, Ricardo argued that growth is about the forces driving the functional distribution of income. The neo-Keynesian school challenged the neoclassical formulation of saving behavior, and in particular that growth is determined by the investment of full-employment savings. In the neo-Keynesian theory, institutional factors, such as corporations' decisions to retain substantial amounts of their earnings, plus class behavior, i.e. the saving propensities of the different classes of income receivers, determine saving behavior. This is an argument that goes back to the Classical economists (see Dobb, 1973; Pasinetti, 1974).

Finally, we suggest that there has to be a move away from the use of highly aggregative data for purposes of studying productivity differences. Use of microeconomic-level data can prove very useful. After all, it is firms that one must understand in order to comprehend how market economies grow. Lewis (2004) argues in such terms and offers empirical evidence regarding the insights that firm-level analyses and case studies can provide for understanding aggregate growth. Another possible way is through 'matched samples' studies of firms. The instructive studies by Daly *et al.* (1985) and Mason *et al.* (1996) also provide very useful insights into why the levels of productivity differ across manufacturing firms in different countries producing the same product, and provide a solid starting point.

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