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IS A THEORY OF TOTAL FACTOR PRODUCTIVITY REALLY NEEED?

Macroeconomics consists of identities and opinions [1]

Abstract: This paper addresses the question of whether or not a theory of total factor productivity (TFP) is needed in order to explain the documented 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 prove 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.

JEL classification: O11, O16, O47, O53

1. Introduction

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 it has provided useful answers to this question (Mankiw *et al.* 1992; Jones 1998, 2002), others take the opposite view (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 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? This model predicts that countries with high saving/investment rates will tend to have a higher level of income per capita; and countries that have high population growth rates will tend to be poorer. 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.

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 precisely because it assumes identical technologies (TFP) (Jorgenson 1995; Durlauf and Johnson 1995; Jones 1997a, 1998, 2002; Hall and Jones 1999; Islam 1999; Parente and Prescott 2000).[2] These authors, therefore, argue for a version of Solow's growth model that incorporates differences in technology levels. Prescott (1998), for example, has argued that a separate, or distinct, theory of total factor productivity (TFP) differences is needed. In a similar vein, Meier (2001, p.25), while suggesting a series of research topics for the new generation of development economists, argues that "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 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 paper is structured as follows. We first show in section 2 why Solow's growth model has limited explanatory power in terms of the variance of per capita income that it can explain, drawing on Prescott's (1998) approach. In section 3 we discuss whether adding human capital to Solow's growth model greatly improves its explanatory power of income differentials and conclude that it does not. We next discuss in section 4 how the arguments

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1 Lewis (2004, p.7)

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 issues in constructing this index relate 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.

regarding the importance of TFP are presented in Jones's (1998, 2002) textbooks.[3] 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 5 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 6 elaborates upon the previous argument and questions Barro's (1999) and Hsieh's (1999, 2002) argument that growth accounting exercises, whose purpose is to estimate the rate of TFP growth – not its level – can be directly carried out from the accounting identity.

In section 7 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. It is also shown that it cannot be tested because the data cannot refute it. We conclude 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. Can Differences in Productivity be Explained by Disparities in Savings (Investment) Ratios?

The productivity and per capita income of the richest country (the US) is presently some 30 to 35 times that of the poorest country (Prichett 1997). The first question we shall review is the extent to which such differences in productivity can 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

[3] 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".

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 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. To show this, let us assume that the economy may be described by the Cobb-Douglas aggregate production function $Y = K^{\alpha}[A(t)L]^{1-\alpha}$, where *Y*, *K* and *L* are output, the capital stock and employment. The parameters α and $(1-\alpha)$ are the output elasticities of capital and labor, and *A(t)* is the level of technology. The value of the capital stock is constructed through the perpetual inventory method:

$$K_t = \sum_{v=0}^{v=m} (1-\delta)^v I_{t-v} \tag{1}$$

where *m* is the age of the oldest vintage still in use, δ is the rate of depreciation and *I* is gross investment.

Let us assume that, over the period under consideration, the investment-output is constant and so investment grows at a rate equal to the growth of output, denoted by $\hat{Y}$. In these circumstances, equation (1) may be written as:

$$K_t = \sum_{v=0}^{v=m} (1-\delta)^v (1-\hat{Y})^v I_t \tag{2}$$

If *t* is sufficiently large, then equation (2) may be written as the approximation $K_t = \frac{I}{\hat{Y}+\delta}$ (ignoring the interaction term $\delta\hat{Y}$) and the capital-output ratio as $\frac{K_t}{Y_t} = \frac{s}{\hat{Y}+\delta}$, where *s* is the investment (savings)-output ratio. As we have assumed that the growth of output over the period of the calculation of the capital stocks (which, because of the depreciation factor could be as short as 30 years) has been constant as has been the average propensity to save, the capital-output ratio could also be regarded as the steady-state level. The Cobb-Douglas production function for a particular country may be written in intensive form as:

$$\frac{Y_t}{L_t} = A_t \left(\frac{K_t}{Y_t} \right)^{\alpha/(1-\alpha)} \qquad (3)$$

It can be seen that the productivity is positively related to the capital –output ratio. Table 1 reports the savings ratios and the calculated associated "steady-state" capital-output ratio. Following Prescott (1998) it is assumed that output growth ($\hat{Y}$) is 0.03 and the depreciation rate (δ) is 0.05. In order to see the extent to which variations in the capital-output ratio can explain differences in productivity, we take the US with a savings ratio of 20% as the reference country. Assuming other countries have the same level of technology ($A^{(1-\alpha)}$), and a value for α as either 0.25 or 0.30, the table also reports the difference in productivity due to differences in the capital-output ratio.

Table 1. Steady-State Investment-Output Ratio, Capital-Output Ratio, Relative Productivities and Rate of Return

	Investment-Output Ratio	Capital-Output Ratio	Relative Productivity		Rate of Return	
			(i)	(ii)	(i)	(ii)
(a)	5%	0.625	0.63	0.55	40%	48%
(b)	10%	1.25	0.79	0.74	20%	24%
(c)	20%	2.50	1.00	1.00	10%	12%
(d)	30%	3.75	1.14	1.19	7%	8%
(e)	40%	5.00	1.26	1.35	5%	6%
Ratio of (e) to (a)		8	2.00	2.45	0.125	0.125

Notes: (i) assumes α = 0.25 and (ii) assumes α = 0.30. The steady-state of rate of return is calculated as $\alpha(n + g + \delta)/s$, where α is capital's share; n is the growth rate of population; g is the rate of technical progress; s is the investment-output ratio. After Prescott (1998).

From Table 1 it can be seen that when α = 0.25, the capital-output ratio of a country with a 40 per cent investment–output ratio (i.e., eight times that of a country investing only 5 per cent of its output) has only twice the level of productivity (or per capita income). This is several orders of magnitude less than that observed in reality. Increasing the output elasticity of capital to 0.30 does not alter the conclusions.

The table also reports the steady-state rates of return associated with each capital-output ratio, and it can be seen that those associated with a small investment-output ratio are implausibly high. Thus, not only can differences in the investment or savings ratio explain very little of the disparities in productivity, but they also involve some very implausible rates of return.

Romer (1994) makes the same point but in a slightly different way. Expressing the Cobb-Douglas in per worker terms as $y = \widetilde{A}k^{\alpha}$, where $y=Y/L$ and $k=K/L$, in growth rate form, he obtains: [4]

$$\begin{aligned} \hat{y} &= \hat{\widetilde{A}} + \alpha\hat{k} \\ &= \hat{\widetilde{A}} + \alpha[sA^{1/\alpha}y^{-(1-\alpha)/\alpha} - n] \end{aligned} \qquad (4)$$

where the circumflex, ^, denotes a proportionate growth rate.

He considers two countries, say, the U.S. and the Philippines, which are growing at the same rate, and where all parameters, except the savings rate and productivity, are the same. It follows that $sy^{-(1-\alpha)/\alpha}$ must be constant. As the level of productivity of the Philippines is only 10 per cent that of the US, the latter, if α = 0.40, would have to have a savings ratio that was $0.1^{-1.5}$ or about 30 times that of the Philippines. If α = 0.25, the figure increases to 1,000 times. In reality, the US savings ratio is not all that different from that of the Philippines. Consequently, under the assumptions of Solow's model, differences in savings and investment can only account for a small difference in relative productivity levels. The explanation must lie elsewhere.

3. Human Capital to the Rescue?

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. In this way, Mankiw *et al.* (1992), using regression analysis, allowed the data to determine the values of the elasticities of the production function in the context of an extended Solow's model that included human capital (H). They 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

[4] Note that this specification of the Cobb-Douglas production function, $Y_t = \widetilde{A}_t L_t^{(1-\alpha)} K_t^{\alpha}$, differs from that in equation (3), but this does not make any difference to the results.

income. The production function consistent with their results is $Y = K^{1/3}H^{1/3}L^{1/3}$. In this formulation the elasticity of physical capital is not different from its share in income. There are also no externalities to the accumulation of physical capital. These results, however, have been seriously questioned by the literature for lacking robustness (see Felipe and McCombie 2004 for a survey of this literature, and also for an assessment of Mankiw *et al.'s* (1992) procedure to test of Solow's (1956) growth model).

Jones (1998) assumed that human capital can be estimated as $H = e^{\eta u}L$, where u is the number of years of schooling and η is the Mincerian rate of return to an extra year of schooling. This is taken empirically to be 0.10, and so an increase in one year's schooling increases the effective labor input by 10 percent. We have reservations with this formulation, but, in this framework, given that the greatest difference between countries in terms of years of schooling is of the order of ten years, it means that education could only account for a factor of 2 in the differences between the richest and poorest countries, as Jones (2002) admits.[5]

Prescott (1998, p.541), following Lucas (1988), used an explicit equation for the production of human capital. For various values of the parameter of the human capital production sector, Prescott uses US data to calibrate a model and finds that either the implied values of time are so implausibly large or else the implied rates of return to education are so high in the poorest countries that he is led to "reject this model as a theory of international income differences" (Prescott, 1998, p.543).

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*.

4. 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 US, (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, then Jones inferred 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 that "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 $Y_t = K_t^{\alpha}(A_t L_t)^{(1-\alpha)}$ is used to show the range of values of *A* necessary to fit the model to the data. He examines the relationship between relative *A'*s and the actual (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:

$$y_i = k_i^{\alpha}(A_i' h_i)^{(1-\alpha)} \quad (5)$$

where *y*, *k* and *h* are output per worker, capital per worker and a measure of human capital per capita (proxied by the level of schooling). The parameters α and $(1-\alpha)$ are the output

[5] 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.

elasticities of capital and labor. The time subscript has been dropped for notational convenience.

Jones derives the steady-state level of productivity from equation (5) by assuming that $\hat{Y} = \hat{K}$ and that the rate of technical progress is the same for all countries (i.e. $g_i = g$). The steady-state level of productivity is given by:

$$y_i^* = \left(\frac{s_{K_i}}{n_i + g + \delta} \right)^{\alpha/(1-\alpha)} A_i^{'} h_i \tag{6}$$

where s_K is the share of physical investment in output.

Equation (6) is used to calculate the ratio of the steady-state levels of productivity of various countries to that of the US:[6]

$$\frac{y_i^*}{y_{US}^*} = \frac{\left(\frac{s'_{K_i}}{n_i + g} \right)^{\alpha/(1-\alpha)}}{\left(\frac{s'_{US}}{n_{US} + g} \right)^{\alpha/(1-\alpha)}} \frac{A_i^{'}}{A_{US}^{'}} \frac{h_i}{h_{US}} \tag{7}$$

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:

$$A_i^{'} \equiv \left(\frac{y_i}{k_i} \right)^{\alpha/(1-\alpha)} \left(\frac{y_i}{h_i} \right) \tag{8}$$

[6] For expositional convenience, 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.

[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.”

The value of *A'* that is calculated from equation (8) is substituted into equation (7) to derive a value for (y_i^* / y_{US}^*). A visual comparison of $ln(y_i^* / y_{US}^*)$ 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 (8) is in these circumstances written as:

$$A_i' \equiv \left(\frac{y_i}{k_i} \right)^{\alpha/(1-\alpha)} y_i \qquad (9)$$

Substituting *A* for *A'* in equation (7) and omitting (h_i / h_{US}) gives the following equation:

$$\frac{y_i^*}{y_{US}^*} = \frac{\left(\frac{s'_{K_i}}{n_i + g} \right)^{\alpha/(1-\alpha)}}{\left(\frac{s'_{US}}{n_{US} + g} \right)^{\alpha/(1-\alpha)}} \frac{\left(\frac{Y_i}{K_i} \right)^{\alpha/(1-\alpha)}}{\left(\frac{Y_{US}}{K_{US}} \right)^{\alpha/(1-\alpha)}} \frac{y_i}{y_{US}} \qquad (10)$$

where, it will be recalled, *g* is the rate of technical progress or (1-α) $\hat{A}$.

Consider the expression $\left(\frac{s'_{K i}}{n_i + g} \right)$. 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:

$$\left(\frac{s'_{K i}}{n_i + g} \right) \left(\frac{Y_i}{K_i} \right) = \left(\frac{\hat{K}}{n_i + g} \right) \qquad (11)$$

Equation (10) may therefore be expressed as:

$$\frac{y_i^*}{y_{US}^*} = \frac{\left(\frac{\hat{K}_i}{n_i + g} \right)^{\alpha/(1-\alpha)}}{\left(\frac{\hat{K}_{US}}{n_{US} + g} \right)^{\alpha/(1-\alpha)}} \frac{y_i}{y_{US}} \qquad (12)$$

or in logarithmic form as:

$$ln(y_i^* / y_{US}^*) = \alpha/(1-\alpha)\, ln(x_i / x_{US}) + 1.0\, ln(y_i / y_{US}) \qquad (13)$$

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

Consequently, if we were to regress $ln(y_i^* / y_{US}^*)$ on $ln(y_i / y_{US})$, we can see immediately that 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 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 unity. In fact, plotting $ln(y_i^* / y_{US}^*)$ against $ln(y_i / y_{US})$ gives a slope that is less than unity, and suggests 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 (8) into equation (7), we obtain equation (12) 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 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, chapter 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. 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

9 This is a condition for steady-state growth in the neoclassical growth model, but is also one of Kaldor's (1961) stylized facts.

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 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.[10] We should thus expect the rate of technical progress (or total factor productivity growth) to vary between countries with their level of technology. This is precisely what the growth accounting studies suggest for most 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.

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[10] In fact, the relationship is likely to be more complex than this. 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, Chapter 2).

Secondly, the statement that the relative income gap will become constant if countries differ in *g* is only true if *g* remains constant over time, whereas, as we have seen, the technological catch-up model (Gomulka 1971, Fagerberg 1987) postulates the opposite: the rate of technical progress is likely to vary depending upon the extent of the technological gap. 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 (12) becomes

$$\frac{y_i^*}{y_{US}^*} = \frac{\left(\dfrac{\hat{K}_i}{n_i + g_i}\right)^{\alpha/(1-\alpha)}}{\left(\dfrac{\hat{K}_{US}}{n_{US} + g_{US}}\right)^{\alpha/(1-\alpha)}} \frac{y_i}{y_{US}} \qquad (14a)$$

or:

$$\frac{y_i^*}{y_{US}^*} = \frac{x_i'}{x_{US}'} \frac{y_i}{y_{US}} \qquad (14b)$$

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

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

levels of productivity. There is no discussion of the steady-state values. The relationship is given by:

$$\frac{A_i^{'}}{A_{US}^{'}} \equiv \frac{\left(\frac{Y}{K}\right)_i^{\alpha/(1-\alpha)} \frac{y_i}{h_i}}{\left(\frac{Y}{K}\right)_{US}^{\alpha/(1-\alpha)} \frac{y_{US}}{h_{US}}} \tag{15}$$

or, assuming that the capital-output ratios are constant, by:

$$\frac{A_i^{'}}{A_{US}^{'}} = \frac{h_{US}}{h_i}\frac{y_i}{y_{US}} \tag{16}$$

Thus:

$$\ln\left(\frac{A_i^{'}}{A_{US}^{'}}\right) = \ln\left(\frac{h_{US}}{h_i}\right) + \ln\left(\frac{y_i}{y_{US}}\right) \tag{17}$$

It should be emphasized that equation (17) 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. It is analogous to the growth accounting approach, as Jones (2002) admits, although in terms of relative levels. As such, while it can give quantitative estimates of the various components given the usual neoclassical assumptions, it cannot give any idea of whether these components are statistically significant in the growth process.

5. 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 Franklin Fisher, *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 (see 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:

$$Y_t^n \equiv P_t Y_t \equiv W_t^n + \Pi_t^n \equiv w_t^n L_t + r_t^n K_t \tag{18}$$

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 (surplus in the NIPA terminology). The symbol $\equiv$ indicates that expression (18) 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] It must be added that the NIPA does not provide the decomposition on the right-hand side of (18), but only the aggregate sum of the payments to the factors of production (wages and profits), that is, $Y_t^n \equiv W_t^n + \Pi_t^n$. The decomposition of the wage bill and total profits into the products of the factor prices times the "quantities" is definitional. Moreover, it will always be true that the wage bill can be written as the product of the average wage rate times employment. On the other hand, whether the wage rate equals the marginal product of labor or not, 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 $w = (w^n / P)$ the average real wage rate and $r = (r^n / P)$ the average ex-post profit rate.

In proportionate growth rate form, equation (18) in real terms becomes: [14]

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

$$\equiv (1-a_t)g_t + (1-a_t)\hat{L}_t + a_t\hat{K}_t \tag{19}$$

where $(1-a_t)g_t \equiv (1-a_t\hat{w}_t + a_t\hat{r}_t$; $(1-a_t) = (w_t L_t)/Y_t$ is labor's share; and $a_t = (r_t K_t)/Y_t$ is capital's share in value added. Assuming that factor shares are constant,

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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).

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* micro production function and no aggregate production function.

i.e., $a_t = a$ and $1 - a_t = 1 - a$, integrating equation (19) and taking anti-logarithms, we obtain:

$$Y_t \equiv B_0 w_t^{1-a} r_t^{a} L_t^{1-a} K_t^{a} \tag{20}$$

where B_0 is the constant of integration; or

$$Y_t \equiv (A_t L_t)^{1-a} K_t^{a} \tag{21}$$

where $A_t \equiv (B_0 w_t^{1-a} r_t^{a})^{1/(1-a)}$. It is obvious that equation (21) *resembles* the Cobb-Douglas production function, where A_t^{1-a} represents, in the traditional parlance, the level of TFP. Moreover, suppose in this economy wage and profit rates grow at constant rates (or if the wage rate grows at a constant rate and the profit rate is constant), then equation (20) could be written as:

$$Y_t \equiv (B_0\, e^{gt} L_t)^{1-a} K_t^{a} \tag{22}$$

where $(1-a)g$ is the weighted average of the constant rates of growth of the wage and profit rates. However, expressions (21) and (22) *are not* production functions. It should be emphasized that these equations have been merely derived as a transformation of the accounting identity, equation (18), using two hypotheses about the data (which can be tested), *viz.*, 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 (22) 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 above, 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 (19) as:

$$y_i^* = \left(\frac{\hat{K}_i}{n_i + g_i} \right)^{a/(1-a)} y_i \tag{23}$$

and the ratio y_i^* / y_{US}^* is given by equations (14a) and (14b), although the latter has been 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 fact that $\hat{Y} = \hat{K}$, then equation (23) is true by definition.

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 $A^{1-a} = Y/(L^{1-a}K^{a})$ (see equation (8) above) are definitionally equal to $A^{1-a} = B_0 w^{1-a} r^{a}$.[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 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 developed than in the developing countries.

The derivation of equation (22) 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 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 (*Y*) on that of labor (*L*), and that of capital (*K*), together with an exponential time trend (*t*), i.e., $Y_t = C\, exp(\lambda\, t)\, L_t^{\alpha}\, K_t^{\beta}\, exp(\varepsilon_t)$, 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 (22), 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 a country with a command economy where factors are not paid their marginal products. All we have used in deriving equation (22) is the identity that output equals the payment to the factors of production, together with the two assumptions. The fact

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

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: (i) the growth rates of capital and labor are not exogenous variables with respect to the growth of output; (ii) the growth of capital is usually measured with errors, which often leads to low estimates of the contribution of capital accumulation; and (iii) the regression framework must be extended to allow for variations in factor shares and the TFP growth 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]

To see that Barro's third 'problem' is not really such, one has to note that, in general, a production function *Y=A F(K,L)* may be expressed in growth rates and estimated econometrically as $\hat{Y}_t = \lambda_t + \alpha_t \hat{L}_t + \beta_t \hat{K}_t + \upsilon_t$ where α_t and β_t are the output elasticities of labor and capital (which, in general, vary in time, as Barro notes), respectively, λ_t is the growth rate of total factor productivity, and v_t is the error term. On the other hand, the accounting identity is given by equation (19). A comparison of both expressions indicates that any functional form (or estimation procedure, such as a time-varying estimation method) that gives a good approximation to the identity could also be mistakenly interpreted as a production function.[18]

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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).

[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." The argument above explains *how* and *why* one can, in fact, estimate the coefficients of equation (22). 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, in the case of equation (22), if the assumptions about the factor shares and the wage and profit rates are empirically incorrect, certainly the estimation of equation (22) –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

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 works reasonably well.[19] Why is this the case? From the identity, we know that $g_t \approx \hat{w}_t + [a_t/(1-a_t)]\hat{r}_t$. Plots of the Solow residual typically show a procyclical fluctuation around its mean growth rate (see, for example, Solow 1957). 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 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 that "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 $g_t \approx \hat{w}_t + [a_t/(1-a_t)]\hat{r}_t$, the one that truly varies the most is $\hat{r}_t$, and it does so procyclically. As we are arguing that this variable is being omitted from

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shares. Once found, one simply has to proceed as above, that is, substitute the expression for the path into equation (19) 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). As the aggregate production function is an integral part of the neoclassical growth model, it follows that it is not possible to test it, including Mankiw *et al.'s* (1992) specification of the augmented Solow model (Felipe and McCombie 2004).

[19] Harrison (2002) has calculated the factor shares for a large number of countries and questioned the assumption about their constancy.

the regression, the inclusion of any other variable that moves procyclically, namely the capital stock adjusted for capacity utilization, will serve as a good proxy. If capital's share is roughly constant, imparting a procyclical fluctuation in the capital stock will reduce that exhibited by the rate of profit. Barro is right, but for the wrong reason (see McCombie 2000-2001).[20]

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) adopted the idea of constructing the series of technical progress as $A = Y/F(K,L)$ as in Solow's (1957) seminal paper but also including human capital in the manner outlined above. The latter two authors asked: "What do the measured differences in productivity across countries actually reflect?" (Hall and Jones 1999, p.94). They argued, following Solow (1957), that they reflect differences in the quality of human capital, on-the-job training, or vintage capital effects in 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 *A* is, by definition (derived above), a weighted average of the logarithm of the wage and profit rates.[21]

Solow (1957) constructed $\widetilde{A} = Y / F(K,L)$ and assigned $\widetilde{A}$=1 to the first year (i.e., he constructed an index of technology).[22] Then he divided output per worker ($y = Y/L$) by $\widetilde{A}$ to generate the new series $q = y / \widetilde{A}$ with a view to eliminating the effect technical progress. Solow then regressed this new series *q* on the capital-labor ratio ($k = K/L$) using

20 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.

21 Hall and Jones (1999) conclude 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.

22 Solow used the production function expressed in the form $Y = \widetilde{A}F(L,K)$ rather than $Y = F(AL,K)$, i.e., in terms of the Cobb-Douglas expressed as $Y = \widetilde{A}L^{1-a}K^{a}$ rather than as $Y = (AL)^{1-a}K^{a}$. This makes no difference to the substance of the argument and there is no conceptual difference between Harrod and Hicks neutral technical change with the Cobb-Douglas production function.

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 (20), 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 $\widetilde{A}_t = w_t^{(1-a)}\, r_t^a$. This implies that $q_t \equiv B_0\, k_t^a$. Therefore, regressing q_t on k_t must, by construction, yield an extremely good fit as long as factor shares are constant. For Solow's data set, the correlation between $k_t^{\bar{a}}$, where $\bar{a}$ is the average capital share and equals 0.341, and k_t 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, p.318-319) must yield an of estimate $b_2 = \bar{a}$, the average capital share.[23] 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.[24] Our analysis implies that we know, before estimating the equations, the coefficients of the regressions Solow (1957) estimated.

6. 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 growth of total factor productivity (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 (see Jorgenson and Griliches 1967), can be performed by simply differentiating the NIPA identity, equation (18) in real terms, to give equation (19). 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 that "It is useful to think about this [growth accounting] as an accounting identity" (Hsieh 2002, p.502) and reasons as follows:

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23 Solow, in error, omits the logarithm symbol.

24 With regards to regression (4a) in Solow (1957, pp.318-319), namely, $q_t = b_6 + b_7\, k_t$, 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%.

"…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; italics added).

Barro (1999) also 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 $Y_t = w_t L_t + r_t K_t$. No assumptions were made about the relations of factor prices to social marginal products or about the form of the production function" (Barro 1999, pp.123). Y_t, r_t, K_t, w_t, and L_t 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 continues: "If the condition $Y_t = w_t L_t + r_t K_t$ holds, then the primal and dual estimates of TFP growth inevitably coincide […] If the condition $Y_t = w_t L_t + r_t K_t$ holds, then the discrepancy between the primal and dual estimates of TFP has to reflect the use of different data in the two calculations" (Barro 1999, pp.123-124).

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 Hsieh's (1999, 2002) and Barro's (1999) 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, not withstanding 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

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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.

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 $X \equiv Y + Z$, then this may be expressed as $\phi\hat{Y} \equiv \hat{X} - (1-\phi)\hat{Z}$, where $\phi \equiv Y/X$. 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 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 total factor productivity growth. 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. 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 (19) above can be rearranged to give:

$$(1-a_t)g_t \equiv \lambda_t \equiv \hat{Y}_t - (1-a_t)\hat{L}_t - a_t\hat{K}_t \equiv a_t\hat{r}_t + (1-a_t)\hat{w}_t \qquad (24)$$

Under the usual neoclassical assumptions, this equation is formally equivalent to the Solow residual or TFPG. The first part, $\lambda_t^P = \hat{Y}_t - (1-a_t)\hat{L}_t - a_t\hat{K}_t$, 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, $\lambda_t^D \equiv (1-a_t)\hat{w}_t + a_t\hat{r}_t$, 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 other 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., $Y = \widetilde{A}(t)F(L,K)$.[26] On the other hand, Euler's theorem implies that $Y = f_L L + f_K K$, where f_L and f_K are the corresponding marginal products, which are assumed be equal to the factor prices, *w* and *r*, respectively. Then it follows that $Y = wL + rK$. This result, however, should not be mistaken with the identity, equation (18). 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 $Y \equiv W + \Pi \equiv wL + rK$ 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:

$$\lambda_t = \hat{Y}_t - \alpha_t \hat{L}_t - \beta_t \hat{K}_t \qquad (25)$$

where α_t and $\beta_t \equiv 1 - \alpha_t$ are 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., $\alpha_t = (1-a_t)$ and $\beta_t = a_t$. 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_t in equation (24) as the rate of technological progress *must* follow from a comparison with equation (25); 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

[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 thankful 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 that this paper addresses. This is because 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.

technical progress? As we have noted above, the aggregate production function, together with the conditions for producer equilibrium (the first-order conditions), provide 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 (18), 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 because of measurement error. Thus, to ensure consistency, one of the variables will have to be obtained residually. The NIPA provides data on *Y* (as indicated above, in nominal terms, Y^n. It is deflated using the output deflator), while data on w^n (and 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* which is often obtained residually. But if there were independent estimates of *r* published, one could equally obtain *K* (or any 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_t or K_t 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 $\dot{\varphi}$ is the capital gain or loss. This amounts to writing the identity as:

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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

$$Y_t \equiv w_t L_t + v_t K_t + \pi_t \qquad (26)$$

where π_t denotes pure profits. This differs from equation (18) in several respects. First, writing the latter does not require any behavioral assumptions. However, in writing the equivalent to our equation (26), 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). Secondly, if Hsieh had in mind equation (26) when he wrote equation (18), then he implicitly assumed that $\pi_t = 0$. This is consistent with long-run perfectly competitive markets, but this again requires an assumption relating to the state of competition. (Hsieh confusingly used the same notation, *r,* in both equations (18) and (26), rather than distinguishing between *r* and *v*).

It is in this case that the identity might not hold, i.e., Y_t may not equal the sum of $w_t L_t + v_t K_t$, if Y_t refers to (deflated) value added as reported in the NIPA. The growth accounting expression (19) captures the effects of monopoly profits included as part of π_t. 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 $\pi_t = \tilde{v}_t K_t$, that is, as the product of the rate of return due to market power multiplied by the value of the stock of capital. This implies that equation (26) can be rewritten as:

$$\begin{aligned} Y_t &\equiv w_t L_t + v_t K_t + \tilde{v}_t K_t \equiv w_t L_t + (v_t + \tilde{v}_t) K_t \\ &\equiv w_t L_t + r_t K_t \qquad (27) \end{aligned}$$

which implies that $(v_t + \tilde{v}_t) \equiv r_t$. In other words, one can decompose the ex-post average profit rate r_t 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.

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made to preserve the labor-share identity. The same applies to the variables that make up the capital share.

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 it is done in growth accounting exercises? It follows from the above arguments that g_t 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 (18), that is, $Y_t \equiv w_t L_t + r_t K_t$, but as $Y_t \equiv W_t + \Pi_t$. The latter is an internally consistent identity; and to the extent that $W \equiv wL$ and $\Pi \equiv rK$, so must the former. Now note that from expression (18) the growth rate of value added equals:

$$\hat{Y}_t \equiv (1-a_t)\hat{W}_t + a_t\hat{\Pi}_t \qquad (28)$$

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 the previous observation it can be inferred that there is no residual, 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 this they advanced the hypothesis that the rise in total output is mostly explained by the growth of total inputs. This implies that the *improvements in the factors are subsumed within the inputs by correct measurement*. Given that by definition $W \equiv wL$ and $\Pi \equiv rK$, 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:

$$\hat{Y}_t \equiv (1-a_t)\hat{W}_t + a_t\hat{\Pi}_t \equiv (1-a_t)(\hat{w}_t + \hat{L}_t) + a_t(\hat{r}_t + \hat{K}_t) \qquad (29)$$

which implies that what Jorgenson and Griliches (1967) tried to do was to match improvements in the quality of *L* with increases in *w*, and improvements in the quality of *K* with increases in r, and this way derived some kind of "efficiency-adjusted" (*EA*) factor inputs such that $L_t^{EA} = (w_t L_t)$ and $K_t^{EA} = (r_t K_t)$. It is obvious that the "residual" $\lambda_t^{EA} \quad \hat{Y}_t - a_t \hat{K}_t^{EA} - (1 - a_t)\hat{L}_t^{EA}$ has to shrink (zero in the limit) to preserve the identity.

Note, finally, that it is trivial to derive the dual λ_t^D by subtracting the accounting identity expressed in real terms from the identity in nominal terms. This way one can derive an expression for the rate of cost diminution ($\hat{\psi}_t$), or the rate of change in unit costs of production (the so-called dual) as:

$$\hat{\psi}_t = \hat{P}_t - [(1 - a_t)\hat{w}_t^n + a_t \hat{r}_t^n] = -[(1 - a_t)\hat{w}_t + a_t \hat{r}_t] = -\lambda_t^D \qquad (30)$$

where $\hat{P}_t$ is the growth of the implicit price deflator. This derivation is again definitionally correct, but a tautology.

7. Valdés's "Test" of the *AK* Model

The final case that we shall consider is the argument of Valdés (1999, pp.104-107) that the "linear-in-K", or *AK*, model gives a very good fit to the data.[28] 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 the growth of TFP 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 TFP 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, Paul Romer (1990), the pioneer of this literature, has identified technological progress with increases in the stock of knowledge. Another possibility is provided by the so-called Schumpeterian endogenous growth models, built on the idea that each innovation hits 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.

[28] 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.

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:

$$Y_t = K_t^{\alpha}(A_t L_t)^{1-\alpha} \qquad (31)$$

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:[29]

$$A_t = \xi(K_t / L_t)^{\theta} \qquad (32)$$

which means that *A* increase by θ percent per each 1 percent increase in the capital-labor ratio (*K/L*). If *A* were exogenous, this model would be the same as Solow's. But *A* is not an endogenous variable in this model in that it depends on 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. Valdés 1999, p.106) and substituting equation (32) into (31) we obtain:

$$Y_t = \xi^{1-\alpha} K_t = cK_t \qquad (33)$$

where $\xi^{1-\alpha} = c$ is a constant. The steady-state conditions are

$$\hat{y} = \hat{k} = s_K c - (n + \delta) \qquad (34)$$

for the growth of output-per worker and capital per worker, and

$$\hat{Y} = \hat{K} = s_K c - \delta \qquad (35)$$

for the growth of total output and capital.

For the US 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 c = *Y/K* = 0.4.
- The rate of depreciation is δ = 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.

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29 Note that equation (31) corresponds to the identity (20) with $A_t^{1-a} \quad B_0 w_t^{1-a} r_t^{a}$.

It follows that:

$$\hat{y} = s_K c - (n + \delta) = 0.0198 = 1.98\%$$

for equation (34), and

$$\hat{Y} = s_K c - \delta = 0.325 = 3.25\%.$$

for equation (35). 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 give by the linear-in-K model for the US 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:

$$\hat{Y} \equiv (1 - a)\hat{w} + a\hat{r} + (1 - a)\hat{L} + a\hat{K} \qquad (36)$$

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

$$\hat{Y} = \hat{K} \qquad (37)$$

or, integrating

$$Y = cK \qquad (38)$$

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.[30]

Consequently, as $s_K c - \delta \equiv (I / Y)(Y / K) - \delta \equiv (I / K) - \delta \equiv \hat{K}$ (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 $\hat{K} \equiv s_K c - \delta$ 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

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30 It should be obvious that the whole process is tautological. The stylized fact (assumption) that $\hat{Y} = \hat{K}$ itself implies the Y=AK, the linear-in-K model !

corollary is that $\hat{y}$ must also equal $\hat{k}$. Hence, equation (34) must give a value of 1.98% and equation (35) of 3.25%.

Thus, the fact that the growth of productivity and the growth of output are closely approximated by equations (34) and (35) 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*. At the expense of laboring the obvious, consider the identity given by equations (18) and (19). Assuming factor shares and the rate of return are constant (or, equivalently, from the latter, $\hat{Y} = \hat{K}$) and the growth of wages is constant, we obtain the Cobb-Douglas relationship $Y \equiv (AL)^{(1-a)} K^a \equiv c'AL$, where c′ is a constant. Alternatively, from equation (18) and these assumptions, we may also drive the relationship $Y \equiv cK$. 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." The converse is equally true.

8. Is a Theory of Total Factor Productivity 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 total factor productivity 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 (1999) and Hsieh's (1999, 2002) argument that the rate of total factor productivity growth 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 fist 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 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 like Parente and Prescott (2000), for example, 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 aggregate level TFP, which then *cause* 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) recently 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: (i) the ability to treat technological advance as a disequilibrium process; (ii) firms capabilities and differences across firms as central elements; and (iii) 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 satistficers 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 ot 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 the articles in Neri (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 (Dobb 1973, Pasinetti 1974).

Finally, we believe that there has to be a move away from the use of highly aggregative data for purposes of studying productivity differences. Use of micro-economic 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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