On the Rental Price of Capital and the Profit Rate: The Perils and Pitfalls of Total Factor Productivity Growth

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ABSTRACT   *This paper considers the implications of the conceptual difference between
the rental price of capital, embedded in the neoclassical cost identity (output equals the
cost of labor plus the cost of capital), which is used in growth accounting studies; and
the accounting profit rate, which can be derived from the National Income and Product
Accounts (NIPA). The neoclassical identity is a 'virtual' identity in that it depends on a
series of assumptions (constant returns to scale and perfectly competitive factor
markets). The income side of the NIPA also provides an accounting identity for output
as the sum of the wage bill plus the gross operating surplus. This identity, however, is a
'real' one, in the sense that it does not depend on any assumption and thus it always
holds. It is shown that because the neoclassical cost identity and the income accounting
identity according to the NIPA may be expressed as formally equivalent expressions,
estimations of aggregate production functions and growth accounting studies are
tautologies. Likewise, the test of the hypothesis of competitive markets using Hall's
(1988) framework gives rise to a null hypothesis that cannot be rejected statistically.
Finally, it is argued that the NIPA identity does hold in constant prices, pace Denison
(1972a, 1972b).*

1. Introduction

In a series of papers, we have – separately and in collaboration – revived and
extended the criticism of the aggregate production function put forward some
years ago by, among others, Shaikh (1974, 1980), Simon, (1979a, 1979b), and
serendipitously by Samuelson (1979).[1] The critique, in a rudimentary form,
dates back to Phelps Brown (1957) and even earlier. The argument is that the

[1]See, for example, Felipe (2001a, 2001b), Felipe & Adams (2005), Felipe & Holz (2001), Felipe &
McCombie (1999, 2001a, 2001b, 2002a, 2002b, 2003, 2004, 2005a, 2005b, 2006, 2007) McCombie
(1987, 1998a, 1998b, 2000, 2000–2001) and McCombie & Dixon (1991).

income accounting identity, according to which value added is definitionally equal to the sum of the wage bill plus total profits, can be expressed as an approximation in a form that resembles an aggregate production function.[2] Therefore, all that estimations of aggregate production functions achieve is to track this identity, and no inferences should be made about the underlying technology of the economy. A corollary is that estimations of putative aggregate production functions should, because of the underlying identity, give estimates of the supposed output elasticities that are close, or identical, to the relevant factor shares, regardless of whether, or not, there is perfect competition. Where this equality does not occur, it is simply because the approximation to the underlying identity is not close enough.

There is, however, a misunderstanding over this argument that has appeared in the course of personal exchanges and workshops, and which we believe is worth clarifying. The confusion arises because while the neoclassical approach also considers the accounting identity, it does so in a slightly different way with important implications. The identity that normally appears in most microeconomic textbooks is the 'total cost' identity, where costs are definitionally equal to the wage bill (as the labor market is assumed to be competitive) and the total cost of capital, which is defined as the competitively determined rental price of capital multiplied by the capital stock. The rental price of capital thus may differ from that implied by the rate of profit that is derived from the National Income and Product Accounts (NIPA). The confusion that has arisen is that it has been erroneously argued that as we implicitly use this 'total cost' definition of the identity, it is hardly surprising that the estimates of the output elasticities are close to the factor shares. If one assumes that markets are perfectly competitive, so the argument goes, this result is precisely what neoclassical production theory predicts.

This paper addresses this issue and considers in detail the differences between these two identities and what they imply for empirical exercises. It is shown that the existence of the neoclassical identity based on the assumption of perfect competition, and which may be termed a 'virtual' identity as compared with the 'real' identity derived from the NIPA, does not affect our argument.[3] We show that our critique of the aggregate production function, which questions the concept of total factor productivity growth as a meaningful measure of technical change, is not invalidated by the conceptual difference between the rental price of capital and the profit rate. This does not imply that the neoclassical identity is wrong, *per se*. One can certainly construct an identity in any way one wishes, as long as the equality of the left-hand and right-hand sides of the equation is preserved. Our contention is that the way it is done in neoclassical economics is problematic because it follows from a theory (namely, the marginal theory of factor pricing at the aggregate level) that is not testable.

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[2]We refer to an aggregate production function as that which uses value data (however deflated) as opposed to physical quantities, i.e., a value-based production function. We thank Jon Temple for suggesting this term. Therefore, firm-level data in value terms (i.e., use of value added or gross output as measures of output) are equally affected by this problem.
[3]We are grateful to Anwar Shaikh for suggesting these two terms for the identities.

The rest of the paper is structured as follows. In the next section we outline and compare the two identities. Section 3 considers the theory and empirical implementation of the rental price of capital. Section 4 summarizes our critique of the production function. Section 5 discusses an application of our arguments to the estimation of market power by Hall (1988). Section 6 addresses a second related issue that may also lead to confusion. In an important exchange with Jorgenson & Griliches (1972), Denison (1972a, 1972b) maintained that the NIPA income accounting identity, which is the starting point of our derivation, holds only for *current*, and not *constant*, prices. We argue that Denison had a slightly different definition of the identity in mind and his strictures do not affect our argument. Section 7 concludes.

2. The Two Identities

In nominal terms, the NIPA identity relates value added to the sum of the total wage bill and total profits and is expressed as:[4]

$$V^n \equiv PV \equiv W^n + \Pi^n \equiv w^n L + r(P_J J_0) \equiv w^n L + r J^n \tag{1}$$

where V^n is output (value added) in current prices (or nominal terms), V_0 is output in constant prices, and P is the value-added price index. W^n and Π^n are the total wage bill and total profits, respectively, in nominal terms, w^n is the nominal wage rate (measured in monetary units, e.g., dollars per hour or per worker), and r is the profit rate, defined as $r \equiv \Pi^n/J^n$ (measured as dollars of profit per dollar of capital, i.e., a pure number). The variable L is the labor input (number of hours worked or number of workers), J is the *value* of the stock of capital in constant prices (measured in the same base year as V) and J^n is the current-price value of the capital stock. P_J is the price deflator of the capital stock, and for expositional ease we shall, unless otherwise stated, assume $P = P_J$ so the rate of profit will be the same whether the identity is measured in current or constant prices.

The identity also holds in constant prices, provided consistent deflators are used. (This is discussed further in Section 6 below). It can be straightforwardly rewritten as $V \equiv F(L, J, t)$, where w in real terms and r are proxied by time (t). This is a form that resembles a standard aggregate production function. Empirically, $F(L, J, t)$ can take any of the standard forms (i.e., the Cobb–Douglas, CES, translog production function, etc).

This argument explains why, despite the results of the Cambridge Capital Theory Controversies (Cohen & Harcourt, 2003) and the literature on aggregation, recently surveyed by Felipe & Fisher (2003), the estimation of the aggregate production function $V = F(L, J, t)$ in a specific functional form sometimes yields good and plausible results. By this we mean that the obtained statistical fit is usually high; the standard errors of the estimates are small; the estimated elasticities are relatively close to the factor shares calculated from data in the NIPA (although sometimes they diverge for reasons discussed below); and that the marginal product of labor often provides a good approximation to the wage

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[4]For expositional ease we have aggregated land with capital rather than treating it separately.

rate. See Fisher (1971a), who confirms this by simulation analysis, and the discussion of Fisher's paper by Shaikh (1980).

We have argued, as an implication, that the residual measure of total factor productivity (TFP) growth is simply a weighted average of the growth rates of the wage and profit rates, where the weights are the factor shares. This is a well-known result of neoclassical production theory and is referred to as the dual measure of total factor productivity growth. We argue, however, that the interpretation in the neoclassical literature of this weighted average as a measure of the rate of technical change (or the rate of increase in efficiency) is theoretically unfounded. This is because it necessarily depends on a supposed link between the income accounting identity and the aggregate production function. As the aggregate production function theoretically does not exist, the neoclassical result is merely a tautology that results from rewriting the income identity in growth rates. The weighted average of the growth rates of the wage and profit rates is simply a measure of how the factor returns grow, weighted according to an arbitrary method. Consequently, it is an arbitrary weighted index of the growth of factor returns.

The neoclassical approach also considers the accounting identity, but with important differences. This is written in the neoclassical paradigm as:

$$pQ \equiv w^n L + \rho_c^n K + \Omega^n \tag{2}$$

where pQ is total revenue, Q is the physical quantity of homogeneous output, p is the dollar price of output, K is the number of identical physical capital units (or 'leets', to use Joan Robinson's term, in a reference to James Meade's 'steel'), ρ_c^n is the competitive rental price of capital in nominal terms (measured in dollars per leet), and Ω^n is the current price value of 'economic profits'. If perfect competition is assumed, as is generally the case, equation (2) becomes $pQ \equiv w^n L + \rho_c^n K$, which is the 'virtual' identity referred to above. This approach assumes that labor and capital markets are competitive and thus the factor prices w^n and ρ_c^n equal their corresponding marginal revenue products, which measure their opportunity cost. This approach tries to 'draw a conceptual distinction between the imputed return to capital and the income of capitalists' (Solow, 1964, p. 11).

The neoclassical cost identity is given by $C^n \equiv w^n L + \rho_c^n K$.[5] These are the *costs* to the firm (including the normal profits) and not its *revenues*. Consequently, it does not include economic profits, if any. It is the neoclassical total cost identity that appears in most microeconomics textbooks, rather than the accounting identity.

The central tenet of this paper is that in applied macroeconomic work, physical quantities are not used in the production function, but rather aggregates which are deflated value measures. The two are not the same. Real output is not a physical quantity, but is measured in, say, dollar prices of a particular base year and the

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[5]It should be noted that this differs from the neoclassical cost function which takes the general form $C = G(w, \rho_c, Q)$, where C, w and ρ_c are in real terms and specific functional forms include, for example, the translog cost function.

same is true for the capital stock.[6] In addition, as we shall see later, the rental price of capital used in empirical applications is not a 'price', but an index. Aggregate data (even at the firm level) and aggregate production functions involve the use of data in value terms, however they are deflated. Micro-production functions involve ideally the use of data in physical terms, although there are very few cases of estimations of such engineering production functions.

The problem is that the identity underlying applied macroeconomic work (including that at the 3 or 4-digit SIC level industries, and firm-level data) is not given by equation (2), $pQ \equiv w^nL + \rho_c^nK + \Omega^n$, but by:

$$PV \equiv w^nL + r_cJ^n + \Omega^n \tag{3}$$

where in the neoclassical analysis r_c is interpreted as the competitive rental price of capital, but is actually a pure number, the rate of return. In many cases, however, it is constructed as an index, in which case it can only be used when equation (3) is expressed in growth rates, as in the growth accounting approach, or in log-levels, but not in levels. While equation (3) is correct from a definitional point of view, the assumption made is that it is the natural extension of the microeconomic identity to the aggregate level. It can be seen that equation (1) implicitly sums the terms r_cJ^n and Ω^n in the neoclassical identity, equation (3), to give rJ^n. This is labeled total profits (Π^n), i.e. $\Pi^n \equiv rJ^n \equiv r_cJ^n + \Omega^n \equiv r_cJ^n + r_{nc}J^n$, where r_{nc} is the non-competitive component of the rate of profit. The accounting identity, equation (1), must hold always by definition, as value added measured in the NIPA includes any economic profits under the category 'operating surplus'. The concepts of the profit rate and the rental price of capital are analogous, but subtly and importantly different. The profit rate is the firm's return on its capital, whereas the rental price of capital is the imputed cost to the firm on its capital. The former incorporates both the imputed cost of capital (in general, an unobservable variable) and oligopolistic, or economic, profits (rents), should these exist. The important aspect to note is that the assumption of perfect competition in the capital markets is made in the neoclassical literature to derive ρ_c^n; while the notion of the profit rate is theory-independent.

This difference between the profit rate and the rental price of capital has, at times, caused confusion concerning the argument about the transformation of the accounting identity into the putative aggregate production function. This has arisen because when we write the NIPA identity, $V = wL + rJ$, where w is the real wage rate ($w = w^n/P$), neoclassical economists usually define the corresponding microeconomic identity as $Q = w^*L + \rho_c^*K$, where $w^* = w^n/p$ and $\rho_c^* = \rho_c^n/p$ are the real wage rate and the rental price of capital both measured commodity, terms. As ρ_c^n is always deflated by p (unlike w^n, which can be deflated by p or P, depending on the context), we write this henceforth in real terms as simply ρ_c. The neoclassical approach, thus, implicitly generally assumes that there are no economic profits in the total cost accounting identity, i.e. $\Omega^* = 0$, where $\Omega^* = \Omega^n/p$. We discuss the case where this is not the situation in Section 5.

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[6]See Rampa (2002) for a discussion of other problems associated with equating real value added with physical output. The rate of growth of real value added will equal that of physical production only if intermediate inputs grow at the same rate as production.

Why does the above distinction matter? The answer is that as the neoclassical model usually assumes perfect competition and constant returns to scale, it is erroneously thought, as we noted above, that our approach also makes the same assumptions, namely that the accounting identity excludes any monopoly profits. As one of the implications of the transformation of the income accounting identity into $V \equiv F(L,J,t)$ is that the putative estimated output elasticities must equal the observed factor shares (thus indicating competitive markets), it has been consequently erroneously argued that our argument is simply a tautology.[7] In other words, as the neoclassical identity assumes perfect competition, it is argued that it is hardly surprising that the transformation we use shows that the output elasticities equal the factor shares. However, we argue that this result will always occur, *whatever the actual state of competition.*

Before discussing this in further detail, it is necessary to discuss first the concept of the rental price of capital.

3. Neoclassical Theory and the Rental Price of Capital

The rental price of capital, ρ_c^n, is a central concept in the neoclassical theory of productivity that has its origins in the neoclassical theory of investment developed by Jorgenson (1963). The rental price of capital is the implicit price that the firm charges itself for the assets that it owns, and is equal to the price that it would have to pay to rent an equivalent asset in a competitive market. However, there are no data on rental costs, except for a few markets (such as for aircraft). In most cases, firms have purchased and own the assets themselves. If well-developed competitive rental markets existed for all types of capital goods, it would be possible to observe the relevant rental rate on capital and, therefore, to calculate economic profits. But as such data do not generally exist, one must typically infer indirectly the rental price of capital.

For this purpose, Jorgenson (1963) assumed the existence of a perfect market for secondhand goods, as well as perfect markets for all inputs and output. The former implies that firms would not need to worry about locking themselves in by purchasing long-lived investment goods, as such goods could be sold on the secondhand market at a price equal to the present value of their expected services over their expected remaining lifetimes. This way, firms are seen as renting capital goods to themselves during each time period and charging themselves an implicit cost, namely, the rental price of capital.

There are two important issues in this framework. First, it is assumed that each factor gets paid according to the marginal product, which reflects its opportunity cost. This follows from the first-order conditions of profit maximization. Above we referred to the neoclassical identity as a 'virtual' identity because it depends on the conditions that $\partial F/\partial L = w^*$ and $\partial F/\partial K = \rho_c^*$. Moreover, at the macro level, these conditions ($\partial F/\partial L = w$ and $\partial F/\partial J = r$) depend on the existence of the aggregate production function $V = F(L, J, t)$. This is by no means an innocuous assumption. Felipe & Fisher (2003) have summarized the

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[7]Ironically, this is precisely the charge we make against the neoclassical approach.

aggregation literature, which indicates that the presumption must be that $F(L, J, t)$ does not exist.

Secondly, it is assumed for labor services that the wage rate correctly measures the marginal aggregate productivity of labor, i.e. $p\partial F/\partial L = w^n$. But what about $p\partial F/\partial K = \rho_c^n$? There is a problem here because, as we have noted, generally, there are no statistics for ρ_c^n, the implicit price that firms pay for capital, K. Consequently, ρ_c^n must be calculated using a number of assumptions.

Following Jorgenson (1963), the rental price of capital is obtained from an infinite-horizon dynamic optimization problem. In this model, the firm chooses the path of labor (L), gross investment (I), and net capital stock (denoted here also by K), so as to maximize the present value of its net cash flow. The firm's constraints are the technology, reflected in the production function $Q = F(L, K)$ and the equation of the motion of capital. The idea behind this formulation is that the firm will choose to hire that number of machines for which the marginal revenue product is equal to their market rental value. The firm's objective is to maximize net worth, that is, the discounted value of net earnings, namely,

$$\int_{s=t}^{\infty} e^{-\psi(s-t)}[p(s)F(L, K) - w^n(s)L(s) - q(s)I(s)]ds \tag{4}$$

subject to $dK/dt = I - \delta K$, where ψ is the nominal expected long-run opportunity cost of capital at time t (representing the opportunity cost of having funds tied up in a machine rather than in, say, a financial investment earning a particular rate of return), and time (s) runs from present time to perpetuity. The variable p is the output price; w^n is the wage rate; and q is the acquisition price of the investment good – the price (measured in dollars) of a capital good that produces one machine-hour of capital per year. δ is the constant rate of depreciation. Setting up the Hamiltonian and applying the maximum principle yields the implied rental price of capital (before taxes):

$$p\frac{\partial F}{\partial K} = \rho_c^n = \psi q + \delta q - \dot{q} \tag{5}$$

where all variables are valued at period t values, $p\partial F/\partial K$ is the marginal revenue product of capital, ρ_c^n is again the rental price of capital services, and $\dot{q} = q_t - q_{t-1}$ is the revaluation (the capital gain or loss). Equation (5) indicates that the imputed rental price of capital is equivalent in competitive equilibrium to the marginal revenue product value per unit of capital services. The expected capital gain or loss is calculated, for example, as a three-year moving average of the annual price change of the capital good (Vijselaar & Albers, 2002; see also OECD, 2001, p. 87, Box 5).[8]

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[8]Hall & Jorgenson (1967) derived the user cost of capital taking into account taxes. However, for purposes of the accounting identity, and for the definition of value added (in the identity), the rental price of capital should be gross of taxes.

For empirical purposes, there are two alternative ways to estimate ψ, the only unknown in equation (5). First, some authors use an observed or current measure of the firm's real current cost of funds, such as the dividend yield of the Standard & Poor 500 portfolio (Hall, 1990, p. 83), or a composite of several rates (Whiteman, 1988, p. 258). Other researchers, however, assume that economic profits are zero (i.e., $\Omega^n = 0$) and then derive the cost of funds residually from the value-added identity equation (2) (Jorgenson & Griliches, 1967; Jorgenson *et al.*, 1987). Hulten (2000, pp. 12, 19) argues that the assumption of constant returns is necessary to estimate the return to capital as a residual, again making the link with the production function.

The second method (i.e., the one that includes the assumption that economic profits are zero) consists of equating the value of property compensation ($\Omega^n = pQ - w^n L$), measured in, say, dollars, to the value of capital services ($\rho_c^n K$), that is, $\Omega^n = pQ - w^n L = \rho_c^n K$. This implies:

$$\Omega^n = \rho_c^n K = (\psi q + \delta q - \dot{q})K \tag{6}$$

From equation (6) one can solve for the unknown rate of return ψ:

$$\psi = \frac{\Omega^n}{qK} - \left(\delta + \frac{\dot{q}}{q}\right) \tag{7}$$

Therefore, the *competitively* earned rate of return computed this way is the ratio of property compensation to the value of assets, less depreciation and plus the growth in capital gains. The rental price of capital is now obtained by substituting the expression for ψ (equation (7)) into the formula for the rental price of capital (equation (5)).[9] This reduces, however, to $\rho_c^n = \Omega^n / K$. With aggregate data (i.e., equation (3)), this derivation implies that the rate of return is $r_c = \Pi^n / J^n$, which is what the actual identity implies.

Nevertheless, the calculation of the profit rate in the identity (1) does not assume that economic profits are zero. It must also be emphasized that, in practice, aggregate data are not measured in homogeneous physical units, as they theoretically should be. In particular, in practice, q is not the price of a capital good, but the investment deflator (e.g., see Hall, 1990, p. 83). The same applies to all the variables used in this section.

As can be seen, the method to derive a value for ρ_c^n is far from straightforward. Griliches & Jorgenson (1966, p. 51) admit that extracting this information from the firms' accounts is an almost insuperable problem, and that the

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[9]An example, following Denison (1972a, p. 45) but with some modifications, will help illustrate the procedure. Assume the price of equipment is $q = \$50,000$ (this is the price of a capital good that produces, say, n machine-hours of capital per year); the rate of return (% per annum), calculated as the ratio of interest plus profit income ($4,000) and capital gains ($1,000) to the value of capital equipment, ($50,000), is $\psi = [(\$4,000 + \$1,000)/\$50,000] = 0.1$; depreciation on equipment $\delta = (\$7,000/\$50,000) = 0.14$; capital gains on equipment holdings $\dot{q}/q = (\$1,500/\$50,000) = 0.03$. Then $\rho_c^n = \$50,000(0.10 + 0.14 - 0.03) = \$10,500$ which is interpreted as the price (or earnings) of n machine-hours of capital per year. This can be disaggregated into $5,000 representing the opportunity cost of the funds invested in the machine, and $7,000, which is the cost of physical cost of deterioration, and to this we have to subtract $1,500 for the change in value.

information must be obtained by a relatively lengthy chain of indirect inference. Harcourt (1972, p. 85) also indicates that the estimates of capital services have to be obtained by a chain of dubious assumptions (e.g., that competitive producer equilibrium conditions were in fact satisfied and that all machines worked in the same proportion as their capacities). Mohr (1986, p. 100), in a very detailed account of measurement issues of the rental price of capital, indicates that there is a kind of no-man's land between the model's theoretical structure and its application, with the result that, in practice, the concept is often both misunderstood and mismeasured. Regarding the measurement of the opportunity cost ψ, he indicates that there is an almost complete lack of consensus and that the literature presents a bewildering array of alternatives (Mohr, 1986, p. 107).

As indicated above, Hulten claims that the assumption of constant returns is necessary to estimate the rate of return residually. In our view this is not true as the income accounting identity is independent of any production function, the state of competition, and the degree of returns to scale. The problem with the neoclassical interpretation of the accounting identity lies in the 'virtual' connection between the identity and the non-existent aggregate production function, and in the fact that in neoclassical economics it is customary to separate the cost of capital ($\rho_c^n K$) from economic profits (Ω^n), on the basis that the wage rate (w^n) and the rental price of capital (ρ_c^n) measure the corresponding marginal productivities. This way, as indicated above, the identity at the microeconomic level appears as:

$$pQ = p\frac{\partial F}{\partial L}L + p\frac{\partial F}{\partial K}K + \Omega^n = w^n L + \rho_c^n K + \Omega^n \tag{8}$$

And assuming long-run competitive markets, i.e., $\Omega^n = 0$:

$$pQ = p\frac{\partial F}{\partial L}L + p\frac{\partial F}{\partial K}K = w^n L + \rho_c^n K \tag{9}$$

Equation (9) is presented in many textbooks as if it were an *actual* identity, although it is written in (constant price) value terms (i.e., aggregate level) as $V = wL + rJ$. In neoclassical theory, the production function and the accounting identity are linked via Euler's theorem (Hulten, 2000, p. 11).

In fact, it is often claimed that the identity is a *consequence* of the theorem, which says that a linear-homogeneous function $Q = F(L, K)$ can be written as $Q = (\partial F/\partial L)L + (\partial F/\partial K)K$. Then, it is argued that *if* the conditions for producer equilibrium hold, that is, $p\partial F/\partial L = w^n$ and $p\partial F/\partial K = \rho_c^n$, it follows that $pQ = F(L, K) = w^n L + \rho_c^n K$. Thus, the argument is that the income identity holds *only* under constant returns and competitive markets. Hulten indicates that there is a

> *close* link between the GDP accounting identity and the production function. If the production function happens to exhibit constant returns to scale and the inputs are paid the value of their marginal products, the value of output equals the sum of the input values. This 'product exhaustion' follows from Euler's Theorem, and it implies that the value shares s^L [labor's share] and s^K [capital's share], sum to one. (Hulten, 2000, p. 11; italics added)

Furthermore, in this sense, the argument continues, the neoclassical theory of production provides a theory of the national accounts (Prescott, 1998, p. 532).

This line of reasoning is erroneous. For the above results to be correct, the aggregate production function *must* exist, *must* be linear and homogeneous of degree one, and the marginal productivity conditions *must* hold. These are too many 'musts'. If the aggregate production function $V = F(L, J)$ does not exist because of the aggregation problems, the alleged link $F(L, J) = wL + r_c J$, where r_c is the real competitive rate of return has no meaning. The actual accounting identity, equation (1), will nevertheless *always* hold as it does not depend upon an aggregate production function and Euler's theorem. The identity is consistent with any (aggregate) production function $V = F(L, J)$, should it exist (which we doubt), and with the lack of a well-behaved aggregate production function. It simply shows how total value added is divided between wages and profits. Furthermore, (aggregate) wage and profit rates may have nothing to do with the aggregate marginal productivities (what do they mean?). In an exchange with Joan Robinson, Fisher argued that 'If aggregate capital does not exist, then of course one cannot believe in the marginal productivity of *aggregate* capital' (Fisher, 1971b, p. 405; emphasis in the original). The same applies to the concept of the marginal productivity of labor at the aggregate level.

Neoclassical economists argue, however, that writing $V \equiv wL + rJ$ implies that economic profits Ω are zero, consistent with their assumptions about the existence of competitive markets. However, the way the actual income accounting identity is written, *all* profits are included in rJ, where r is the ex-post profit rate. This implies $rJ = r_c J + \Omega$. This does not represent a problem since economic profits can be written as $\Omega = r_{nc} J$, that is, as the product of that component of the rate of return due to economic profits, denoted by r_{nc}, times the value of the stock of capital, which implies $r = r_c + r_{nc}$. Consequently, the following identity holds: $V \equiv wL + rJ \equiv wL + r_c J + r_{nc} J$. This is seen as equivalent to $Q \equiv wL + \rho_c K + \rho_{nc} K$, where ρ_{nc} is the implicit firm-level price of capital resulting from economic profits. In the words of Samuelson: 'No one can stop us from labelling this last vector [residually computed profit returns to "property" or to the nonlabor factor] as rJ as J.B. Clark's model would permit—even though we have no warrant for believing that noncompetitive industries have a common profit rate r and use leets capital J in proportion to the $PV - w^n L$ elements!' (Samuelson, 1979, p. 932; the notation has been changed to make it consistent with that in this paper).

4. The Income Accounting Identity and the Production Function

At this stage it is useful to summarize our critique and its main implications and see how the above discussion does not undermine it in any way. We start by writing the value-added accounting identity, equation (1), in real terms as is standard in the literature (Samuelson, 1979; Barro, 1999; Fernald & Neiman, 2003) as $V_t \equiv w_t L_t + r_t J_t$, where $w = (w^n/P)$ and $J = (J^n/P)$. The latter can be expressed in growth rates as (subscript 't' denotes time):

$$\hat{V}_t \equiv a_t \hat{w}_t + (1 - a_t)\hat{r}_t + a_t \hat{L}_t + (1 - a_t)\hat{J}_t \equiv \varphi_t + a_t \hat{L}_t + (1 - a_t)\hat{J}_t \quad (10)$$

where $\wedge$ denotes a growth rate, $a_t \equiv w_t L_t / V_t$ is the share of labor in output or *revenue*, $(1 - a_t) \equiv r_t J_t / V_t$ is the share of capital, and $\varphi_t \equiv a_t \hat{w}_t + (1 - a_t) \hat{r}_t$. Equation (10) can be rearranged to give:

$$\varphi_t \equiv \hat{V}_t - a_t \hat{L}_t - (1 - a_t) \hat{J}_t \equiv a_t \hat{w}_t + (1 - a_t) \hat{r}_t \qquad (11)$$

Equation (11) yields the residual measure of total factor productivity growth, assuming perfect competition. The first part of the equation is equivalent to the growth accounting equation derived from a neoclassical aggregate production function. In the neoclassical approach $\varphi_t = \hat{V}_t - a_{ct} \hat{L}_t - (1 - a_{ct}) \hat{J}_t$ is referred to as the primal measure of total factor productivity growth, where a_c is labor's share in total *costs*, which in the case of perfectly competitive markets equals the revenue shares, $a_c = a$. (Strictly speaking $\hat{V}$ should be the growth of total costs, i.e., excluding any economic profits; this is discussed further below.) The second part of equation (11), namely $a_t \hat{w}_t + (1 - a_t) \hat{r}_t$, resembles the dual measure of total factor productivity growth, derived in neoclassical economics from the cost function, and calculated as $\varphi_t = a_{ct} \hat{w}_t + (1 - a_{ct}) \hat{r}_t$. This will differ from $a_t \hat{w}_t + (1 - a_t) \hat{r}_t$ to the extent that $\hat{r}$ includes the growth of economic profits and a and a_c are not equal.

As indicated above, while neoclassical economists are aware of the income accounting identity and these results, it is important to point out the different interpretation. Barro (1999, p. 123), for example, indicates that: 'the dual approach can be derived readily from the equality between output and factor income.' Then he writes the income accounting identity, differentiates it, and writes it in growth rates (see his equations (7) and (8)). We interpret his statement about the *equality* to mean that the equation is indeed an identity. Moreover, Barro reasons: 'It is important to recognize that the derivation of equation [the growth accounting equation in his paper] uses only the condition $V = rJ + wL$ [in our notation]. 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). It is difficult to follow this, as the rate of return in the identity is defined earlier by Barro to be the (competitive) rental price of capital.

Barro continues 'If $V = rJ + wL$ [in our notation] holds, then the primal and dual estimates of TFP growth inevitably coincide' (Barro, 1999, p. 123). He comments that 'the discrepancies between the primal and dual estimates of TFP growth rates reflect departures from the condition $V = rL + wL$' (Barro, 1999, p. 124). If left- and right-hand sides of the expression are equal because it is an identity by construction (e.g., data from the national accounts), and no assumptions are needed to write it, how can it not hold? The reason is that Barro seems to consider that Euler's theorem and the existence of an aggregate production function (although not its specific functional form) are involved in the derivation. Thus, if the dual is calculated from independent estimates of the weighted growth rates of wages and the rental price of capital, and differs from the primal, it could be because the estimates of the growth of the capital stock and of the rental price of capital implicit in the primal are subject to measurement error. In other words, the dual, calculated directly using the weighted growth of factor costs, differs from the primal. However, calculating the growth accounting

equation from the identity as either the primal or the dual does, *pace* Barro, require that factors are paid their marginal social products and a well-behaved aggregate production exists.

Shapiro (1987) tried to test whether the primal and dual measurements of productivity are equal by calculating them independently and regressing one on the other. But given the arguments above regarding the problems with the theoretical underpinnings of the method, *all* that Shapiro's procedure amounts to is a test of whether or not the growth rates of the rate of profit and of the rental price of capital are equal (i.e., whether $\hat{r} = \hat{\rho}_c$). The result of the test depends on the procedure adopted to calculate the rental price of capital (ρ_c), and whether this is correct, although there is no easy way to check this.

To complete our argument and see the problem of the neoclassical framework, suppose that one accepts the usefulness of the aggregate production function as an empirical device and disregards the aggregation problems (Solow, 1957). To keep things simple, and without affecting the argument, let us assume that the estimated form is a Cobb–Douglas such as $\ln V_t = b_1 + b_2 t + b_3 \ln L_t + b_4 \ln J_t + u_t$, where u is the error term. Here t is a time trend and b_2, measures the constant rate of TFP growth.[10] To see what occurs, let us return to equation (10) and assume that in the economy in question factor shares are constant, i.e. $a_t = a$. It is *not* assumed that factors are paid their marginal social products, that there is perfect competition, or indeed that an aggregate production function actually exists. This yields:

$$\hat{V}_t \equiv a\hat{w}_t + (1-a)\hat{r}_t + a\hat{L}_t + (1-a)\hat{J}_t \tag{12}$$

Let us make a second assumption that real wage and profit rates grow at constant rates, i.e., $\hat{w}_t = \hat{w}$ and $\hat{r}_t = \hat{r}$.[11] Substitution into equation (12) yields:

$$\hat{V}_t \equiv a\hat{w}_t + (1-a)\hat{r}_t + a\hat{L}_t + (1-a)\hat{J}_t \equiv \varphi + a\hat{L}_t + (1-a)\hat{J}_t \tag{13}$$

Integrating and taking anti-logarithms yields:

$$V_t \equiv A_0 e^{\varphi t} L_t^a J_t^{1-a} \tag{14}$$

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[10]Hsieh (1999, 2002) and Fernald & Neiman (2003) argue, like Barro, that TFP growth can be derived directly form the accounting identity. Hsieh (1999, p. 134), for example, erroneously argues that 'the advantage of using the national income accounting identity instead of a cost function to derive the dual growth accounting methodology is that it makes explicitly clear that the equality of dual and primal measures of [total factor productivity growth] do not depend an any assumptions about the underlying technology.' This is a misunderstanding of the issue.

Quite often, such econometric estimations using time-series data lead to very poor results. On this, see Sylos Labini (1995), Hulten (2000), McCombie (1998b) and Felipe & Adams (2005). Hulten (2000, p. 22) argues that the poor results 'are familiar to the practitioners of the productivity art.' On this see also Nadiri (1970, pp. 1153–1155) who briefly mentions the standard econometric problems encountered by practitioners estimating production functions, among which the most important is simultaneous equation bias. Given our arguments, this should not be a problem, as the solution is, theoretically, the simultaneous estimation of the production function and the first-order conditions (Kim & Lau, 1994).

[11]Alternatively, we could assume that the rate of profit is constant, so that $\hat{r}_t = 0$.

How is equation (14) to be interpreted? Given the way it has been derived, it must be the income accounting identity, namely $V_t \equiv w_t L_t + r_t J_t$, rewritten under the assumptions that factor shares are constant and that wage and profit rates grow at constant rates. From an econometric point of view, this implies that if in the economy in question the two assumptions about the factor shares and the wage and profit rates happen to be correct, and one estimated as $\ln V_t = b_1 + b_2 t + b_3 \ln L_t + b_4 \ln J_t + u_t$, one would obtain a suspiciously perfect fit, estimates of the coefficients equal to the factor shares, i.e., $b_3 = a$ and $b_4 = (1 - a)$ (indicating putative 'constant returns to scale'), and the estimate of b_2 equal to $\hat{\varphi} = a\hat{w}_t + (1 - a)\hat{r}_t$. These results, however, follow solely from the income identity.

What if when the Cobb–Douglas relationship is estimated the results are poor, as sometimes happens? That will simply imply that one or both of the assumptions used to derive it are incorrect. It does not invalidate the argument. For example, if $\hat{w}_t$ and $\hat{r}_t$ are not constant, the assumption $\hat{w}_t = \hat{w}$ and $\hat{r}_t = \hat{r}$ will be incorrect and the standard Cobb–Douglas form with a linear time trend will give a poor fit. What we need to find is the correct empirical paths of $\hat{w}_t$ and $\hat{r}_t$. Upon substitution of these into equation (13) and proceeding as before we will obtain the corresponding 'aggregate production function'. To see this, simply integrate equation (12) (that is, we do not make any assumption about the path of the growth rates of the wage and profit rates) and take anti-logarithms, obtaining:

$$V_t \equiv B_0 w_t^a r_t^{1-a} L_t^a J_t^{1-a} \equiv B(t) L_t^a J_t^{1-a} \tag{15}$$

where $B(t) = B_0 w_t^a r_t^{1-a}$. What is necessary is to determine the path of $B(t)$. Empirical work suggests that a trigonometric function works well (Felipe, 2001a; Felipe & Adams, 2005; Felipe & McCombie, 2003). Naturally, nothing in neoclassical economics implies that $\ln B(t)$ has to be a linear function of time. McCombie & Dixon (1991), Felipe (2000), McCombie (2000) and Felipe & McCombie (2001a, 2003) show how to derive the CES and translog as transformations of the identity.

Similar arguments apply if the production function is estimated in growth rates. Barro (1999, p. 122) proposes this as an alternative approach to growth accounting. He differentiates the aggregate production function $V = F(A_t, L_t, J_t)$ (his equation (1) using our notation), obtaining $\hat{V}_t = \varphi_t + \alpha_t \hat{L}_t + \beta_t \hat{J}_t$ (his equation (2) using our notation). Here α_t and β_t denote the factor output elasticities. Note that all variables have the subscript t because they need not be constant. Then Barro argues that φ_t measures the growth due to technological change. That is, in order to estimate this regression, he assumes that φ_t, α_t, and β_t are constant, which may, or may not be empirically true. What is important about his argument is that in discussing the pros and cons of the regression approach, he acknowledges that 'the regression framework has to be extended from its usual form to allow for time variations in factor shares and the TFP growth rate' (Barro, 1999, pp.122–123). Unfortunately, this just takes us back to the identity given by equation (10). Therefore, there is a specification that

allows for time-varying parameters that will give a prefect fit to the data, where $\alpha_t \equiv a_t$, $\beta_t \equiv (1 - a_t)$, and $\varphi_t \equiv a_t \hat{w}_t + (1 - a_t) \hat{r}_t$.

It should also be noted that the second part of equation (11) is a weighted average of the growth rates of the wage and profit rates. As indicated above, neoclassical theory refers to this as the dual measure of total factor productivity growth and it is derived from the cost function (Shapiro, 1987). As increases in factor prices can be sustained only if output increases with given inputs, 'the *appropriately* weighted average growth of the factor prices measures the extent of TFP growth' (Barro, 1999, p. 123; italics added). In the long run, increases in real factor prices have to be related to increases in the productivity of the corresponding factors. There are, however, three questions with regard to this:

(i) The measure of total factor productivity is derived in neoclassical economics from a construct, the aggregate production function, which is without any sound theoretical foundation. The irony is that this is well established in the neoclassical literature. As long ago as 1970 (although the aggregation literature dates from considerably before this date) Nadiri acknowledged that the aggregation problem matters because 'without proper aggregation we cannot interpret the properties of an aggregate production function, which rules the behavior of total factor productivity' (Nadiri, 1970, p. 1144). Likewise, recent simulations by Felipe & McCombie (2006) show that the rate of TFP growth derived from micro data (simulated physical quantities) is very different from the aggregate rate of TFP (obtained by aggregating through prices the physical data).

(ii) We have shown that an equation that resembles a putative aggregate production function can be derived tautologically as a transformation of an accounting identity, and as such the weighted average of the growth rates of the wage and profit rates can be interpreted only as an arbitrary weighted growth of factor returns.[12] As indicated earlier, it provides information about how factor returns grow. This information is part of the accounting identity. In this respect, it is worth noting two things. First, that the growth rate of real value added equals $\hat{V}_t \equiv a_t \hat{W}_t + (1 - a_t) \hat{\Pi}_t$, that is, the growth (measured in terms of value added) registered by any economy between two periods is, by definition, the sum of the growth of the total wage bill plus the growth of total profits, each weighted by its share in value added. This means that growth of value added can be understood as the result the overall distributional changes between labor and capital. As a matter of arithmetic, there is nothing wrong with rewriting the wage bill as the product $W = wL$, and total profits as the product $\Pi = rJ$, and further arguing, again as a matter of arithmetic, that overall growth can be decomposed into changes in L, J, w, and r, that is, $\hat{V}_t \equiv a_t(\hat{w}_t + \hat{L}_t) + (1 - a_t)(\hat{r}_t + \hat{J}_t)$. In this formulation $a_t(\hat{w}_t + \hat{L}_t)$ and $(1 - a_t)(\hat{r}_t + \hat{J}_t)$ are simply the growth

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[12]Shaikh (1980) interprets it as a 'measure of distributional changes.' This is quite appropriate given that the measure combines factor shares and factor rewards.

of labor's and capital's remunerations as components of total income growth. They can be further disaggregated into the components given by the growth of the remuneration per worker $a_t\hat{w}_t$ and the rate of return $(1 - a_t)\hat{r}_t$ and those given by the growth of the number of workers $a_t\hat{L}_t$ and the capital input $(1 - a_t)\hat{J}_t$. The term $a_t\hat{w}_t + (1 - a_t)\hat{r}_t$ indicates by how much factor payments changed and contributed to growth. Obviously, this term can contribute positively or negatively to overall growth. In general, profit rates tend to be stable or decline in time. Thus, the contribution of $(1 - a_t)\hat{r}_t$ to overall growth is either zero (if the profit rate is stable, which implies $\hat{r}_t = 0$) or negative (if the profit rate declines, which implies $\hat{r}_t < 0$). In the long run, most of the positive contribution of $a_t\hat{w}_t + (1 - a_t)\hat{r}_t$ to growth comes from $a_t\hat{w}_t$. And often, observed low or negative values of $a_t\hat{w}_t + (1 - a_t)\hat{r}_t$ are the result of zero or negative values of $\hat{r}_t$.

Second, it is important to note that the decomposition above does not imply that $a_t\hat{L}_t$ and $(1 - a_t)\hat{J}_t$ measure in any sense the independent contributions of labor and capital in a *causal* sense. Not only may the underlying production processes be so complex that they cannot be represented by a single-commodity model in any meaningful way, but trying to attribute the contribution to output growth of that of a single factor of production separately may be conceptually problematic. Improvements in production processes come through learning by doing and arise to a large extent when there is capital accumulation. But the development and use of new types of machinery open up the scope for more inventions, which otherwise would not have occurred. Moreover, these improvements ultimately are due to labor, or human ingenuity. Growth in this sense is both path dependent and caused by the complementary growth of the factors of production.

(iii) As Nelson (1981, p. 1054) has pointed out, the production process is a complementary effort between the various inputs. It is rather like baking a cake; and in what way is it meaningful to discuss the quantitative contribution of the ingredients such as flour or milk to the cake? The problem with the neoclassical production function is that it has channeled the analysis of growth along a very narrow and, in our opinion, not very illuminating path (see also Nelson, 1998). Nor does endogenous growth theory take us much further forward, being similarly based on the aggregate production function.

What are we to make, therefore, of Barro's argument that an economy that experiences an increase in both its real wage and profit rates must have increased its overall level of productivity? It could be argued that $\varphi_t = a_t\hat{w}_t + (1 - a_t)\hat{r}_t$ measures such a rate of growth of efficiency. Certainly, under these circumstances one can say that the economy is better off, since obviously this is contributing positively to output growth. The point to note, however, is that it is not possible to ascribe this unambiguously to the result of technical change in the way it is done in the neoclassical model (i.e., by claiming that there is a theoretical justification). There is no reason to assume that the factor shares, i.e., the appropriate or theoretically justified weights according to Barro, equal the

output elasticities of the true aggregate production function (if it, in fact, exists), or that production is necessarily subject to constant returns to scale (although this is what the use of value data will show).

Our derivation is simply a tautology resulting from an identity with no behavioral assumptions or implications. Wages are likely to be correlated with labor productivity, and changes in the rate of profit are also likely to be associated with changes in the output–capital ratio. (If factor shares are constant, then the growth of the wage rate will be, by definition, equal to the growth of labor productivity and the growth in the rate of profit will be equal to the growth of the output–capital ratio.) But the only possible way to argue that φ_t in equation (10) is a measure of the rate of technical change is to postulate the existence of an aggregate production function, together with constant returns to scale and the conditions for producer equilibrium. This is required as a justification for using the factor shares to weight the growth rates of the wage and profit rates in order to derive a combined index of total factor productivity growth, and for considering $a_t \hat{L}_t$ and $(1 - a_t)\hat{J}_t$ as a measure of the contribution, in a *causal* sense, of the growth of the factor inputs to output growth.

Apart from all the theoretical issues raised, our contention in the previous section is that there is no way to know if the rental price has been calculated correctly or whether the figures used in empirical applications really do correspond to the theoretical counterpart. There is no way of determining, for example, whether any difference between primal and dual is due to measurement errors or to the presence of monopoly profits.[13,14]

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[13]In this sense, we agree with Fisher & McGowan (1983, p. 82) when they claim that: 'Accounting rates of return are frequently used as indices of monopoly power and market performance by economists and lawyers. Such procedure is valid only to the extent that profits are indeed monopoly profits, accounting profits are in fact economic profits, and the accounting rate of return equals the economic rate of return.' This is exactly what we show above. Fisher & McGowan are correct when they argue that using r in lieu of r_c is wrong to the extent that $r = r_c + r_{nc}$. The empirical question remains how to estimate correctly r_c and r_{nc}.

[14]Hall (1990, p. 84) quite correctly indicates that the difference between the revenue and cost-based residuals depends on the level of pure profit (Ω). Fernald & Neiman (2003, p. 2) derive TFP growth directly from the accounting identity and argue that the primal-dual difference reflects economically interesting imperfections in output, labor and capital markets including heterogeneity in the user cost of capital and sizeable economic profits. Shapiro (1987), Hall (1990) and Fernald & Neiman (2003) clearly understand the issue, but continue within the neoclassical approach. Shapiro (1987, p. 122, fn. 4) notes correctly that if the rental price of capital were derived from the national accounts (i.e., the way we derive the profit rate), the regression of the primal on the dual would be tautological. The argument of this paper is, however, that the identity (1) is not linked to the aggregate production function and thus it does not have any associated assumptions built in. This is, in our opinion, what makes the tests of Shapiro and Hall problematic. Furthermore, as indicated above, their whole argument rests on whether the measurement of the rental price of capital, which is theory dependent, is correct.

5. The Rental Price of Capital and Market Power: Hall (1988) revisited

In this section we consider how the issue of economic profits is dealt with in the influential neoclassical study of Hall (1988) and the intrinsic shortcomings that it suffers from because of the underlying NIPA identity. Hall argued that Solow's procedure for estimating the growth of TFP (the residual) was flawed because it assumed perfect competition. Hall putatively showed how it was possible to specify a model using aggregate data for output and factor inputs where the size of the mark-up due to market power could be estimated. We have argued in Felipe & McCombie (2002a) that the underlying identity, in effect, invalidates this procedure and presented econometric analysis to support this contention. In this section, we develop the theoretical basis of our argument, as it again clearly shows that the identity does not depend upon the assumption of perfectly competitive markets. (For notational convenience, henceforth, we drop the t subscripts, except for where they make for clarity.)

As we have noted, the orthodox neoclassical production function is given by $Q = F(L, K, t)$, where Q is the volume of output, say the number of widgets, L is employment or total hours worked, and K is again the number of machines (or machine hours). Consequently, no value relationship appears in this production function. The marginal product of labor, given by $\partial Q/\partial L$, is again measured in widgets, but may be expressed in monetary units, $p(\partial Q/\partial L)$, where p is the price of widgets (in, say, dollars per widget, and it is not a deflator). The expression for output in value terms again comes from the virtual accounting identity $pQ \equiv w^n L + \rho_c^n K + \Omega^n$, where w^n and ρ_c^n are nominal monetary values (dollars per worker and dollars per machine, respectively). Under the assumption of perfect competition, the elasticity of labor is:

$$\frac{\partial Q}{\partial L} \frac{L}{Q} = \alpha = a = \frac{w^n L}{pQ} \tag{16}$$

where a is the labor share, and the elasticity of capital is given by:

$$\frac{\partial Q}{\partial K} \frac{K}{Q} = (1 - \alpha) = (1 - a) = \frac{\rho_c^n K}{pQ} \tag{17}$$

where $(1-a)$ is capital's share. (In the following discussion, the shares may change over time.)

Under conditions of perfect competition, we also know from neoclassical theory that $p = x$, where x is the marginal cost. Consequently, the monetary value of the marginal physical product of labor is $p(\partial Q/\partial L) = x(\partial Q/\partial L) = w^n$. Furthermore, we also know that if factors are paid their marginal products, the total product is exhausted (Euler's theorem):

$$Q \equiv C^* \equiv w^*L + \rho_c K \equiv F_L L + F_K K \tag{18}$$

where $F_L = \partial Q/\partial L = w^* = w^n/x$; $F_K = \partial Q/\partial K = \rho_c^* = \rho_c^n/x$; and C^* denotes total cost in commodity terms.

In nominal terms, equation (18) becomes:

$$xQ \equiv C^n \equiv w^n L + \rho_c^n K \equiv x F_L L + x F_K K \tag{19}$$

Suppose, following Hall (1988), that *only* the labor market is competitive (i.e., $\Omega^n \neq 0$). We now have:

$$pQ \equiv w^n L + \rho_c^n K + \Omega^n \equiv w^n L + \rho_c^n K + \rho_{nc}^n K$$
$$\equiv w^n L + (\rho_c^n + \rho_{nc}^n)K \tag{20}$$

recall that ρ_{nc}^n is the component of the nominal rate of profit due to economic profits and $p > x$. Total cost to the firm is again given by $C^* = (w^n/x)L + (\rho_c^n/x)K$. The output elasticity of capital is now given by $(\partial Q/\partial K)(K/Q) = (\rho_c^n/x)(K/Q)$. This is because the non-competitive (monopoly or oligopoly) element of the rate of return, ρ_{nc}^n, is not related to the technical conditions of production, but is merely the result of prices and redistribution. Note that $(w^n/p) < (w^n/x)$ and $(\rho_c^n/p) < (\rho_c^n/x)$. So we have two identities given by equations (18), (19) and (20) and given the previous inequalities it follows that:

$$\alpha = \frac{w^n L}{xQ} > \frac{w^n L}{pQ} \tag{21}$$

and

$$(1 - \alpha) = \frac{\rho_c^n K}{xQ} < \frac{(\rho_c^n + \rho_{nc}^n)K}{pQ} \tag{22}^{15}$$

It will be seen that the output elasticities sum to unity, that the output elasticity of labor is greater than its revenue share and, conversely, that the output elasticity of capital is less than its revenue share. Intuitively, this is because part of capital's revenue share is due to monopoly profits and these have nothing to do with capital's contribution to output.

Let us now consider Hall's analysis. For the moment, we shall assume no technical change (we subsequently relax this condition). The marginal cost (or, alternatively, the opportunity cost) of a widget is:

$$x = \frac{w^n \Delta L}{\Delta Q} + \frac{\rho_c^n \Delta K}{\Delta Q} \tag{23}$$

Note that ρ_{nc}^n does not enter into this expression as it is not an economic or opportunity cost to the firm. Multiplying equation (23) by $\Delta Q/Q$ and rearranging we obtain:

$$\frac{\Delta Q}{Q} = \left(\frac{w^n L}{xQ}\right)\frac{\Delta L}{L} + \left(\frac{\rho_c^n K}{xQ}\right)\frac{\Delta K}{K} \tag{24}$$

or

$$\hat{Q} = a_c\hat{L} + (1 - a_c)\hat{K} \tag{25}$$

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[15]From equation (18) we have $1 \equiv [(w^n L)/(xQ)] + [(\rho_c^n K)/(xQ)]$; from equation (20), $1 \equiv [(w^n L)/(pQ)] + [((\rho_c^n + \rho_{nc}^n)K)/(pQ)]$; and from equation (21), $[(w^n L)/(xQ)] > [(w^n L)/(pQ)]$. Consequently, equation (22) follows.

where $\hat{Q}$ denotes the growth rate of output, etc, and a_c is the share of labor in total costs, namely, $C^n = w^n L + \rho^n_c K$, and not in total revenue, namely, $pQ \equiv w^n L + \rho^n_c K + \rho^n_{nc} K$.

We may express equation (24) as:

$$\hat{Q} - \hat{K} = \left(\frac{w^n L}{xQ}\right)(\hat{L} - \hat{K}) = a_c(\hat{L} - \hat{K}) \tag{26}$$

As $a_c = (w^n L/xQ) = (w^n L/pQ)(p/x) = a(p/x)$, where a is, as before, labor's share in total revenue, this may be written as:

$$\hat{Q} - \hat{K} = (p/x)a(\hat{L} - \hat{K}) \tag{27}$$

Denoting (p/x) by μ, equation (27) becomes $\hat{Q} - \hat{K} = \mu a(\hat{L} - \hat{K})$, where the estimate of μ gives the value of the mark-up, i.e., (p/x). Thus, to test putatively the joint hypotheses of perfect competition, the marginal productivity theory of distribution, and constant returns to scale, Hall should have estimated:

$$\hat{Q} - \hat{K} = c + \mu[a(\hat{L} - \hat{K})] \tag{28}$$

where c is the constant term. But as he used value data for US manufacturing he actually estimated:

$$\hat{V} - \hat{J} = c + \mu[a(\hat{L} - \hat{J})] \tag{29}$$

and tested whether μ was significantly different from unity for 26 industries, using an instrumental variable approach (Hall, 1988, Table 5, p. 941). He found that in most cases this was the case (with the estimate sometimes taking implausibly high values, although in two cases taking a negative value). Hall argued that this demonstrated that manufacturing is subject to considerable market power.

However, in view of our arguments, we are in a position to offer an alternative, more parsimonious, interpretation. The problem is that the empirical analysis does not use physical measures of output but rather constant-price value added, i.e. $V_t = \sum p_{i0} Q_{it}$ where p_{i0} denotes the base year prices of the various quantities of each product i, and V_t is value added at time t in constant prices. Thus, when the expression $PV = V^n$ (often misleadingly interpreted as pQ, i.e. current price multiplied by a physical quantity, as noted above) is written as the current price value of total output (i.e., value added), the obvious point is often forgotten that P is a price deflator (an index), not a price, and V is constructed using value data, namely the observed prices.

One of the implications of this issue is that, unlike a physical measure, value added is affected by the distribution of income. Assume that there is a fixed bundle of physical outputs. If the distribution of income changes (and consequently demand for these products) so will the 'constant price' value of our measure of output. The other point to note is that the relative prices used will be observed market prices and will be affected by any market power. Thus, we have in current prices:

$$V^n \equiv PV \equiv \sum p^n_i Q_i \equiv \sum w^n_i L_i + \sum r_i J^n_i \equiv W^n + \Pi^n \tag{30}$$

Equation (30) may be expressed as $V^n \equiv w^n L + rJ^n$ where w^n and r are the average observed wage rate and rate of profit. By definition, from the accounting identity, the observed rate of return can be calculated as $r \equiv (V^n - w^n L)/J^n$ (assuming the other four series are available). In growth rates we have (assuming, for the moment, that there is no growth in the weighted average of the growth rate of the wage and profit rates)

$$\hat{V} \equiv a\hat{L} + (1-a)\hat{J} \tag{31}$$

or,

$$(\hat{V} - \hat{J}) \equiv a(\hat{L} - \hat{J}) \tag{32}$$

Thus, if we were to estimate $(\hat{V} - \hat{J}) = c + \mu\,[a(\hat{L} - \hat{J})$ we must find $\mu = 1$, regardless of the state of competition.

Introducing putative technical change does not alter the story, except that it is now possible to find $\mu \neq 1$ because of misspecification of the rate of growth of wages and the rate of profit. It is for this reason that Hall finds that μ exceeds unity. To see this, we must look at the case where an allowance is made for technical change.

According to neoclassical production theory, the measure of marginal cost with technical change and capital growth is:

$$x = \frac{w^n \Delta L + \rho_c^n \Delta K}{\Delta Q - \lambda Q} \tag{33}$$

where $-\lambda Q$ is the amount by which output would have risen given no increase in L or K, assuming Hicks neutral technical change of a rate given by λ (see Hall, 1988, p. 926). Equation (33) may be written as a relationship between the growth of output and inputs as $\hat{Q} = \lambda_t + a_c\hat{L} + (1 - a_c)\hat{K}$, ($\lambda$ has an explicit time subscript to emphasize that it changes over time) and the mark-up may be estimated by using the equation (27) as:

$$\hat{Q} - \hat{K} = \lambda_t + \mu[a(\hat{L} - \hat{K})] \tag{34}$$

using an instrumental variable approach, but where, again, value data has to be used, namely, $\hat{V}$ instead of $\hat{Q}$ and $\hat{J}$ instead of $\hat{K}$. But if we use value data the following is definitionally true from the underlying identity (now the weighted growth of w and r is not constant):

$$\hat{V} \equiv a\hat{w} + (1-a)\hat{r} + a\hat{L} + (1-a)\hat{J} \tag{35}$$

Consequently, $(\hat{V} - \hat{J}) \equiv a\hat{w} + (1-a)\hat{r} + \mu[a(\hat{L} - \hat{J})]$, where $\mu = 1$ by definition. Hall finds that $\mu > 1$ because his approach amounts to estimating:

$$(\hat{V} - \hat{J}) = c + \mu[a(\hat{L} - \hat{J})] \tag{36}$$

In other words, he assumes that the Solow residual or the rate of technical progress is a constant with a random error term.

However, as the expression $a\hat{w} + (1-a)\hat{r}$ empirically fluctuates procyclically around a constant, proxying it by a constant causes, in effect, an omitted

variable bias, which affects the estimate of μ. This is biased upwards and hence gives the misleading result of the existence of market power. The instrumental variable approach does not overcome this problem, and moreover, as we are dealing with an identity the questions of exogeneity, endogeneity and simultaneity do not arise. This is not to say market power does not exist, it is just that this method cannot test this hypothesis.

Hall (1988) also approaches the problem from another angle. Suppose, he argues, that there is no market power. Then the Solow residual is given by:

$$(\hat{Q} - \hat{K}) - a(\hat{L} - \hat{K}) = \lambda + e_t \tag{37}$$

where it is assumed that λ is constant and e_t is a random error term. With market power, the Solow residual is given by

$$(\hat{Q} - \hat{K}) - a(\hat{L} - \hat{K}) = \lambda - (\mu - 1)\,[a(\hat{L} - \hat{K}) + u_t \tag{38}$$

where u_t is the error term.

Assume that there is an instrumental variable that is correlated with output and input growth, but not with shifts in productivity, i.e., not with the right-hand side of equation (37) where there is no market power. If there is market power, Hall suggests that the instrument will now be correlated with the residual, because of the presence of $(\mu - 1)a(\hat{L} - \bar{K})$ on the right hand side of equation (38). Hall suggested military spending, the world oil price and the political party of the US President as possible instruments. Generally, he finds that the instruments are correlated with the Solow residual and that 'the evidence favors a certain amount of market power as against the hypothesis of pure competition' (Hall, 1988, p. 938).

However, using value data, the identity is given by:

$$(\hat{V} - \hat{J}) - a(\hat{L} - \hat{J}) \equiv a\hat{w} + (1 - a)\hat{r} \tag{39}$$

Moreover, we know that empirically the weighted growth of the real wage rate and the rate of profit varies procyclically. Thus, any instrumental variable that is correlated with the left-hand side of equation (39) must necessarily be correlated with the right-hand side, and no inference of the existence market power, or otherwise should be drawn from this result.

To conclude this section, it will be recalled that the definition of value added is $V \equiv wL + r_c J + r_{nc} J$. Suppose we were to accept all the neoclassical assumptions and that there is market power and wish to calculate the growth of TFP (*tfp*). Given all the usual neoclassical assumptions, we would use cost shares, and the growth of TFP would be given by:

$$tfp \equiv \hat{V} - a_c\hat{L} - (1 - a_c)\hat{J} \tag{40}$$

But the growth of value added from the national accounts equals:

$$\hat{V} \equiv a\hat{w} + a_{r_c}\hat{r}_c + (1 - a - a_{r_c})\hat{r}_{nc} + a\hat{L} + (1 - a)\hat{J} \tag{41}$$

where a, a_{r_c} and $(1 - a - a_{r_c})$ are the shares of wages (wL), competitive profits $(r_c J)$, and monopoly profits $(r_{nc} J)$ in total revenue (V). It follows that *tfp* is

given by substituting equation (41) into equation (40):

$$tfp = a\hat{w} + a_{r_c}\hat{r}_c + (1 - a - a_{r_c})\hat{r}_{nc} + (a - a_{r_c})\hat{L} + (a_{r_c} - a)\hat{J} \qquad (42)$$

It can be seen that the residual is also capturing the effects of the monopoly profits. Ideally, if there is market power, and under the neoclassical assumptions, we wish to calculate the true Solow residual or the growth of *TFP*, then for consistency we should deduct monopoly profits from the recorded value added in the national accounts. It follows that $V' \equiv V - r_{nc}J \equiv wL + r_cJ$ and:

$$\hat{V}' = a_c\hat{w} + (1 - a_c)\hat{r}_c + a_c\hat{L} + (1 - a_c)\hat{J} \qquad (43)$$

The true growth of total factor productivity is given by:

$$tfp' \equiv a_c\hat{w} + (1 - a_c)\hat{r}_c \equiv \hat{V}' - a_c\hat{L} - (1 - a_c)\hat{J} \qquad (44)$$

and not by $\hat{V} - a_c\hat{L} - (1 - a_c)\hat{J}$ which is the implicit measure in Hall (1988).

We are now back to an accounting identity (although different from the revenue identity) – in fact, it is the neoclassical virtual identity discussed earlier – and all the arguments about the problems this poses for estimating production functions follow through exactly. Intuitively, the neoclassical approach implicitly assumes that V is a physical measure (i.e., numbers of widgets or Q) and so its value is invariant to the state of competition. Once again, we return to the problem that the measure of output is not a physical measure, but a constant price value measure.

6. Denison's Denial of the Constant Price Accounting Identity

In this penultimate section we address another issue regarding the accounting identity, and which may lead some readers to believe that our approach is problematic.[16] It must be recalled that the identity, equation (3), is widely used in macroeconomic work (e.g., Barro, 1999), and that Samuelson (1979) and Simon (1979b), among others, used it also in the same context we have. However, in his celebrated exchange with Jorgenson & Griliches (1972), Denison (1972a, 1972b) makes the claim that while the accounting identity, equation (1), $V^n \equiv PV \equiv W^n + \Pi^n \equiv w^nL + rJ^n$, is consistent, it does not hold in constant prices, i.e., $V \equiv wL + rJ$, is invalid. If this is correct, how can the identity be mistaken for an aggregate production function, where magnitudes in constant prices are used? We address this issue and argue that the identity does indeed hold in constant prices.

Denison argues as follows:

> But current price measures have little to do with 'productivity measurement' *and the identity does not hold in constant prices at factor cost—unless one abolishes the concept of productivity change.* Productivity change is precisely a measure of the degree to which the identity does not hold. There is no such

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[16]This section elaborates upon Felipe & McCombie (2004).

accounting relationship between input and output at constant prices by any method of valuation. (Denison, 1972b, p. 100; italics added)

As we have shown above, if the value added and the capital stock deflators do not differ, the accounting identity may be expressed in real terms by dividing the nominal wage rate and the nominal value of the capital stock by the value added deflator, that is, $V^n/P = (w^n/P)L + r(J^n/P)$. Thus, equation (14) implies that, when factor shares are constant, the estimate of φ in the standard Cobb–Douglas function $V = A_0\, e^{\varphi t}\, L^{b_3}\, J^{b_4}$ will be a weighted average of the growth rates of the real wage rate (expressed in terms of the output deflator) and of the profit rate.

   The fact that the wage rate, capital stock and the value added deflators may differ does not invalidate our argument. In this case, the accounting identity in real terms is given by $V^n/P \equiv (w^n/P_w)L + r(J^n/P_J)$ where P, P_w, and P_J are the price deflators for value added, the wage rate and the capital stock, respectively. The wage rate deflator can be calculated as a weighted average of the other two deflators, for example $P_w \equiv P^{1/a_t}P_J^{(1-a_t)/a_t}$, so that $\hat{P} \equiv a_t\hat{P}_w + (1 - a_t)\hat{P}_J$. Therefore, the accounting identity in levels will be $V^n/P \equiv (w^n/P_w)L + r(J^n/P_J)$, and in growth rates $\hat{V}^n - \hat{P} \equiv a_t(\hat{w}^n - \hat{P}_w) + (1 - a_t)\hat{r} + a_t\hat{L} + (1 - a_t)(\hat{J}^n - \hat{P}_J)$. The factor shares have time subscripts 't' to emphasize that they need not be constant. Consequently, both versions of the identity hold exactly in real terms. There are, of course, the usual index number problems, but these are very much a second-order problem and do not invalidate the argument.[17]

   Let us return now to Denison and elaborate upon what we believe he may have meant in the quotation above, for we think his arguments are somewhat obscure and require some elucidation. In our view, Denison appears to have chosen an unusual way to consider the identity in constant prices. We infer that he treats the wage and the profit rate in the same way as the price of goods and services, so that when he constructs the constant-price identity he holds the wage rate and the rate of profit constant at their initial base-year values. Consequently, Denison's identity in the base period 0 (in current and constant prices, which in this period are the same), is given by:

$$V_0^n(D) \equiv w_0^n L_0 + r_0 J_0^n \equiv \sum p_{i0}Q_{i0} \tag{45}$$

where D denotes our interpretation of Denison's definition of the identity (this is the same as the conventional identity in period 0). Note that the variables are expressed in nominal terms, i.e., in current period 0 prices. p_{i0} is the base-period (i.e., period 0) value of the ith good (Q_i)

   However, Denison's definition, holding wages and the rate of profit constant at period 0 values, does not lead to an identity in constant prices in period 1:

$$\frac{V_1^n(D)}{P_1} \equiv w_0^n L_1 + r_0\frac{J_1^n}{P_1} \neq \sum p_{i0}Q_{i0} \tag{46}$$

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[17]The value-added deflator has to be calculated from the gross output (sales) and the intermediate inputs deflators. It is usually available in the NIPA, which normally reports value added in current and constant prices. It is important to note that for income accounting purposes, the CPI is not a suitable deflator of the wage rate unless all wages are spent on consumption goods.

where the superscript 'n', again, denotes variables measured in nominal terms, i.e., V_1^n and J_1^n represent variables in period 1, measured in period 1 prices; the subscripts 0 and 1 represent the values in the corresponding period (this means that w_0^n is the actual wage in period 0, in period 0 prices; it is not the nominal wage rate in period 1 deflated so it is expressed in period 0 prices). $V_1^n(D)$ is Denison's constant-price measure of value added at base year prices.

The conventional identity in period 1, in constant prices of period 0, is given by:

$$\frac{V_1^n(D)}{P_1} \equiv \frac{w_1^n}{P_1}L_1 + r_1\frac{J_1^n}{P_1} = \sum p_{i0}Q_{i1} \tag{47}$$

where P_1 is the value-added deflator that converts current prices in period 1 to prices at period 0. With technical progress, in all plausible cases, $w_1^n/P_1 > w_0^n$, i.e., the deflated value of the nominal wage in period 1 will exceed the value of the nominal wage in the base period.

At the expense of laboring the obvious, as there are no independent deflators for wages and the rate of profit, the standard procedure is to deflate both value added and the wage rate by the value-added deflator.[18] If we were using the definition for value added on the expenditure side, then consumption and investment would be deflated by their own deflators, a weighted average that would equal the value-added deflator. This does not affect the argument, as whatever deflation procedure is chosen, the left and right side of the equation must be equal in constant prices.

Some support is provided for our interpretation by Denison's statement that 'productivity change is precisely a measure of the degree to which the identity does not hold.' Expressing equation (46) in growth rates, we get, with a little manipulation, an expression for TFP growth as:

$$\hat{V}(D) - a\hat{L} - (1 - a)\hat{J} = 0 \tag{48}$$

which is compatible with Denison's argument that this holds only if 'one abolishes the concept of productivity change.'

However, the usual definition of TFP growth from equation (47) is $tfp \equiv \hat{V} - a\hat{L} - (1 - a)\hat{J} \equiv a\hat{w} + (1 - a)\hat{r}$. Comparing this with equation (48) it can be seen that total factor productivity growth is precisely a measure of the degree to which Denison's identity *does not* hold, as Denison himself noted.

Moreover, Denison quotes Jorgenson & Griliches (1972, p. 79) as defining total factor productivity 'as the ratio of real product to real factor input, *or equivalently, as the ratio of the price of factor input to the product price*' (Denison 1972b, p. 100, fn. 11; Denison's italics). Denison continues:

> the italicized portion may have been have been included to protect their assertion of an identity; their discussion on page 82, where they say productivity is *equal* to the difference between changes in the *prices* of output and input,

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[18]The studies by Samuelson (1979), Simon (1979a, 1979b), Barro (1999) and Hulten (2000), and the paper by Fernald & Neiman (2003) explicitly use the identity in constant prices.

each multiplied by the corresponding quantity, supports this inference. Viewing the ratio as the difference in the price movements of input and output would make the identity hold in constant prices by making the input definitionally equal to output, that is by measuring inputs over time as the product of their quantities and marginal products. This is the definition they have consistently denied using. (Denison 1972b, p. 100, fn. 11, Denison's italics)

As indicated above, we believe that there is some ambiguity in the discussion, as Denison does not explicitly mention how the inputs are to be weighted. Hence the argument requires some interpretation.

Assuming, for example, a Cobb–Douglas production function (setting the constant term to unity), the ratio of real output to real input can be written as $(V_1^n/P_1)/(L_1^a J_1^{1-a})$, where $J_1 = J_1^n/P_1$, while the ratio of the price of factor input to the product price can be written as $(w_1^n/P_1)^a r_1^{1-a}$.[19] This preserves the identity in the sense that:

$$\left(\frac{V_1^n/P_1}{L_1^a J_1^{1-a}}\right) \equiv \left(\frac{w_1^n}{P_1}\right)^a r_1^{1-a} \equiv TFP \tag{49}$$

It follows that:

$$V_1 \equiv w_1^a r_1^{1-a} L_1^a J_1^{1-a} \equiv w_1 L_1 + r_1 J_1 \tag{50}$$

Nevertheless, Denison seems to repeat his earlier mistaken criticism (Denison, 1961) of Jorgenson & Griliches (1967), which they had answered in footnote 1 on page 254 of their paper.

We infer from Denison's argument in the last part of the quotation above that he erroneously suggests that Jorgenson & Griliches effectively get rid of the residual by the expedient of defining the growth of the labor and capital input as $(\hat{w} + \hat{L})$ and $(\hat{r} + \hat{J})$. In other words, Denison argues that Jorgensen & Griliches define the input of a factor as its quantity multiplied by its marginal product, so that the growth of the input is the growth of the quantity *plus* the rate of change of its marginal product. It is difficult to see any justification for this erroneous interpretation of Jorgenson & Griliches's methodology, but it is not easy to see how else to interpret Denison.

Consequently, Denison's assertion that the identity cannot hold in constant prices, while correct in his own terms, has no relevance for either the growth accounting approach or our critique.

7. Conclusions

In this paper we have examined two issues relating to our earlier critique of the estimation of production function with value data (i.e., aggregate production functions), namely, that the value added identity can be rewritten as a form

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[19]Strictly speaking, because the value of TFP alters as the units of measurement change, (for example, employment measured in number of hours worked instead of in terms of number of workers), it is only useful to discuss indices or growth rates of TFP.

that resembles an aggregate production function, with the consequence that econometric estimation of the latter is a pointless exercise. The first question is to what extent the critique is affected by, or depends on, the distinction between the notions of rental price of capital and profit rate. The second issue is whether or not the income accounting identity holds in constant prices.

We conclude that the conceptual difference between profit rate and rental price of capital does not affect our argument. The notion of profit rate includes both what neoclassical economics refers to as the rental price of capital and any monopolistic profits, should these exist. This was further confirmed by discussing Hall's (1988) influential paper where he sought to estimate the mark-up due to market power. We have demonstrated why Hall's attempt to estimate the mark-up is flawed. It has also been shown that Denison's claim that the underlying identity in constant prices does not exist, while correct in terms of his own definition of an identity, does not invalidate our argument.

We remain convinced that estimating value-based production data does not tell us anything about the underlying technology of the economy and hence the concept of TFP growth, which rests on the production function for its justification, is problematic.

Acknowledgments

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