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Investment-specific technological change and growth accounting ☆

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Abstract

Greenwood et al. [1997. Long-run implications of investment-specific technological change. American Economic Review 87(3), 342–362; and 2000. The role of investment-specific technological change in the business cycle. European Economic Review 44, 91–115] and Hercowitz [1998. The 'embodiment' controversy: a review essay. Journal of Monetary Economics 41, 217–224] have claimed that the Jorgenson form of growth accounting is conceptually flawed and severely understates the importance of technological progress embodied in new capital goods for explaining growth. To the contrary, this paper shows that in its technology aspects their model is a special case of the Jorgensonian growth accounting model. What they call investment-specific technological change is shown to be closely related to the more familiar concept of total factor productivity (TFP) growth: statements about the one can be translated into statements about the other. Empirically, differences between their conclusions and those of growth accounting studies about the extent to which embodiment explains US economic growth are found to relate more to data than to methodology.

Keywords: Investment-specific technological change; Embodiment; TFP; Growth accounting

JEL classification: O47; O41; O51

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1. Introduction

In a set of related papers, Greenwood et al. (1997, 2000) and Hercowitz (1998), hereafter GHK, have claimed that the growth accounting framework which they ascribe to Jorgenson is flawed. They develop an alternative framework centred round the concepts of "neutral technological change" and "investment-specific technological change". Greenwood et al. (1997) use their framework as the basis for determining what proportion of growth is due to investment-specific technological change, i.e. what is the quantitative importance of "embodiment". They claim that Jorgensonian growth accounting severely understates the role of embodiment. Greenwood et al. (2000) use the framework to determine how important investment-specific shocks are to business cycles.

In what follows, I show that, contrary to their claim, their model can be analysed as a special case of the more general Jorgensonian approach. Consequently, as I also show, their criticisms of the Jorgenson framework are incorrect. Section 1 shows that their concept of investment-specific technological change (hereafter ISTC) is closely related to the more familiar concept of total factor productivity (TFP). In section 3, I show why their criticism of the Jorgensonian approach to growth accounting is not correct. Section 3 also discusses how to measure the contribution of embodied technological progress in the GHK and Jorgenson frameworks. Section 4 then compares and (as far as possible) reconciles two very different estimates of this contribution, due to Greenwood et al. (1997) and Jorgenson and Stiroh (2000a), respectively.

2. The relationship between ISTC and TFP

I begin by setting out the GHK model and then go on to show how it is can be derived as a special case of a two-sector, neo-classical model. In its simplest form the GHK model can be written as follows (using as far as possible their notation)[1]:

$$y = c + i = z \cdot l \cdot f(k/l), \tag{1}$$

$$i^* = iq, \tag{2}$$

$$\dot{k} = i^* - \delta k, \tag{3}$$

Eq. (1) is the aggregate production function, where constant returns to scale have been imposed. Output (y), which can be used for either consumption (c) or investment (i), is produced with the aid of capital (k) and labour (l). The output of investment goods is measured in consumption units. z is a productivity shock which GHK refer to as "neutral technological change". Eq. (2) shows investment in efficiency units (i^*), that is, the number of new "machines" produced (i), converted to units of constant quality. The new feature

[1]The model of Greenwood et al. (1997) and (2000) is actually more complicated since it has two capital goods sectors, structures and equipment, and they also assume that investment incurs adjustment costs. But these complications have no relevance for the issues discussed in Sections 2 and 3. In the empirical analysis of Section 4, I extend the model to incorporate two capital goods sectors. The model in Hercowitz (1998) is identical to the one considered here except in three unimportant respects. First, constant returns to scale (which GHK assume) are explicitly imposed in Eq. (1). Second, Hercowitz adds a resource cost term to Eq. (1), which however is later dropped from his analysis. Third, Eq. (3) in Hercowitz is in discrete time. Growth accounting theory is most easily developed in continuous time, so I employ the continuous analogue of his equation.

here is q which measures ISTC. The growth rate of q can be thought of as the rate of quality improvement in investment goods. Empirically, q is measured by the ratio of consumption goods prices to investment goods prices. The extent to which output growth is due to increased quality of the capital stock is called the extent of embodiment by GHK. Eq. (3) describes the evolution of the capital stock when measured in efficiency units.

At first sight, this model seems to offer a radically different approach to that of conventional growth accounting. It also offers a challenge to conventional national income accounting. In the GHK model, output is measured in consumption units, i.e. nominal output of the investment good is deflated by the consumption price index. In national income accounting, nominal expenditure on investment is deflated by price indices for investment goods. However, contrary to appearances, I show in what follows that the model of Eqs. (1)–(3) can be derived as a special case of a conventional two-sector model, where TFP is growing at different rates in the two sectors. As a result, everything that GHK say about ISTC and neutral technological change can be translated into statements about TFP growth. Also, there is no need to reformulate national income accounting.

Implicit in the GHK model above are two final goods industries, one producing consumption goods, and the other investment goods.[2] Label these two sectors by subscript c and i. Measure the output and the price of investment goods in units of constant quality (efficiency units), i.e. output of investment goods is i^*: this is in accordance with standard production theory and national income accounting. Assume that each sector's technology can be described by a production function exhibiting constant returns to scale and unbiased technical progress:

$$\begin{aligned} c &= A_c \cdot l_c \cdot f^c(k_c/l_c), \quad A_c > 0, \\ i^* &= A_i \cdot l_i \cdot f^i(k_i/l_i), \quad A_i > 0. \end{aligned} \tag{4}$$

Here k_x, l_x are capital and labour inputs in sector $x (x = c, i)$, and $A_x(t)$ is the level of TFP in sector x. Sector inputs must add to the economy-wide totals:

$$\begin{aligned} k_c + k_i &= k, \\ l_c + l_i &= l. \end{aligned} \tag{5}$$

Denote TFP growth in the two sectors by $\hat{A}_c, \hat{A}_i$ where a "hat" ($\wedge$) denotes a growth rate: that is, $\hat{A}_x = \mathrm{d} \ln A_x(t)/\mathrm{d}t, \quad x = c, i$, where t is time. Assuming perfect competition, TFP growth (in continuous time) in the two sectors can be measured by

$$\begin{aligned} \hat{A}_c &= \hat{c} - \alpha_c \hat{k}_c - (1 - \alpha_c)\hat{l}_c, \\ \hat{A}_i &= \hat{i}^* - \alpha_i \hat{k}_i - (1 - \alpha_i)\hat{l}_i. \end{aligned} \tag{6}$$

Here α_x is the (possibly time-varying) capital share in industry x:

$$\alpha_x = rk_x/(wl_x + rk_x), \quad x = c, i, \tag{7}$$

where r is the rental on capital and w is the wage. Competition ensures that these input prices are the same in both sectors.

Eq. (6) measures TFP growth from the "quantity" side, but TFP growth can also be measured from the "price" side. Using this latter, dual approach, the growth of TFP

[2] The two-sector interpretation of the GHK model has also been noted by Whelan (2001) and by Ho and Stiroh (2001).

equals the rate at which the output price would fall over time, if input prices were held constant (Jorgenson and Griliches, 1967; Barro, 1999). Under the assumptions of constant returns to scale and perfect competition, there exists a price (unit cost) function in each sector, which is dual to the production function. With appropriate normalization these price functions can be written as

$$p_c = A_c^{-1} \cdot w \cdot g^c(r/w),$$
$$p_i = A_i^{-1} \cdot w \cdot g^i(r/w), \tag{8}$$

where p_c, p_i are the prices of consumption and investment respectively. These functions relate output prices (= unit costs) to input prices when costs are minimized. Note that $q = p_c/p_i$.

Now consider a special case: assume that the unit cost functions, or, equivalently, the production functions, are identical in the two industries up to a time-varying scale factor (TFP): that is $g^c(\cdot) = g^i(\cdot) = g(\cdot)$ say and $f^c(\cdot) = f^i(\cdot) = f(\cdot)$ say. Then input shares and input ratios will be the same in the two sectors, i.e. $\alpha_c = \alpha_i$ and $k_c/l_c = k_i/l_i = k/l$ at all input prices and from (8) by division,

$$q = p_c/p_i = A_i/A_c. \tag{9}$$

Differentiating with respect to time:

$$\hat{q} = \hat{p}_c - \hat{p}_i = \hat{A}_i - \hat{A}_c. \tag{10}$$

So ISTC turns out to equal just the excess of TFP growth in the investment good sector over TFP growth in the consumption good sector.

We now show how the other concept of the GHK model, neutral technological change, is related to TFP. Continuing with the special case, output measured in consumption units is

$$y = c + i = c + i^*/q = c + (A_c/A_i) \cdot i^*,$$
$$y = A_c \cdot l \cdot f(k/l), \tag{11}$$

using (9), (1), (2) and (4). Now comparing Eq. (11) with Eq. (1) of the GHK model, we find that

$$z = A_c. \tag{12}$$

In other words, "neutral technological change" is equivalent to TFP growth in the consumption good sector. Hence, as asserted, the GHK model can be derived from a special case of the two-sector model.

In general, relative prices may change either because TFP is growing at different rates or because one sector is more capital intensive than the other. For example, suppose the investment good sector is the more capital intensive, that wages are rising over time relative to the rental on capital (as would be the case in a steady state), and that TFP growth rates are the same in the two sectors. Then the relative price of the investment good will be falling: i.e. q will be rising. But we would hesitate to describe this fall in relative price as ISTC, since by assumption TFP growth is the same in both sectors. The contrary assumption, that price and production functions are identical up to a time-varying scale factor, leaves differences in TFP growth as the sole cause of relative price change, and only by making this crucial assumption can GHK derive an aggregate production function like (1).[3]

[3]This is acknowledged in their (1997) paper (see pp. 356–358) and in their (2000) paper (see pp. 108–109).

3. Jorgensonian growth accounting

The previous section showed the relationship between the GHK concepts of neutral technological change and of ISTC on the one hand and sectoral TFP growth rates on the other. This section derives the relationship between the GHK concepts and the *aggregate* TFP growth rate. In so doing, it shows that GHK's criticisms of Jorgensonian growth accounting are incorrect.

Hercowitz (1998) and Greenwood et al. (1997) draw a contrast between what they call the "Solow" view and the "Domar-Jorgenson" or just "Jorgenson" model of growth accounting. In aid of their interpretation they cite Jorgenson's (1966) article on embodiment and also Hulten (1992). They claim that Jorgenson is advocating a particular form of the aggregate production function given by

$$y = c + qi = z \cdot l \cdot f(k/l). \tag{13}$$

This equation should be compared with Eq. (1): the only difference is the presence of q. Now if Eq. (1), together with (2) and (3), constitute the correct model, then Eq. (13) is just a mistake, unless q happens to be constant, in which case these two models are equivalent. But if q is constant, then ISTC must necessarily be zero. Empirically, however, GHK find ISTC to be large. So this leads them to conclude that the Jorgenson approach is wrong and underestimates the role of technological change embodied in new equipment.

There is only one problem with this argument. Neither in the cited 1966 article nor anywhere else in his extensive empirical work does Jorgenson rely on an aggregate production function of the form of (13).[4] His starting point is always the accounting relationship that the value of all types of output in current prices must equal the value of all types of inputs, also in current prices. Specialized to the present model of two industries where each produces only final goods, the accounting relationship is

$$p_c c + p_i i^* = wl + rk. \tag{14}$$

Like all good accounting relationships, this equation also embodies a model, namely that competitive payments to inputs exhaust the value of output. By totalling differentiating this relationship with respect to time, we can derive Divisia quantity and price indices for aggregate output and aggregate input, in the spirit of Jorgenson (1966). Define s as the current price share of investment in the value of output:

$$s = p_i i^* / (p_c c + p_i i^*) = i/y. \tag{15}$$

Then a Divisia index of output (GDP), denoted by Y, is

$$\hat{Y} = (1 - s)\hat{c} + s\hat{i}^*. \tag{16}$$

Note that a different symbol is used for output here, Y not y, since this is not the same concept as the output of GHK's aggregate production function, Eq. (1).

[4]It is true that Hulten (1992) appears to attribute to Jorgenson an aggregate production function of the form (13): this is Hulten's Eq. (7). But Hulten just uses this to derive Divisia indices of output and input (his Eq. (8)), for which the aggregate production function is not necessary. So the aggregate production function is not an essential part of Hulten's argument. (Apart from this point, nothing in the present paper is in disagreement with Hulten, 1992). Nor does the aggregate production function (13) appear in Domar (1963), which is cited by Greenwood et al. (1997).

Using now the more familiar quantity approach, and writing the aggregate share of capital as $\alpha = rk/(rk + wl)$, TFP growth at the aggregate level (μ) is found to be

$$\mu \equiv \partial \ln Y/\partial t = \hat{Y} - \alpha\hat{k} - (1-\alpha)\hat{l} = (1-s)\hat{A}_c + s\hat{A}_i, \tag{17}$$

where use is made of (6), (7) and (16). In other words, aggregate TFP growth is a weighted average of TFP growth rates in the two sectors, where the weights are shares in final output. This is a special case of Domar aggregation (Domar, 1961).[5]

We saw in the previous section that neutral technological change and ISTC can be interpreted in terms of sectoral TFP. So it is no surprise that the aggregate TFP growth rate can also be translated into GHK terminology. Substituting (10) and (12) into (17),

$$\mu = \hat{z} + s\hat{q}. \tag{18}$$

In the terminology of GHK, the aggregate TFP growth rate equals neutral technological change plus ISTC, the latter weighted by the investment share. Of course, this interpretation is subject to their (implicit) assumption of identical production functions in the two sectors: empirically, (17) and (18) will yield different results if this assumption is not a good approximation.[6]

Now let us consider the different ways to answer the question of interest to GHK: what is the proportion of growth which is attributable to embodiment? The traditional answer of growth accounting is to express the contribution of TFP growth in the investment goods industry as a proportion of aggregate TFP growth: from (17) this is

$$\frac{s\hat{A}_i}{\mu} = \frac{s\hat{A}_i}{(1-s)\hat{A}_c + s\hat{A}_i}. \tag{19}$$

Alternatively, and more in the spirit if GHK, we could calculate the proportional contribution of ISTC to aggregate TFP growth:

$$\frac{s\hat{q}}{\mu} = \frac{s\hat{q}}{\hat{z} + s\hat{q}} = \frac{s(\hat{A}_i - \hat{A}_c)}{(1-s)\hat{A}_c + s\hat{A}_i}. \tag{20}$$

GHK however ask a different question: what is the contribution of embodiment (ISTC) to the growth of consumption per hour in balanced (steady state) growth? As shown in the appendix to Oulton (2004a), the balanced growth rate of consumption per hour worked,

[5]In the more general case where industries make intermediate sales as well as final ones, the Domar weights are the ratios of gross output to aggregate final output; aggregate TFP growth is then a weighted sum, not a weighted average. The more general result is derived in Hulten (1978) and is discussed in Oulton (2001). Jorgenson et al. (1987) also show how the result is modified if some of the assumptions are relaxed, e.g. if any of the input prices differ between industries. Domar aggregation has been applied recently to study the impact of productivity growth in ICT industries and investment in ICT on aggregate output and productivity (Jorgenson and Stiroh, 2000b; Oliner and Sichel, 2000).

[6]A related issue is whether, as Greenwood et al. (1997) have claimed, the U.S. NIPAs are conceptually flawed since there each type of output is deflated by its own price index rather than all types being deflated by the price of consumption, as in equation (1). This issue is examined in Oulton (2004a). The conclusion reached there is that there is nothing wrong with the standard national accounts definition of real output (as employed e.g. in Eq. (16)). But if we are seeking a measure of welfare rather than output, then a better measure is *net* (not gross) domestic product deflated by the price of consumption (Weitzman, 1976; Oulton, 2004b).

Table 1
GHK versus growth accounting: a comparison of estimates

	Greenwood et al. (1997)	Jorgenson and Stiroh (2000a)
Period	1954–1990	1958–1996
Parameters:		
$\hat{z}$	*0.39*	0.36
$\hat{q}$	*3.21*	1.23
ε	*0.17*	n.a.
σ	*0.13*	n.a.
s_e or Domar weight	*0.073*	*0.101*
$\hat{A}_c$	0.39	*0.36*
$\hat{A}_e$	3.60	*1.59*
μ	0.62	*0.48*
$s_e\hat{A}_e/\mu$	0.42	*0.33*
h	*1.34*	0.81
Embodiment (ISTC):		
Contribution to μ [$= s_e\hat{q}/(\hat{z}+s_e\hat{q})$, from (26)]	0.38	0.26
Contribution to h [$= \varepsilon\hat{q}/(\hat{z}+\varepsilon\hat{q})$, from (27)]	*0.58*	0.37

Notes: Growth rates (denoted by "hats") are in percent per annum. Other quantities are ratios. Figures in *italic* are those given in, or directly derived from, the article at the head of the column. Other figures are derived by me from the figures in italic, using Eqs. (23)–(27). ε,σ are the elasticities of output with respect to equipment and structures respectively. Estimates involving balanced growth use the GHK estimates of ε and σ.

denoted by h, in the two-sector model is

$$h = \frac{(1-\alpha)\hat{A}_c + \alpha\hat{A}_i}{1-\alpha} = \frac{\hat{z}+\alpha\hat{q}}{1-\alpha}. \tag{21}$$

The capital share α is now assumed constant, implying that the underlying production functions are Cobb–Douglas, since this is required for the existence of balanced growth. The contribution of ISTC is now defined by GHK to be what balanced growth would be if sector neutral technological progress ($\hat{z}$) were zero.[7] Expressed as a proportion of the actual balanced growth rate, this is

$$\frac{\alpha\hat{q}/(1-\alpha)}{h} = \frac{\alpha\hat{q}}{\hat{z}+\alpha\hat{q}} = \frac{\alpha(\hat{A}_i - \hat{A}_c)}{(1-\alpha)\hat{A}_c + \alpha\hat{A}_i}. \tag{22}$$

4. What proportion of growth is due to embodiment (ISTC)?

Empirically, the issue of interest to Greenwood et al. (1997) is the extent to which technological progress is embodied, i.e. caused by ISTC. They find that ISTC accounted for 58% of the growth in consumption per hour over the period 1954–1990. As we have argued, this issue can also be addressed using the more general growth accounting framework. Jorgenson and Stiroh (2000a, Table 1) provide data on Domar weights and TFP growth rates in the equipment-producing sectors of the US economy. It can then be

[7]The use of the balanced growth rate as the reference point is consistent with Hulten (1979); he argued that the contribution of TFP to economic growth should be measured as inclusive of the contribution of the capital accumulation induced by a positive rate of growth of TFP.

calculated (using Eqs. (17) and (19)) that TFP growth in these sectors accounts for 33% of aggregate TFP growth over 1958–1996.[8] This large difference is due to some extent to methodology but mostly to data. These will be discussed in turn.

Greenwood et al. (1997) actually work with a slightly more complicated model than that of Sections 2 and 3. They assume two capital good sectors, structures and equipment, but that only equipment enjoys ISTC; in our terms this means that TFP growth in structures is the same as in the consumption sector. The properties of this model are derived in the appendix to Oulton (2004a). As shown there, in this extended model

$$\hat{q} = \hat{A}_e - \hat{A}_c, \tag{23}$$

where $\hat{A}_e$ is the growth rate of TFP in the equipment sector (compare (10)). The balanced growth rate of consumption per hour is now

$$h = \frac{(1-\varepsilon)\hat{A}_c + \varepsilon\hat{A}_e}{1-\alpha} = \frac{\hat{z} + \varepsilon\hat{q}}{1-\alpha}, \tag{24}$$

where ε is the elasticity of output (whether of consumption or investment goods) with respect to equipment and (as before) α is the aggregate share of capital in income: $\alpha = \varepsilon + \sigma$ where σ is the elasticity of output with respect to structures. (Eq. (24) can be compared to (21).) These elasticities are assumed constant, implying that the underlying production functions are Cobb–Douglas, as is required for the existence of balanced growth.

The aggregate TFP growth rate in the extended model is

$$\mu = (1-s_e)\hat{A}_c + s_e\hat{A}_e = \hat{z} + s_e\hat{q}, \tag{25}$$

where s_e is the current price share of equipment investment in aggregate output (compare (18)). Hence the contribution of ISTC to aggregate TFP growth is

$$\frac{s_e\hat{q}}{\mu} = \frac{s_e\hat{q}}{\hat{z} + s_e\hat{q}} = \frac{s_e(\hat{A}_e - \hat{A}_c)}{(1-s_e)\hat{A}_c + s_e\hat{A}_e}, \tag{26}$$

which can be compared to (20), while the contribution of ISTC to balanced growth is now

$$\frac{\varepsilon\hat{q}/(1-\alpha)}{h} = \frac{\varepsilon\hat{q}}{\hat{z} + \varepsilon\hat{q}} = \frac{\varepsilon(\hat{A}_e - \hat{A}_c)}{(1-\varepsilon)\hat{A}_c + \varepsilon\hat{A}_e}, \tag{27}$$

which can be compared to (22).

We can now quantify these various concepts using data from Greenwood et al. (1997) on the one hand and from Jorgenson and Stiroh (2000a) on the other. Table 1 puts the relevant data from each of these articles side by side. It also uses each article's data to estimate the other article's growth concepts. For example, we can use the Jorgenson–Stiroh data to estimate ISTC and the GHK data to estimate TFP. Using the GHK data, the aggregate TFP growth rate was 0.62% p.a. while using Jorgenson and Stiroh's it was only

[8] TFP growth in the equipment-producing sectors averaged 1.59% p.a. and these sectors had a Domar weight of 0.101. The overall TFP growth rate was 0.48% p.a. Hence the contribution of the equipment producing sectors was 0.101*1.59/0.48 = 0.33. The figure of 1.59% p.a. for TFP growth in the equipment-producing industries is derived as a weighted average of the TFP growth rates in three industries: Industrial Machinery and Equipment, Electronic and Electric Equipment, and Instruments; the weights are the Domar weights. These data are from Table 1 of Jorgenson and Stiroh (2000a).

0.48% p.a. The (literal) bottom line is that, on the GHK data, 58% of balanced growth is due to ISTC, while using the Jorgenson–Stiroh data this proportion is only 37%.

The main reason for this disparity is that the estimate of ISTC from the Jorgenson–Stiroh data is only 1.23% p.a. while that from the GHK data is 3.21% p.a. Another way of making the same point is that TFP growth in the equipment-producing industries is 1.59% p.a. using Jorgenson–Stiroh data, but 3.60% p.a. using GHK data. The Jorgenson–Stiroh estimates are based ultimately on the US NIPA, including the official price indices. The GHK estimate of $\hat{q}$ is the difference between the growth rates of a deflator for consumption (excluding housing and durables) and one for producers' durable equipment. The deflator for durable equipment, which derives from Gordon (1990), falls much more rapidly than the official deflator: see Fig. 1 of Hercowitz (1998). In fact, in extending the Gordon series, which ends in 1983–1990, GHK state that they cut about 1.5 percentage points/annum from the growth of the official deflator (Greenwood et al., 1997, footnote 20).

In summary, the main reason for the different results yielded by the GHK and Jorgenson–Stiroh data is that GHK use a deflator for durable equipment which falls much more rapidly than the official one which is implicit in Jorgenson–Stiroh. Deciding which deflator is nearer the truth is beyond the scope of this paper.

A second reason relates to GHK's use of balanced consumption growth as the reference. When embodiment is measured relative to TFP growth, the two estimates of the embodiment contribution are much closer: from the penultimate line of Table 1 the contributions are 38% according to GHK versus 26% according to Jorgenson–Stiroh. The formula for the contribution to TFP, Eq. (26), involves the share of equipment investment in GDP (s_e) while the formula for the contribution to balanced growth, Eq. (27), involves the elasticity of output with respect to equipment (ε). According to GHK, the actual share of equipment investment in output (s_e) averaged 0.073, whereas their calibration yields an elasticity of output with respect to equipment (ε) which is more than twice as high, 0.17. So GHK's higher estimate of ISTC gets a bigger weight in calculating the contribution to balanced growth and this accentuates the gap between the GHK and Jorgenson–Stiroh results.

There is certainly theoretical support for using balanced growth as the benchmark (Hulten, 1979). But the fact that GHK are asking a different question should be borne in mind when comparing their results with those of growth accounting studies.

5. Conclusion

The GHK model has been shown to be a special case of the framework developed and applied by Jorgenson and others to the study of productivity growth. ISTC has been found to be closely related to the more familiar concept of TFP growth. The criticism that GHK make of Jorgenson's approach has been shown to be incorrect: Jorgenson's approach does not employ the particular aggregate production function, which they attribute to him.

There is a large difference between GHK and the growth accounting study of Jorgenson and Stiroh (2000a) over the importance of technical progress in the equipment-producing sectors in explaining US growth. But the main reason for this difference is data, not methodology. GHK use a deflator for equipment which falls much more rapidly than the official one.

While this paper has been critical of GHK, it is only fair to point out that they have gone beyond growth accounting pure and simple by embedding their assumptions about technology in a DSGE model. This enables them to model (for example) the effect on the US business cycle of productivity shocks which hit the equipment-producing sector.[9] The present paper, which aims just to clarify the relationship of their work to growth accounting, should not be taken as impugning the value of this type of contribution.

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[9]See Bakhshi and Larsen (2005) for an application of their model, with extensions, to study the effect in the UK of shocks arising from the ICT sector.