CENTRE *for* ECONOMIC PERFORMANCE

CEP Discussion Paper No 869

May 2008

Mapping Prices into Productivity in Multisector Growth Models

L. Rachel Ngai and Roberto M. Samaniego

THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

Abstract

Two issues related to mapping a multi-sector model into a reduced-form value-added model are often neglected: the composition of intermediate goods, and the distinction between value added productivity and gross output productivity. We demonstrate their quantitative significance for the case of the well known model of Greenwood, Hercowitz and Krusell (1997), who find that about 60% of economic growth can be attributed to investment-specific technical change (ISTC). When we recalibrate their model to allow for even a small equipment share of intermediates, we find that ISTC accounts for almost the entirety of post-war US growth.

JEL Codes: E13, O30, O41, O47

Keywords: Intermediate goods, investment-specific technical change, growth accounting, gross output, multisector growth models.

This paper was produced as part of the Centre's Macro Programme. The Centre for Economic Performance is financed by the Economic and Social Research Council.

Acknowledgements

The authors are grateful to Alwyn Young for useful conversations. Comments welcome. All errors and omissions are the authors'.

L. Rachel Ngai is an Associate of the Macro Programme at the Centre for Economic Performance and a Lecturer in the Department of Economics, London School of Economics. Roberto M. Samaniego is an Assistant Professor in the Department of Economics, The George Washington University, Washington, DC, USA.

Published by
Centre for Economic Performance
London School of Economics and Political Science
Houghton Street
London WC2A 2AE

ISBN 978-0-85328-265-5

1 Introduction

There is growing interest in multisector models of economic growth.[1] In these models, it is common to draw a link between the relative prices of different goods and productivity growth rates affecting those goods. These models generally do not account explicitly for intermediate goods, but are formulated in terms of value added. These value-added models are isomorphic to models that allow for intermediates: nonetheless, the existence of an isomorphism between the two types of models does not imply that neglecting the existence and structure of intermediate goods has no quantitative implications. In fact, it may lead to significant biases in the importance attributed to different sources of economic growth.

We argue that there are two neglected factors that are quantitatively important when mapping a multi-sector model with intermediate goods to a reduced-form one-sector model: the potential role of each sector as an intermediate good, and the distinction between value added prices and gross output prices. First, we demonstrate the significance of the composition channel for the case of the well known model of Greenwood, Hercowitz and Krusell (1997) (henceforth GHK), who find that about 60% of economic growth can be attributed to investment-specific technical change (ISTC). We focus on this model because it is highly tractable, and because it has motivated several other studies in which ISTC plays an important role. In particular we show that, if the output of the equipment sector is used as an intermediate good (for example, in the form of fabricated parts or electronic components), then the relative price of intermediate goods declines relative to consumption. This model reduces to the one-sector version of the GHK model yet, when we calibrate the model to a reasonable intermediate goods share, we find that the ability of ISTC to account for growth is boosted by half. Thus, for reasonable parameterizations of the model economy, ISTC can account for *the entirety of post-war US growth.* This is so even though the equipment share of intermediates is small – just 10%.

GHK motivate their general equilibrium approach (and contrast it with the approach of Hulten (1992)) by observing that capital accumulation provides a channel thought which ISTC may be amplified, so that general equilibrium growth accounting may be necessary to establish the full contribution of ISTC to growth. According to our results, accounting for the composition of intermediate goods provides a so-far neglected general equilibrium channel that amplifies the aggregate impact of ISTC. Interestingly, in a discussion of intermediate goods, GHK state that "provided the

[1] Examples include models of investment-specific technical change such as Greenwood, Hercowitz and Krusell (1997), Cummins and Violante (2002) and Fisher (2006); and models of structural change such as Kongsamut, Rebelo and Xie (2001) and Ngai and Pissarides (2008).

role of intermediate inputs is similar in all sectors, the use of a one-sector model and value-added data should provide roughly the same answer as the more elaborate multisector framework" (see p.354, footnote14). We show that, in fact, allowing for intermediate inputs greatly increases the aggregate impact of ISTC, even when intermediate input shares *are* constant across sectors. Essentially, if the equipment sector produces intermediates as well as final goods, then investment-specific technical change is reflected in the productivity index of the value-added production function in all sectors. Therefore, growth accounting in a reduced-form value added model tends to underestimate the contribution of ISTC to economic growth.

There is a second reason why accounting for intermediate goods may be quantitatively significant in a multisector world. Relative productivity movements across sectors are often calibrated using the relative price of gross output in those sectors. We show that, in a multisector value-added model, the correct mapping between output prices and model productivity requires a transformation based on the intermediate share of gross output – which is roughly 50%. Thus, a given wedge between relative goods prices reflects a much larger wedge between relative productivities in the industries that produce those goods. The issues we raise are well known in the productivity literature – see Hulten (1978). However, their relevance for quantitative general equilibrium work seems to have been overlooked. An exception is Vourvachaki (2007), who studies the contribution of Information and Communication Technology to growth in other sectors of the economy through its use as an intermediate. For simplicity, we follow GHK in assuming that production functions are identical across sectors except for sector-specific productivity. If, for example, capital shares are different across sectors, then the relationship linking relative prices and relative productivity would be more complex, and also involves the differences in capital shares, as in Hornstein and Krusell (1996). Nonetheless, it would still be affected by the factors we raise.

Section 2 develops the model economy, and Section 3 discusses the mapping between the model of GHK and a multi-sector framework with intermediate goods. Section 4 calibrates the GHK model using their own parameterization as well as some parameters on the structure of intermediate goods. Section 5 concludes.

2 Economic Environment

We will first review the GHK model, then present a three-sector model with intermediate goods that reduces to the model in GHK. The household sector is identical in both cases and is presented below.

There is a representative household with the following life-time utility

$$E\sum_{t=0}^{\infty}\beta^{t}U\left(c,l\right)$$

where per-period utility U is a function of consumption c and labor l :

$$U(c,l)=\theta\log c+(1-\theta)\log\left(1-l\right).$$

Households own all the capital of this economy. Capital income and labor income are subject to taxation at rates τ_k and τ_l respectively, and the proceeds of taxation are redistributed to households via a lump-sum transfer τ, so that:

$$\tau=\tau_k\left(r_e k_e+r_s k_s\right)+\tau_l wl.$$

where k_e is equipment capital and k_s is structures capital.

The household's maximization problem may be formulated recursively:

$$\begin{aligned}
V\left(k_e,k_s\right) &= \max_{c,i_e,i_s,l}\left\{U\left(c,l\right)+\beta EV\left(k_e',k_s'\right)\right\} &(1)\\
&\quad s.t.\\
c+i_e+i_s &= \left(1-\tau_k\right)\left[R_e k_e+R_s k_s\right]+\left(1-\tau_l\right)Wl+\tau\\
k_s' &= \left(1-\delta_s\right)k_s+i_s &(2)\\
k_e' &= \left(1-\delta_e\right)k_e+i_e q &(3)
\end{aligned}$$

the last two equations are the accumulation equations for each type of capital. Equation (2) is standard. However, Equation (3) is less so, and allows for investment-specific technical change. By spending i_e on equipment, household can obtain $i_e q$ units of equipment. In other words, $1/q$ is the inverse of the relative price of equipment in terms of consumption goods.

2.1 GHK one-sector model

The one-sector model in the GHK is as follows. There is one final good y in this economy which can be used as consumption c, investment in structures i_s, or investment in equipment i_e. The final good is produced using a combination of equipment k_e, structures k_s and labor l, such that

$$\begin{aligned}
y &= zF\left(k_e,k_s,l\right) &(4)\\
F\left(k_e,k_s,l\right) &= k_e^{\alpha_e}k_s^{\alpha_s}l^{1-\alpha_e-\alpha_s}, &(5)
\end{aligned}$$

where z is the total factor (or neutral) productivity index for value-added.

The market clearing condition is:

$$y = c + i_e + i_s. \tag{6}$$

The representative firm's maximization problem is

$$\max_{k_e, k_s, l} \left[y - R_e k_e - R_s k_s - Wl \right] \tag{7}$$

2.2 A Three-sector model with intermediate goods

In a discussion regarding intermediate goods and multisector model, GHK state that

> "In principle, a multisector general equilibrium model could have been developed, where a portion of each sector's output is used as intermediate inputs in other sectors.....Provided the role of intermediate inputs is similar in all sectors, the use of a one-sector model and value-added data should provide roughly the same answer as the more elaborate multisector framework" (see p.354, footnote14).

We take on this challenge and derive a many-sector model with intermediate goods[2]. We find there are two potential channels that may actually increase the quantitative contribution of ISTC to economic growth in such a model.

There are three final goods sectors: equipment, structures and consumption. In each sector i, gross output d_i is produced with the following production function:

$$d_i = A_i F\left(k_{ei}, k_{si}, m_i, l_i\right); \quad i = c, e, s \tag{8}$$

where $F(.)$ is:

$$F\left(k_e, k_s, m, l\right) = \left(k_e^{\alpha_e} k_s^{\alpha_s} l^{1-\alpha_e-\alpha_s}\right)^{1-\alpha_m} m^{\alpha_m} \tag{9}$$

The intermediate goods are produced in the intermediate sector as follows:

$$m = \prod_{i \in c,e,s} \left(\frac{h_i}{\varphi_i}\right)^{\varphi_i}; \quad \sum_{i \in c,e,s} \varphi_i = 1,\ \varphi_i \geq 0. \tag{10}$$

Market clearing for each final good sector requires:

$$d_i = i_i \frac{p_c}{p_i} + h_i \quad i = s, e \tag{11}$$

$$d_c = c + h_c \tag{12}$$

[2] The intermediate goods is modelled in a similar way as in the multi-sector model of Ngai and Pissarides (2007).

where p_i is the price index for gross output d_i, $i = e, s, c$.

The market clearing condition for intermediates, capital and labor input are

$$\sum_{i=c,e,s} m_i = m, \tag{13}$$

$$\sum_{i=c,e,s} k_{ji} = k_j; \quad j = e, s, \tag{14}$$

and

$$\sum_{i=c,e,s} l_i = l. \tag{15}$$

2.2.1 Competitive equilibrium

Households: The household sector is identical to (1) in the one-sector model with the capital accumulation equation as follows:

$$k_i' = (1 - \delta_i) k_i + i_i \frac{p_c}{p_i} \qquad i = e, s. \tag{16}$$

Here, $\frac{p_c}{p_i}$ is the price of a unit of investment good i in terms of consumption.

Final goods sectors: Profit maximization for firms in final good sector $i = e, s, c$ is:

$$\max_{k_{ei}, k_{si}, m_i, l_i} \left[p_i d_i - R_e k_{ei} - R_s k_{si} - p_m m_i - W l_i \right]. \tag{17}$$

The Cobb-Douglas production function (9) implies constant expenditure shares on all inputs – for instance, in the case of intermediate goods:

$$p_m m_i = \alpha_m p_i d_i. \tag{18}$$

Free mobility of inputs across sectors then implies the capital-labor ratio and intermediate-labor ratio are equalized across sectors, so together with market clearing conditions (13) and (15), for any sector $i = e, s, c$ we obtain:

$$\frac{m_i}{l_i} = \frac{m}{l}; \qquad \frac{k_{ji}}{l_i} = \frac{k_j}{l} \qquad j = e, s \tag{19}$$

and it follows that relative prices of gross output reflect the inverse of relative productivities in gross output production (8):

$$\frac{p_i}{p_j} = \frac{A_j}{A_i}. \tag{20}$$

Intermediate goods sector: Intermediate goods producers solve:

$$\max_{h_s,h_c,h_e} \left[p_m m - \sum_{i=e,s,c} p_i h_i \right]$$

given the intermediate goods' production function (10), optimality for $i \in \tilde{M}$ requires:

$$p_i h_i = \varphi_i p_m m, \tag{21}$$

together with (10), the price-index for intermediate goods is $p_m = \prod_{i=c,e,s} p_i^{\varphi_i}$, so the relative price of intermediate goods follows from (20):

$$\frac{p_m}{p_c} = \prod_{i=c,e,s} \left(\frac{p_i}{p_c}\right)^{\varphi_i} = \prod_{i=c,e,s} \left(\frac{A_c}{A_i}\right)^{\varphi_i}. \tag{22}$$

2.2.2 Aggregation

To aggregate the three sectors, we first derive value-added for each sector. Let p_{yi} be the price-index and y_i be the real value-added in sector i. By definition,

$$p_{yi} y_i \equiv p_i d_i - p_m m_i = (1 - \alpha_m) p_i d_i, \tag{23}$$

where the equality follows from the optimal choice of intermediate goods (18). Aggregate real value-added (in terms of consumption goods) is defined by $y \equiv \sum_{i=s,c,e} \frac{p_{yi} y_i}{p_c}$. Using (18), aggregate expenditure on intermediate goods follows from the market clearing for intermediate goods (13)

$$p_m m = \alpha_m \sum_{i=s,c,e} p_i d_i = \frac{\alpha_m}{1-\alpha_m} p_c y. \tag{24}$$

Using (23), the expression for relative prices (20) and the production function (8), we find that

$$y = (1-\alpha_m) \sum_{i=s,c,e} A_c \left[\left(\frac{k_{ei}}{l_i}\right)^{\alpha_e} \left(\frac{k_{si}}{l_i}\right)^{\alpha_s} \right]^{1-\alpha_m} \left(\frac{m_i}{l_i}\right)^{\alpha_m} l_i,$$

and, using (19),

$$y = (1-\alpha_m) A_c \left[k_e^{\alpha_e} k_s^{\alpha_s} l^{1-\alpha_e-\alpha_s} \right]^{1-\alpha_m} m^{\alpha_m},$$

which, together with the relative price of intermediate goods (22) and the aggregate expenditure share of intermediate goods (24), yields an expression for aggregate real value-added:

$$y = z k_e^{\alpha_e} k_s^{\alpha_s} l^{1-\alpha_e-\alpha_s} \tag{25}$$

$$z = (1-\alpha_m)\,\alpha_m^{\alpha_m/(1-\alpha_m)} A_c \left(\prod_{i=c,e,s} A_i^{\varphi_i}\right)^{\alpha_m/(1-\alpha_m)}. \tag{26}$$

We now verify the capital accumulation equations (16) and the market clearing conditions (11)&(12) in the three-sector model can be reduced to (2) & (3) and (6) in the GHK one-sector model. Equation (20) derives the relative prices (in gross output) based on the relative productivity indexes for the gross output. As a result, the capital accumulation patterns in (16) are identical to those of (2) and (3) in GHK, provided $A_c = A_s \neq A_e$ and

$$q = \frac{p_c}{p_e} = \frac{A_e}{A_c}. \tag{27}$$

Thus, the rate of ISTC is linked to the decline in relative prices of equipment, as measured in terms of gross output.

Finally, we show that the market clearing conditions (11) and (12) reduce to the resource constraint (6) in the GHK one-sector model. By the definition of y and (23)

$$y = (1-\alpha_m) \sum_{i=s,c,e} \frac{p_i d_i}{p_c},$$

together with the market clearing conditions (11) and (12), and the optimal input composition (21),

$$y = (1-\alpha_m)(i_e + i_s + c) + \frac{p_m m}{p_c},$$

the result follows from (24).

3 ISTC in the multisector model

We now underline the two channels through which the quantitative implications of ISTC in a multi-sector model with intermediate goods might differ from a reduced-form one-sector value-added model.

3.1 Equipment's share in intermediate goods

In the one-sector value added model of GHK, the residual z is interpreted as an index of "neutral technical change" – technical change from sources other than the investment specific technical change. However, the productivity index z of aggregate real-value added derived from the multisector model is:

$$z = (1-\alpha_m)\,\alpha_m^{\alpha_m/(1-\alpha_m)} A_c^{1/(1-\alpha_m)} \left(\frac{A_e}{A_c}\right)^{\alpha_m \varphi_e/(1-\alpha_m)}, \tag{28}$$

which includes the ISTC term A_e/A_c. Hence, if equipment is used as an intermediate good ($\varphi_e > 0$), the index z remains influenced by technical progress specific to the equipment sector.

Observation 1 When equipment is used as an intermediate good, the correct expression for "neutral" productivity growth is

$$\gamma_{\tilde{z}} = \gamma_z \gamma_q^{-\alpha_m \varphi_e/(1-\alpha_m)}. \tag{29}$$

Observation 1 implies that GHK understate the quantitative contribution of ISTC. By deriving the full three-sector model, we show that γ_z itself includes the contribution from ISTC through the equipment's share as intermediate goods. Therefore a correct measure of neutral productivity growth is $\gamma_{\tilde{z}}$ in (29). Thus, given price data on q and a growth rate for aggregate value added y, the contribution of ISTC is larger when the composition of intermediate goods is taken into account.

A significant finding of GHK, replicated in other studies,[3] is their growth accounting result that ISTC accounts for about 60% of economic growth. Long run growth accounting in their model yields the expression

$$\gamma_y = \gamma_z^{\frac{1}{1-\alpha_e-\alpha_s}} \gamma_q^{\frac{a_e}{1-\alpha_e-\alpha_s}} \tag{30}$$

which remains the case in the multisector framework also. However, this does not fully account for the influence of ISTC upon growth. Using expression (29), the "complete" growth accounting expression is

$$\gamma_y = \gamma_{\tilde{z}}^{\frac{1}{1-\alpha_e-\alpha_s}} \gamma_q^{\frac{a_e+\varphi_e \alpha_m/(1-\alpha_m)}{1-\alpha_e-\alpha_s}} \tag{31}$$

What is different is that the exponent of γ_q has an additional term, corresponding to $\frac{\varphi_e \alpha_m/(1-\alpha_m)}{1-\alpha_e-\alpha_s}$ or, if $\alpha_m \approx 0.5$, then this is $\frac{\varphi_e}{1-\alpha_e-\alpha_s}$. Thus, given price data on γ_q and a

[3] See Cummins and Violante (2002) and Fisher (2006).

growth rate for aggregate value added γ_y, the contribution of ISTC is underestimated when the composition of intermediate goods is not taken into account. Section 4 explores how significant this underestimate might be. Since α_e is small (a typical value is 0.3), even a small value of φ_e may have a large influence on growth accounting computations.

3.2 Distinction of gross output and value-added productivity

The second channel is through the distinction of gross output and value-added productivity indexes in a multi-sector model with intermediate goods. As shown in equation (27) the rate of ISTC in GHK's capital accumulation equation (3) is related to the decline in relative prices in gross output. This, in equilibrium, is linked to the relative productivity indexes for gross output rather than value-added which was used in the two-sector model of GHK (equation 25, p.357). We now derive the real-value added for each sector to illustrate the point. Using the definition of price-index for value-added, $p_i = p_{yi}^{1-\alpha_m} p_m^{\alpha_m}$, and the condition for optimal intermediate use (18), the gross output in sector i is

$$d_i = \frac{p_{yi}}{p_i} \alpha_m^{\beta} A_i^{1/(1-\alpha_m)} k_{ei}^{\alpha_e} k_{si}^{\alpha_s} l_i^{1-\alpha_e-\alpha_s}, \tag{32}$$

so that real value-added in each sector is

$$\begin{aligned} y_i &= z_i k_{ei}^{\alpha_e} k_{si}^{\alpha_s} l_i^{1-\alpha_e-\alpha_s} \\ z_i &= (1-\alpha_m)\, \alpha_m^{\beta/(1-\beta)} A_i^{1/(1-\alpha_m)}. \end{aligned} \tag{33}$$

This establishes the link between the productivity index for value-added (z_i) and for gross output (A_i). An implication of (33) is that there is indeed an isomorphism between the multisector model with intermediate goods, the 2-sector value-added model of GHK, and the 1-sector model developed fully in that paper. However, the productivity growth rate of gross output and the effective productivity growth rate of value added are not the same.

Observation 2 The rate of ISTC is captured by the rate of decline of the relative prices of equipment measured in gross output (not value-added). The correct calibration for a multisector model without intermediate goods requires

$$\frac{\gamma_{z_e}}{\gamma_{z_c}} = \left(\frac{\gamma_{A_e}}{\gamma_{A_c}} \right)^{1/(1-\alpha_m)} = \gamma_q^{1/(1-\alpha_m)}.$$

Therefore, the presence of q in the two-sector model in GHK, their equation (25) on p.357, should be replaced by $q^{1/(1-\alpha_m)}$. To see the potential impact of this mistake, imagine if GHK were to calibrate their two-sector model using the relative price of equipment as measured by Gordon's price series (which is in terms of gross output price). They would have set $\gamma_{z_e}/\gamma_{z_c} = \gamma_q = 1.032$ as given by their equation (25), then attribute the rest of economic growth to the neutral productivity growth γ_{z_c}. Our Observation 2 shows that the correct estimate of the divergence in productivity across sectors is $\gamma_{z_e}/\gamma_{z_c} = 1.032^{1/(1-\alpha_m)}$ which is basically 1.032^2 for $\alpha_m \approx 0.5$. This would imply much smaller growth left to be explained by the neutral productivity growth. In other words, GHK would have understated the quantitative contribution of ISTC to economic growth if they have calibrated their two-sector model. Their quantitative finding that 60% of economic growth can be attributed to ISTC is based on the calibration of their one-sector model, so their growth accounting is not affected by this observation. However, γ_q does not reflect the rate of investment-specific technical change in value-added form: rather, $\gamma_q^{1/(1-\alpha_m)} \approx \gamma_q^2$ does.

The effects of this claim are best seen in terms of growth accounting. The main message is that: to be interpretable as reduced-form models of a world with intermediate goods, value-added multi-sector models need to adjust the mapping between gross output prices and industry productivity by the intermediate goods share.

4 Calibration

We have shown analytically (Observation 1) that the finding of GHK that 60% of economic growth can be attributed ISTC understates the contribution of ISTC due to the role of equipment as an intermediate good. We now establish our claim quantitatively using data on the share of intermediate goods in gross output (α_m) and the share of equipment in intermediate goods (φ_e).

4.1 The GHK calibration

To calibrate the one-sector formulation of the model, we follow the same procedure as GHK, using the same values of parameters as theirs. The interested reader may refer to their paper for details.

Parameter	α_e	α_s	α_m	φ_e	γ_q	g	τ_k	τ_l	δ_e	δ_s
Value	0.17	0.13	0.5	0.10	1.032	1.0124	0.42	0.40	0.056	0.124

Table 1 – Parameters used in calibration. Sources: Greenwood et al (1997) and the US Bureau of Economic Analysis.

In addition to the parameters reported in GHK, we require values for α_m and φ_e. We construct these from the Input-Output tables reported by the US Bureau of Economic Analysis.[4] Figure 1 shows that the intermediate share of gross output is close to one half, consistent with the values reported in Yamano and Ahmad (2006), Vourvachaki (2007), Jones (2008) and others. Hence, we set $\alpha_m = 0.50$. As for φ_e, Figure 2 shows that the equipment share of intermediate goods averages around 10%,[5] and we set $\varphi_e = 0.10$.

If $\varphi_e = 0$, ISTC accounts for about 60% of economic growth, as in GHK. However, if $\varphi_e = 10\%$, as suggested by the data, the contribution of ISTC to growth rises to 93%. An equipment share of intermediates as low as 12% is enough for ISTC to account for the entirety of post-war US economic growth. See Figure 3.

4.2 Sensitivity

There is some controversy regarding the appropriate measure of q. GHK use the quality adjusted price of capital, based on the work of Gordon (1990), relative to the official deflator for consumption and services, and find that $\gamma_q = 1.032$. Using a similar method Cummins and Violante (2002) find that $\gamma_q = 1.04$, and we will examine this value. Finally, Whelan (2002) argues that Gordon (1990) and GHK overestimate q, as they assume no quality improvements in consumption and services. Hence, we also repeat the exercise using official price indices. According to official price data, $\gamma_q = 1.008$.

[4] We use the Benchmark I-O tables from 1947-1997. These are generally reported every 5 years, except that there are no tables for 1952-53. After 1997 we use annual I-O tables. While there was a major revision of the methodology for constructing IO tables in 1997 (mainly concerning the treatment of auxiliary services), the BEA also reports tables using the methodology before revisions, and these were the tables we used.

[5] Gordon (1990), and hence GHK, does not consider software as equipment. Hence, our value of φ_e was derived without considering software as part of equipment. Our value of φ_e is thus a lower bound and, in this sense, our results are conservative. Cummins and Violante (2002) do consider software as part of equipment and, although there are other differences between their method and GHK, they find a higher value of γ_q.

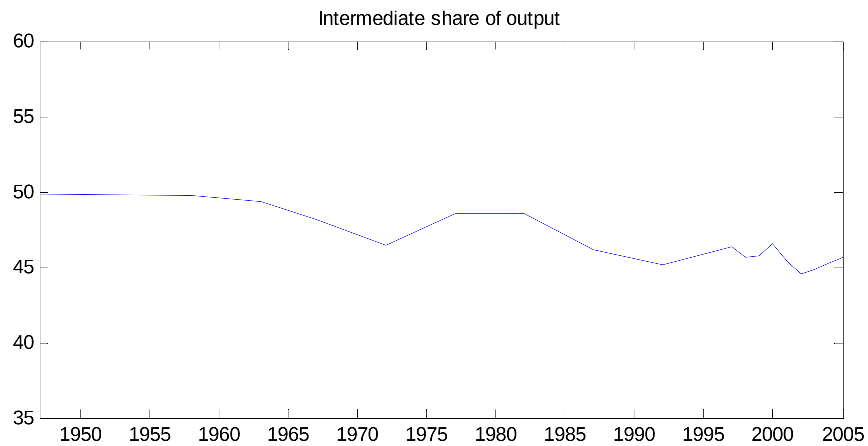

Figure 1: Share of intermediate goods in gross output. Source: US Bureau of Economic Analysis.

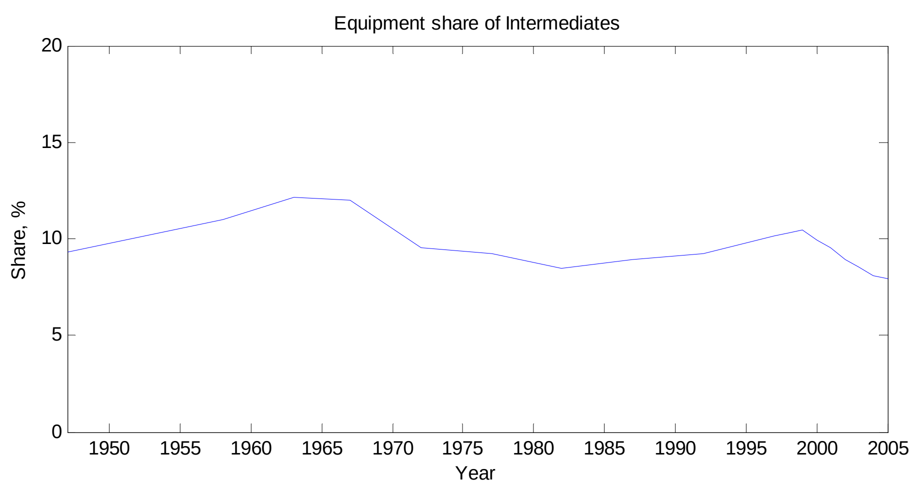

Figure 2: Share of intermediate goods that is composed of by equipment. Source: US Bureau of Economic Analysis.

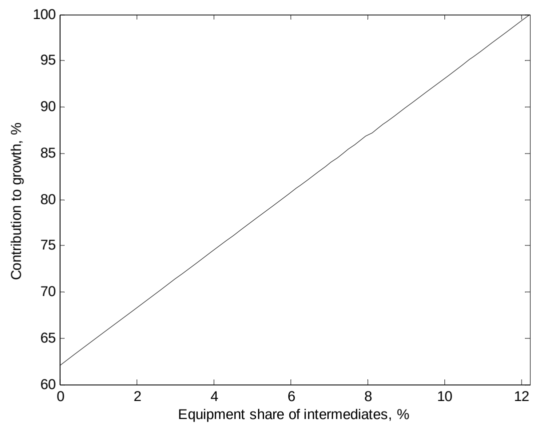

Figure 3: Contribution of ISTC go growth, for the GHK calibration and different values of φ_e.

For these alternative calibrations, we again use the same values of parameters as GHK – provided they do not hinge on the value of γ_q. In particular, the value of α_e and of the capital tax rate τ_k depend on γ_q – and this parameter is crucial for the growth accounting exercise in GHK. Figure 4 shows the dependence of α_e and τ_k on the choice of γ_q: however, the differences are very small. Thus, the calibrated parameters turn out not to be too sensitive to the choice of γ_q, and a calibration with a wide range of values of γ_q is consistent with essentially the same parameters as those used by GHK. Figure 4 also shows the sensitivity of the contribution of ISTC to economic growth to the assumed value of γ_q – varying from about 16% for official price data to almost 80% for the values in Cummins and Violante (2002), even assuming that $\varphi_e = 0$.

Results from varying φ_e are reported in Table 2. For these alternative values of γ_q, we find that raising φ_e from zero to 10% amplifies the contribution of ISTC to growth by over 50%. Thus, in a calibration in which γ_q is low, this amplification will not be too large in absolute terms, as the ISTC channel for growth is weak to begin with. On the other hand, if γ_q is high as suggested by GHK and CV, the amplification has a significant impact on growth accounting.

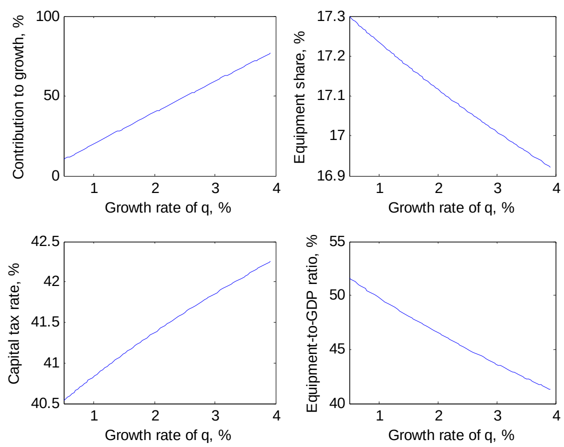

Figure 4: Calibration of the one-sector model. The contribution to growth of ISTC assumes that $\varphi_e = 0$.

		Contribution of ISTC to growth		
γ_q	Source	$\varphi_e = 0$	$\varphi_e = 0.10$	Increase
1.008	Bureau of Economic Analysis	16%	24%	49%
1.032	Greenwood et al (1997)	62%	93%	50%
1.04	Cummins and Violante (2002)	77%	119%	50%

Table 2 – Contribution of ISTC to growth, for different values of γ_q. The table also reports the relative increase in this contribution when φ_e is raised from 0 to 10%.

Table 3 displays the impact on the computed rate of ISTC for each of these calibrations, varying the intermediate share α_m from zero to 50%. As can be seen, the intermediate share has a substantial impact on the rate of ISTC in value-added form (the growth rate of z_e/z_c) implied by a given growth rate of relative output prices (the growth rate of A_e/A_c).

		Rate of ISTC	in value-added form
γ_q	Source	$\alpha_m = 0$	$\alpha_m = 0.5$
1.008	Bureau of Economic Analysis	0.8%	1.6%
1.032	Greenwood et al (1997)	3.2%	6.5%
1.04	Cummins and Violante (2002)	4.0%	8.2%

Table 3 – Rate of ISTC, for different values of γ_q and α_m.

In the model of GHK, this turns out not to have an impact on the growth accounting exercise. However, there are contexts in which the growth rate of itself matters. For example, in the multisector value-added model of Ngai and Pissarides (2008), rates of structural change depend upon the differences in sector-specific TFP growth (in value-added). Hence, a calibration of that model considering the appropriate mapping between a multisector value added model and gross output prices would imply a larger difference in sector-specific TFP growth – which would strenghten the ability of the model to account for structural change in the data.

5 Conclusion

We have argued that research mapping relative prices into rates of technical change needs to be sensitive to the distinction between gross-output and value added. We argue there are two channels why it matters. First, when rates of technical change differ across sectors, those sectors that experienced faster technical change can contribute to economic growth by being used as intermediate goods. Second, the prices reported in the national income and product accounts and elsewhere are generally reported in terms of gross output. However, macroeconomic models are usually formulated in terms of value added. While there exists a simple isomorphism between models with and without intermediate goods under certain assumptions, the use of gross-output *prices* to impute TFP growth rates in value added models does need to account for the share of intermediate goods in gross output.

We demonstrated this using the example of GHK, a widely-cited paper that attributes a significant proportion of aggregate growth to investment-specific technical change. When our suggested mapping is used, we find that GHK in fact *underestimate* the contribution of ISTC to economic growth. More generally, neglecting the value added-gross output distinction underestimates the divergence of industry TFP growth rates in value added multisector models. In multi-sector models in which cross-industry resource reallocation is important, this could have a significant influence on quantitative results regarding structural change and policy, among other applications.

6 Bibliography

Cummins, Jason and Violante, Giovanni. "Investment-Specific Technical Change in the US (1947-2000): Measurement and Macroeconomic Consequences." Review of Economic Dynamics 5(2) (2002) 243-284.

Fisher, Jonas D. M. 2006. "The Dynamic Effects of Neutral and Investment-Specific Technology Shocks," Journal of Political Economy 114(3), 413-451.

Gordon, Robert J. 1990. The Measurement of Durable Goods Prices. University of Chicago Press, Chicago.

Greenwood, Jeremy, Hercowitz, Zvi and Krusell, Per. "Long-Run Implications of Investment-Specific Technological Change", American Economic Review, 87 (3) (1997) 342-62.

Hornstein, Andreas and Per Krusell. 1996. "Can Technology Improvements Cause Productivity Slowdowns? " NBER Macroeconomic Annual, Vol 11. pp. 209-259.

Hulten, Charles R. Growth Accounting with Intermediate Inputs. Review of Economic Studies, 45(3), 511-518.

Hulten, Charles R. Growth Accounting when Technical Change is Embodied in Capital", American Economic Review, 82 (4) (1992) 964-80.

Jones, Charles. 2008. Intermediate Goods Weak Links, and Superstars: A Theory of Economic Development. Mimeo: University of California – Berkeley.

Kongsamut, Piyabha, Serigio Rebelo and Danyang Xie. 2001. Beyond Balanced Growth. Review of Economic Studies 68(4), 869-82.

Ngai, L. Rachel and Christopher A. Pissarides. 2007. Structural Change in a Multisector Model of Growth. American Economic Review 97.

Ngai, L. Rachel and Christopher A. Pissarides. 2008. Trends in Hours and Economic Growth, Review of Economic Dynamics 11, 239-256.

Vourvachaki, Evangelia. 2007. "Multi-Sector Growth: The Role of Information and Communication Technologies and Other Intermediates in Recent Growth Experiences", LSE PhD Thesis.

Yamano, Norihiko and Nadim Ahmad. 2006. The OECD Input-Output Database: 2006 Edition. OECD Science, Technology and Industry Working Papers 2006/8, OECD Directorate for Science, Technology and Industry.

CENTRE FOR ECONOMIC PERFORMANCE
Recent Discussion Papers

868	L. Rachel Ngai Roberto M. Samaniego	Mapping Prices into Productivity in Multisector Growth Models
867	Alex Bryson Harald Dale-Olsen	A Tale of Two Countries: Unions, Closures and Growth in Britain and Norway
866	Arunish Chawla	Multinational Firms, Monopolistic Competition and Foreign Investment Uncertainty
865	Niko Matouschek Paolo Ramezzana Frédéric Robert-Nicoud	Labor Market Reforms, Job Instability, and the Flexibility of the Employment Relationship
864	David G. Blanchflower Alex Bryson	Union Decline in Britain
863	Francesco Giavazzi Michael McMahon	Policy Uncertainty and Precautionary Savings
862	Stephen Hansen Michael F. McMahon	Delayed Doves: MPC Voting Behaviour of Externals
861	Alex Bryson Satu Nurmi	Private Sector Employment Growth, 1998-2004: A Panel Analysis of British Workplaces
860	Alejandro Cuñat Szabolks Deak Marco Maffezzoli	Tax Cuts in Open Economies
859	Bernd Fitzenberger Karsten Kohn Alexander Lembcke	Union Density and Varieties of Coverage: The Anatomy of Union Wage Effects in Germany
858	Dimitra Petropoulou	International Trade, Minimum Quality Standards and the Prisoners' Dilemma
857	Andreas Georgiadis	Efficiency Wages and the Economic Effects of the Minimum Wage: Evidence from a Low-Wage Labour Market
856	L. Rachel Ngai Christopher A. Pissarides	Employment Outcomes in the Welfare State
855	Carlo Rosa	Talking Less and Moving the Market More: Is this the Recipe for Monetary Policy Effectiveness? Evidence from the ECB and the Fed
854	Dimitra Petropoulou	Competing for Contacts: Network Competition, Trade Intermediation and Fragmented Duopoly

853	Barbara Petrongolo Christopher A Pissarides	The Ins and Outs of European Unemployment
852	Mirko Draca Steve Machin Robert Witt	Panic on the Streets of London: Police, Crime and the July 2005 Terror Attacks
851	Augustin de Coulon Jonathan Wadsworth	On the Relative Gains to Immigration: A Comparison of the Labour Market Position of Indians in the USA, the UK and India
850	Andreas Georgiadis	HRM Practices and Knowledge Processes Outcomes: Empirical Evidence from a Quasi-Experiment on UK SMEs in the Tourism Hospitality and Leisure Sector
849	Mirabelle Muûls Dimitra Petropoulou	A Swing-State Theory of Trade Protection in the Electoral College
848	Dimitra Petropoulou	Information Costs, Networks and Intermediation in International Trade
847	Bernardo Guimaraes	Optimal External Debt and Default
846	Javier Ortega Laurence Rioux	On the Extent of Re-Entitlement Effects in Unemployment Compensation
845	Richard E. Baldwin Frédéric Robert-Nicoud	A Simple Model of the Juggernaut Effect of Trade Liberalisation
844	Richard B. Freeman	Labor Market Institutions Around the World
843	Emma Hall Carol Propper John Van Reenen	Can Pay Regulation Kill? Panel Data Evidence on the Effect of Labor Markets on Hospital Performance
842	Fabrice Defever Farid Toubal	Productivity and the Sourcing Modes of Multinational Firms: Evidence from French Firm-Level Data
841	Barbara Petrongolo	What are the Long-Term Effects of UI? Evidence from the UK JSA Reform
840	Kevin D. Sheedy	Robustly Optimal Monetary Policy
839	Christopher A. Pissarides	The Unemployment Volatility Puzzle: Is Wage Stickiness the Answer?
838	Kevin D. Sheedy	Inflation Persistence when Price Stickiness Differs between Industries

The Centre for Economic Performance Publications Unit
Tel 020 7955 7673 Fax 020 7955 7595 Email info@cep.lse.ac.uk
Web site http://cep.lse.ac.uk