International-price and terms-of-trade effects on factor productivity: international comparisons

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Abstract

In this paper, we present, a technique to decompose factor prices into the contribution of major determinants, namely changes in domestic and international prices, changes in capital and labour quantities, and technological progress. This is done in an open-economy framework. While building on the same principles as GDP growth accounting, our technique considers the specific form of factor demand functions when these are derived from a GDP Translog function. We also break down the combined effect of changes in export and import (i.e. international) prices into a pure terms-of-trade effect and a residual international-price effect. This distinction is important, and is illustrated by the fact that an equiproportional change in international prices, while not affecting terms of trade, can trigger changes in factor productivity and therefore impact on workers' and capital owners' welfare. Decomposition of movements in factor productivity is implemented empirically using data from ten OECD countries.

1 Introduction

An important empirical and theoretical literature has been developped to investigate the link between international prices and technological progress on labour and capital productivity. Some of this research, based on GDP functions, has focused on the *potential* impact of a variety of variables on movements in factor productivity, but has neglected measurements of their actual impact. This paper aims to fill this gap. This is done by developing, in a GDP-function context, a technique to decompose factor prices into the contribution of major determinants, namely changes in domestic and international prices, changes in capital and labour quantities, and technological progress. While building on the same principles as GDP growth accounting, our technique considers the specific form of factor demand functions when these are derived from a GDP translog function. More precisely, given that the (inverse) input-demand functions derived from a translog GDP function do not have the translog form, the direct transposition of Diewert and Morrison's (1986) and Kohli's (1990) growth accounting technique to changes in factor prices does not result in their complete decomposition. We show that a complete decomposition can, however, be obtained by slightly modifying Diewert's technique, provided that the parameters of the translog GDP function are known.

We also consider Kohli's (2004) recent suggestion to break down the combined effect of changes in export and import (i.e. international) prices into a pure terms-of-trade effect and a residual international-price effect (the equivalent of Kohli's balance-of-trade effect). This distinction is important, and is illustrated by the fact that an equiproportional change in international prices (due to exchange-rate movements, for instance), while not affecting terms of trade, can trigger changes in factor productivity. Put otherwise, when changes in international prices occur, their impact can be decomposed into a pure terms-of-trade effect, and an effect capturing the imbalance between the elasticity of factor reward with respect to import prices and with respect to export prices.

The paper is structured as follows. Section 2 introduces the principles underpinning the technique to decompose factor productivity growth. This will hinge on the use of indexes, which capture the contribution of a given determinant to productivity movements. Alternative approaches are presented in Section 3. Section 4 introduces the economic model in which contribution indexes will be implemented: the GDP-function model. Section 5 applies the decomposition technique to factor productivity when this is derived from a Translog GDP function. Section 6 constructs indexes capturing the effect of movements in international prices and in the terms of trade. Section 7 describes briefly data construction and the econometric method adopted. Contribution indexes are calculated for 10 countries and discussed in Section 8. Section 9 concludes.

2 Decomposition of productivity growth: the principle

This section presents the basic idea of decomposing period-to-period changes in factor (marginal) product into the contributions of a set of determinants.[1]

Consider the following twice continuously differentiable aggregate production function:

$$y_t = y(x_{L,t}, x_{K,t}),$$

where $x_{L,t}$ is the quantity of labour, $x_{K,t}$ is the capital stock and y_t is output. Subscript t denotes time.

It is well known that marginal product of factor j, which will be denoted v_j, can be obtained through differentiation of the production function. Hence we have:

$$v_{j,t} = v_j(x_{L,t}, x_{K,t}) = \frac{\partial y(x_{L,t}, x_{K,t})}{\partial x_{j,t}}.$$

Let us assume that, between time 0 and time 1, labour endowment changes from $x_{L,0}$ to $x_{L,1}$ and that capital stock grows from $x_{K,0}$ to $x_{K,1}$. The resulting change in output and in capital productivity can be illustrated as in Figure 1, where output is represented as a function of x_K for a given level of x_L.

The change in capital productivity can be captured by the following

[1]For illustrative purpose, we will focus on two production factors: capital and labour.

index:[2]

$$I \equiv \frac{v_{K,1}}{v_{K,0}} = \frac{v_K(x_{L,1}, x_{K,1})}{v_K(x_{L,0}, x_{K,0})} = \frac{\text{slope of tangent at B}}{\text{slope of tangent at A}}.$$

Naturally, movement from A to B can be decomposed in two effects: a labour-quantity effect and a capital-quantity effect. These two contributions can be assessed using various approaches. One method is, first, to assess the labour-quantity effect by determining what the change in capital productivity would have been, had only labour endowment increased between time 0 and time 1 (changes in the slope of tangent from A to C) and, second, to determine the impact of growth in capital stock on productivity, given labour quantity at time 1 (movement from C to B). This decomposition follows path ACB and the corresponding factor-quantity effects can be calculated as:

$$\text{labour-quantity effect} \quad : \quad I_L^{ACB} = \frac{\text{slope of tangent at C}}{\text{slope of tangent at A}} = \frac{v(x_{L,1}, x_{K,0})}{v(x_{L,0}, x_{K,0})} \text{ and}$$

$$\text{capital-quantity effect} \quad : \quad I_K^{ACB} = \frac{\text{slope of tangent at B}}{\text{slope of tangent at C}} = \frac{v(x_{L,1}, x_{K,1})}{v(x_{L,1}, x_{K,0})}.$$

where the superscript indicates the path followed.

It can be easily shown that the product of the two contribution indexes equals the capital-productivity adjustment index I:

$$I = I_K^{ACB} I_L^{ACB}.$$

Alternatively, one can assume that the capital-quantity effect is the impact of change in capital stock on capital productivity, given labour quantity at time 0. This is illustrated by the passage from A to D. The labour-quantity effect, represented by the passage from D to B, is assessed by determining the impact of change in labour endowment, given capital stock at time 1. Graphically, the contribution indexes relative to decomposition path ADB are given by:

$$\text{capital-quantity effect} \quad : \quad I_K^{ADB} = \frac{\text{slope at D}}{\text{slope at A}} = \frac{v(x_{L,0}, x_{K,1})}{v(x_{L,0}, x_{K,0})} \text{ and}$$

$$\text{labour-quantity effect} \quad : \quad I_L^{ADB} = \frac{\text{slope at B}}{\text{slope at D}} = \frac{v(x_{L,1}, x_{K,1})}{v(x_{L,0}, x_{K,1})}.$$

[2]For the sake of simplicity, throughout this paper. the time subscripts will be used only when necessary to avoid ambibuity. It will indicated by 0, 1 or t. Indexes always refer to changes between two consecutive periods.

Again, adjustment of capital productivity can be broken down into the product of two contribution indexes:

$$I = I_K^{ADB} I_L^{ADB}.$$

In practice, the values of a given contribution index varies according to the decomposition method chosen. Since there is *a priori* no reason why one would prefer one method over the other, it is tempting to compute an average – or, more precisely, a geometric average – of each contribution index. Thus one gets:

$$\text{capital-quantity effect} : I_K = \sqrt{I_K^{ACB} I_K^{ADB}} = \sqrt{\frac{v(x_{L,1}, x_{K,1})}{v(x_{L,1}, x_{K,0})} \frac{v(x_{L,0}, x_{K,1})}{v(x_{L,0}, x_{K,0})}} \text{ and}$$

$$\text{labour-quantity effect} : I_L = \sqrt{I_L^{ACB} I_L^{ADB}} = \sqrt{\frac{v(x_{L,1}, x_{K,0})}{v(x_{L,0}, x_{K,0})} \frac{v(x_{L,1}, x_{K,1})}{v(x_{L,0}, x_{K,1})}}.$$

Interestingly, I_K is made up of two indexes: index I_K^{ADB}, which measures the capital-quantity effect given labour quantity at its *initial* level $(x_{L,0})$, and index I_K^{ACB}, measuring the capital-quantity effect given labour quantity at its *final* level $(x_{L,1})$. This is reminiscent of Laspeyres and Paasche indexes, respectively. The same can be said for I_L, index I_L^{ACB} having the Laspeyres form and index I_L^{ADB} having the Paasche form. Since the geometric average of a Laspeyres and a Paasche index yields a Fisher index, the contribution indexes I_K and I_L will be called *Fisher(-like) contribution indexes*. As it is known, Fisher indexes are preferable over Paasche or Laspeyres indexes, in that they take into account substitution occurred between the base period and the current period.

In sum, when output quantity is a function of two inputs and considering only current-period or base-period (and not intermediate) values of x_L and x_K, the number of possible decomposition paths is two. In our example, these are illustrated by sequences ACB and ADB, and provide the necessary material to construct Fisher-contribution indexes for each determinant. It is important to emphasize the fact that, for any arbitrary 2-variable continuous production function, the product of all Fisher-contribution indexes (one for each determinant) gives a *complete* decomposition of total change in factor productivity, that is:

$$I = I_K I_L.$$

Can this procedure be extended to any n-input case? To answer, consider the following 3-input production function:

$$y_t = y(x_{S,t}, x_{U,t}, x_{K,t}),$$

where $x_{S,t}$ is the quantity of skilled labour and $x_{U,t}$ is the quantity of unskilled labour.

Again, productivity of factor j (denoted v_j) is calculated by differentiation of the production function:

$$v_{j,t} = v_j(x_{S,t}, x_{U,t}, x_{K,t}) = \frac{\partial y(x_{S,t}, x_{U,t}, x_{K,t})}{\partial x_{j,t}}.$$

Consider that x_S, x_U and x_K change from $x_{S,0}$, $x_{U,0}$ and $x_{K,0}$ to $x_{S,1}$, $x_{U,1}$ and $x_{K,1}$, respectively, between time 0 and time 1.

Figure 2 illustrates the production function, output and capital productivity for all different combinations of reference values for x_S, x_U and x_K. Slope of tangent at points A and B illustrate capital productivity at time 0 and time 1, respectively. It can be easily shown that total change in capital productivity

$$I = \frac{v_{K,1}}{v_{K,0}} = \frac{v_K(x_{S,1}, x_{U,1}, x_{K,1})}{v_K(x_{S,0}, x_{U,0}, x_{K,0})} = \frac{\text{slope of tangent at B}}{\text{slope of tangent at A}}$$

can be decomposed following $3! = 6$ possible paths: $ACEB$, $ACGB$, $ADEB$, $AFGB$, $ADHB$ and $AFHB$. Each of these provide a measure of the contribution of each determinant to total change in capital productivity. For instance, the contribution indexes making up path $ADHB$ are:

$$\begin{aligned}
\text{unskilled–labour-quantity effect} \quad &: \quad I_U^{ADHB} = \frac{\text{slope of tangent at D}}{\text{slope of tangent at A}} = \frac{v(x_{S,0}, x_{U,1}, x_{K,0})}{v(x_{S,0}, x_{U,0}, x_{K,0})}, \\
\text{capital-quantity effect} \quad &: \quad I_K^{ADHB} = \frac{\text{slope of tangent at H}}{\text{slope of tangent at D}} = \frac{v(x_{S,0}, x_{U,1}, x_{K,1})}{v(x_{S,0}, x_{U,1}, x_{K,0})} \text{ and} \\
\text{skilled–labour-quantity effect} \quad &: \quad I_S^{ADHB} = \frac{\text{slope of tangent at B}}{\text{slope of tangent at H}} = \frac{v(x_{S,1}, x_{U,1}, x_{K,1})}{v(x_{S,0}, x_{U,1}, x_{K,1})}.
\end{aligned}$$

For each determinant explaining changes in capital productivity, a general contribution index can be computed as a geometric average of the corresponding single-path indexes:

$$\begin{aligned}
I_S &= (I_S^{ACEB} I_S^{ACGB} \mathrm{I}_S^{ADEB} \mathrm{I}_S^{AFGB} I_S^{ADHB} I_S^{AFHB})^{1/6}, \\
I_U &= (I_U^{ACEB} I_U^{ACGB} I_U^{ADEB} I_U^{AFGB} I_U^{ADHB} I_U^{AFHB})^{1/6}, \\
I_K &= (I_K^{ACEB} I_K^{ACGB} I_K^{ADEB} I_K^{AFGB} I_K^{ADHB} I_K^{AFHB})^{1/6}.
\end{aligned}$$

Clearly, the product of general contribution indexes equals (1 plus) the productivity change rate:

$$I = I_S I_U I_K.$$

It is interesting to note that indexes I_S, I_U and I_K are more general than Fisher-like indexes, in that they comprise "hybrid" elements. Index I_S, for instance, is calculated as:

$$\begin{aligned} I_S &= \left(\frac{v(x_{S,1},x_{U,0},x_{K,0})}{v(x_{S,0},x_{U,0},x_{K,0})}\frac{v(x_{S,1},x_{U,0},x_{K,0})}{v(x_{S,0},x_{U,0},x_{K,0})}\frac{v(x_{S,1},x_{U,1},x_{K,0})}{v(x_{S,0},x_{U,1},x_{K,0})}\times \right. \\ &\left. \frac{v(x_{S,1},x_{U,0},x_{K,1})}{v(x_{S,0},x_{U,0},x_{K,1})}\frac{v(x_{S,1},x_{U,1},x_{K,1})}{v(x_{S,0},x_{U,1},x_{K,1})}\frac{v(x_{S,1},x_{U,1},x_{K,1})}{v(x_{S,0},x_{U,1},x_{K,1})}\right)^{1/6} \\ &= \left(\frac{v(x_{S,1},x_{U,0},x_{K,0})}{v(x_{S,0},x_{U,0},x_{K,0})}\frac{v(x_{S,1},x_{U,1},x_{K,1})}{v(x_{S,0},x_{U,1},x_{K,1})}\right)^{1/3} \times \\ &\left(\frac{v(x_{S,1},x_{U,1},x_{K,0})}{v(x_{S,0},x_{U,1},x_{K,0})}\frac{v(x_{S,1},x_{U,0},x_{K,1})}{v(x_{S,0},x_{U,0},x_{K,1})}\right)^{1/6} \end{aligned}$$

which includes not only the Fisher-like component $\left(\frac{v(x_{S,1},x_{U,0},x_{K,0})}{v(x_{S,0},x_{U,0},x_{K,0})}\frac{v(x_{S,1},x_{U,1},x_{K,1})}{v(x_{S,0},x_{U,1},x_{K,1})}\right)^{1/3}$, but also $\frac{v(x_{S,1},x_{U,1},x_{K,0})}{v(x_{S,0},x_{U,1},x_{K,0})}$ and $\frac{v(x_{S,1},x_{U,0},x_{K,1})}{v(x_{S,0},x_{U,0},x_{K,1})}$, which clearly have neither the Paasche nor the Laspeyres form. Since indexes I_S, I_U and I_K are more flexible than a Fisher-like contribution index, they will be referred to as *flexi*-Fisher contribution indexes.[3]

This method can be extended to any n-variable case. However, the number of decomposition paths to identify is equal to $n!$, making this decomposition technique difficult to handle and time consuming when the number of explanatory variables is high. This raises interest for the use of alternative approaches, which will be summarized in the next section.

3 Decomposition of productivity growth: alternative approaches

The previous section introduced a general technique to decompose changes in factor productivity into a set of partial contributions. One of its main

[3] Alternative names are welcome!

advantages consists in its general applicability: the implementation of flexi-Fisher indexes is not restricted to a particular functional form. Moreover, given that it takes into account reference values both at time 0 and time 1, it corrects for biases caused by the selection of only one reference period.

As has been pointed out, however, flexi-Fisher indexes require numerous calculations in the presence of a high number of inputs. To overcome this drawback, one might be willing to forego one of their advantages. For instance, instead of working with the whole set of decomposition paths, it is possible to consider only a subset of it. In this case, if the volatility of the explanatory variables is low, the values of the resulting contribution indexes are likely to be close to those obtained using flexi-Fisher indexes.

Alternatively,[4] one can compute "pure" Fisher-like indexes (and not flexi-Fisher indexes). Referring to the 3-input example presented in the previous section, these are obtained as (an apostrophe stands for "pure" Fisher-like indexes):

$$\begin{aligned}
I'_S &= \left(\frac{v(x_{S,1}, x_{U,0}, x_{K,0})}{v(x_{S,0}, x_{U,0}, x_{K,0})}\frac{v(x_{S,1}, x_{U,1}, x_{K,1})}{v(x_{S,0}, x_{U,1}, x_{K,1})}\right)^{1/2}, \\
I'_U &= \left(\frac{v(x_{S,0}, x_{U,1}, x_{K,0})}{v(x_{S,0}, x_{U,0}, x_{K,0})}\frac{v(x_{S,1}, x_{U,1}, x_{K,1})}{v(x_{S,1}, x_{U,0}, x_{K,1})}\right)^{1/2}, \\
I'_K &= \left(\frac{v(x_{S,0}, x_{U,0}, x_{K,1})}{v(x_{S,0}, x_{U,0}, x_{K,0})}\frac{v(x_{S,1}, x_{U,1}, x_{K,1})}{v(x_{S,1}, x_{U,1}, x_{K,0})}\right)^{1/2}.
\end{aligned}$$

Their product is generally close but *not* equal to productivity change index I. Therefore, in order to get a complete decomposition of I, one needs to make use of an implicit index: it can be assumed, for example, that whatever is not explained by changes in x_S and x_U is attributed to x_K. This yields the following implicit capital-quantity contribution index $\widetilde{I}'_K$:

$$\widetilde{I}'_K = \frac{I}{I'_S I'_U},$$

the value of which will thus differs from I_K. The downside of this approach is that it does not apply a uniform treatment to all determinants.

Finally, it is also possible to decompose I using elasticities. For the sake of illustration, let us refer again to our 3-input example. Starting from total

[4] What follows is presented in more detail in Sfreddo (2001).

differential:

$$dv_K = \frac{\partial v_S(.)}{\partial x_S} dx_S + \frac{\partial v_U(.)}{\partial x_U} dx_U \frac{\partial v_K(.)}{\partial x_K} dx_K \tag{1}$$

one gets:

$$d \ln v_K = \varepsilon_{KS} d \ln x_S + \varepsilon_{KU} d \ln x_U + \varepsilon_{KK} d \ln x_K, \tag{2}$$

where $\varepsilon_{Ki} = \partial \ln v_K / \partial \ln x_i$ are elasticities. When applied to changes occurred between time 0 and time 1, the following discrete-time version of equation (2) can be used:

$$\Delta \ln v_K \cong \tfrac{1}{2}(\varepsilon_{KS,0}+\varepsilon_{KS,1})\Delta \ln x_S+\tfrac{1}{2}(\varepsilon_{KU,0}+\varepsilon_{KU,1})\Delta \ln x_U+\tfrac{1}{2}(\varepsilon_{KK,0}+\varepsilon_{KK,1})\Delta \ln x_K,$$

or

$$\frac{v_{K,1}}{v_{K,0}} \cong \left(\frac{x_{S,1}}{x_{S,0}}\right)^{\frac{1}{2}(\varepsilon_{KS,0}+\varepsilon_{KS,1})} \left(\frac{x_{U,1}}{x_{U,0}}\right)^{\frac{1}{2}(\varepsilon_{KU,0}+\varepsilon_{KU,1})} \left(\frac{x_{K,1}}{x_{K,0}}\right)^{\frac{1}{2}(\varepsilon_{KK,0}+\varepsilon_{KK,1})}, \tag{3}$$

where $\Delta \ln h = \ln h_1 - \ln h_0 = \ln(h_1/h_0)$ and use is made of elasticities at time 0 and time 1 ($\varepsilon_{Ki,0}$ and $\varepsilon_{Ki,1}$) to take account of input substitution. Expression (3) is made up of three components, each capturing the influence of a given input. Expression (3) can thus be rewritten as:

$$I \cong \overline{I}_S \overline{I}_U \overline{I}_K, \tag{4}$$

with

$$\begin{aligned} \overline{I}_S &\equiv \left(\frac{x_{S,1}}{x_{S,0}}\right)^{\frac{1}{2}(\varepsilon_{KS,0}+\varepsilon_{KS,1})} \\ \overline{I}_U &\equiv \left(\frac{x_{U,1}}{x_{U,0}}\right)^{\frac{1}{2}(\varepsilon_{KU,0}+\varepsilon_{KU,1})} \\ \overline{I}_K &\equiv \left(\frac{x_{K,1}}{x_{K,0}}\right)^{\frac{1}{2}(\varepsilon_{KK,0}+\varepsilon_{KKS,1})}, \end{aligned}$$

where $\overline{I}_S$,$\overline{I}_S$ and $\overline{I}_K$ are *elasticity-based* contribution indexes. Again, this technique, while being easily implemented, does not usually yield a complete decomposition of I. This calls for the use of an implicit index, for instance:

$$\overline{\tilde{I}}_K = \frac{I}{\overline{I}_S \overline{I}_U},$$

where $\tilde{\tilde{I}}_K$ is the implicit (elasticity-based) capital-quantity contribution index.

It is noteworthy that if the productivity function has the Translog form, flexi-Fisher, Fisher-like and elasticity-based indexes all yield exactly the same numerical value. In this case, no implicit index is therefore needed to get a complete decomposition of I.

4 The framework: a GDP-function model

Having presented the basic principles and technique for productivity decomposition, we will now turn to the construction of the economic model in which contribution indexes will be implemented.

Consider a multi-output, multi-input aggregate production sector of an economy composed of a large number of profit-maximizing firms which exhibit decreasing marginal returns and constant returns to scale and which operate under perfect competition. Denoting T_t the production possibilities set (or the technology) at time t, we can write the aggregate variable profit function:

$$\pi(\mathbf{p}_t, \mathbf{x}_t, t) = \max_y \left[\mathbf{p}_t'\mathbf{y}_t : (\mathbf{y}_t, \mathbf{x}_t) \in T_t\right], \tag{5}$$

where $\mathbf{y}_t \equiv [y_{1,t}, y_{2,t}, ..., y_{N,t}]'$ and $\mathbf{p}_t \equiv [p_{1,t}, p_{2,t}, ..., \mathbf{p}_{N,t}]'$ are the N-dimensional vectors of output quantities and output prices respectively, while $\mathbf{x}_t \equiv [x_{1,t}, x_{2,t}, ..., x_{Z,t}]'$ is the Z-dimensional vector of fixed input quantities at time t. Variable inputs are treated as negative (variable) outputs. Time variable t is added to account for technological progress.

We consider that $\mathbf{p}_t$ (given competition) and $\mathbf{x}_t$ (due to its fixity) are exogenous to the production sector.

On a macroeconomic level, $\mathbf{y}_t$ can be viewed as the quantity vector of the five major components of GDP: private consumption (C), government consumption (G), gross fixed capital formation (I), exports of goods and services (X) and (with negative value) imports of goods and services (M). Intermediate goods and services need not be considered since they net out. In the remainder of this paper, we will aggregate C, I and G into a representative domestic good, that will be denoted D. Similarly, we can view $\mathbf{x}_t$

as the vector of the two main primary fixed inputs, namely capital (K) and labour (L).

We will thus assume that an economy's industries combine imports with the existing labour and capital to produce goods and services for domestic consumption and for export. Imports are therefore viewed as intermediate production goods, rather than final consumption goods. This treatment of imports stems from the evidence that a large share of them consists of raw materials and semi-finished commodities. Even goods imported and sold for final consumption are conditioned, packed and distributed domestically before reaching the final consumer; a non-negligible proportion of their value is therefore of domestic origin.

Expression (5) may be regarded as a GDP-maximizing program given an exogenous stock of capital and labour. In this sense it is a GDP function.[5]

We assume that $\pi(.)$ is twice and continuously differentiable. Due to constant returns to scale, it is linearly homogeneous in $\mathbf{x}_t$ and decreasing marginal returns imply concavity with respect to $\mathbf{x}_t$. Furthermore $\pi(.)$ is convex and linearly homogeneous in $\mathbf{p}_t$.

One of the most appealing features of GDP functions is that, assuming perfect competition in the output markets, one can derive a system of output supply (and variable-input demand) functions by simple differentiation. This property results from the well-known Hotelling's lemma. Omitting the time subscripts for the sake of simplicity, this means:

$$\mathbf{y}(\mathbf{p}, \mathbf{x}, t) = \bigtriangledown_{\mathbf{p}} \pi(\mathbf{p}, \mathbf{x}, t),$$

where $\mathbf{y}(.)$ is the vector of output supply functions and $\bigtriangledown_{\mathbf{p}} \pi(.)$ the gradient vector of $\pi(.)$ with respect to $\mathbf{p}$.

Also, by differentiating function $\pi(.)$ with respect to input quantities, we obtain the following system of input marginal-revenue functions:

$$\mathbf{w}(\mathbf{p}, \mathbf{x}, t) = \bigtriangledown_{\mathbf{x}} \pi(\mathbf{p}, \mathbf{x}, t),$$

where $\mathbf{w}(.)$ is the vector of marginal-revenue functions and $\bigtriangledown_{\mathbf{x}} \pi(.)$ the gradient vector of $\pi(.)$ with respect to $\mathbf{x}$. Because functions $\mathbf{w}(.)$ also express factor marginal product in nominal terms, we will often refer to them as

[5]For an extensive study of GDP functions, see Kohli (1991).

(nominal) factor-productivity functions. Moreover, $\mathbf{w}(.)$ can be also seen as inverse input-demand functions, input-reward functions or input-user-cost functions, given that, assuming factor mobility and competition, primary factors are paid their marginal revenue.[6]

The Translog GDP function is well suited to represent $\pi(\mathbf{p}, \mathbf{x}, t)$.[7] It is as follows:

$$\ln(\pi) = \alpha_0 + \Sigma_i \alpha_i \ln(p_i) + \Sigma_j \beta_j \ln(x_j) + \frac{1}{2}\Sigma_i \Sigma_h \gamma_{ih} \ln(p_i) \ln(p_h) + \Sigma_i \Sigma_j \delta_{ij} \ln(p_i) \ln(x_j) + \frac{1}{2}\Sigma_j \Sigma_k \varphi_{jk} \ln(x_j) \ln(x_k) + \Sigma_i \delta_{it} \ln(p_i) t + \Sigma_j \varphi_{jt} \ln(x_j) t + \beta_t t + \frac{1}{2}\varphi_{tt} t^2, \quad (6)$$

where subscripts i and h refer to outputs and variable inputs $(i, h = D, X, M)$ and subscripts j and k refer to fixed inputs $(j, k = K, L)$.

The following restrictions on the coefficients are imposed:
- $\gamma_{ih} = \gamma_{hi}$ and $\varphi_{jk} = \varphi_{kj}$ (symmetry, implied by Young's theorem);
- $\Sigma_i \alpha_i = 1$, $\Sigma_i \gamma_{ih} = 0$ (and thus $\Sigma_h \gamma_{ih} = 0$), $\Sigma_i \delta_{ij} = 0$, $\Sigma_i \delta_{it} = 0$ given linear homogeneity in output prices;
- $\Sigma_j \beta_j = 1$, $\Sigma_j \varphi_{jk} = 0$ (and thus $\Sigma_k \varphi_{jk} = 0$), $\Sigma_j \delta_{ij} = 0$, $\Sigma_j \varphi_{jt} = 0$ given linear homogeneity in input quantities.

While homogeneity and symmetry are guaranteed, no restrictions on the coefficients can be imposed to *a priori* ensure global concavity in input quantities and global convexity in output prices. The researcher must therefore investigate for possible violations of the curvature conditions by checking the sign-definiteness of $\Sigma_{\mathbf{pp}}$ and $\Sigma_{\mathbf{xx}}$ once the econometric estimation has been performed.

The derived output supply functions are obtained by differentiation, as shown above. Knowing that $y_i = \partial\pi/\partial p_i$ and $\partial \ln(\pi)/\partial \ln(p_i) = (\partial\pi/\partial p)(p_i/\pi)$, applying Hotelling's lemma to a Translog GDP function yields the following output-*share* supply functions:

$$s_i \equiv \frac{p_i y_i}{\pi} = \alpha_i + \Sigma_h \gamma_{ih} \ln(p_h) + \Sigma_j \delta_{ij} \ln(x_j) + \delta_{it} t, \quad (7)$$

[6] In the remainder of this paper, we will therefore use the terms "(nominal) productivity", "(nominal) marginal product", "factor marginal revenue", "factor reward" and "factor cost" interchangeably.

[7] The Translog function was first formally introduced by Christensen et al. in 1973, but it had been used and briefly presented by the same authors in 1971. See Christensen *et al.* (1973).

s_i being the share of output i in GDP (with y_M and s_M being negative)

Similarly, the input-*share* revenue functions are:

$$s_j \equiv \frac{w_j x_j}{\pi} = \beta_j + \Sigma_i \delta_{ij} \ln(p_i) + \Sigma_k \varphi_{jk} \ln(x_k) + \varphi_{jt} t. \tag{8}$$

Finally, output(-*quantity)* supply functions can be easily obtained using (6) and (7):

$$y_i(\mathbf{p}, \mathbf{x}, t) = \frac{s_i(\mathbf{p}, \mathbf{x}, t) \exp\left[\ln \pi(\mathbf{p}, \mathbf{x}, t)\right]}{p_i}. \tag{9}$$

and input(-*unit)* (nominal) productivity functions are computed using (6) and (8):

$$w_j(\mathbf{p}, \mathbf{x}, t) = \frac{s_j(\mathbf{p}, \mathbf{x}, t) \exp\left[\ln \pi(\mathbf{p}, \mathbf{x}, t)\right]}{x_j}. \tag{10}$$

Although we are mainly interested in movements in factor productivity (see expression (10)), the construction of the complete system is needed for the purpose of the econometric estimation.

5 Productivity decomposition in a Translog GDP-function framework

The decomposition of period-to-period changes in of labour and capital (nominal) marginal product is the central issue of this paper. Its principles have been presented in Sections (2) and (3) and will now be implemented in a GDP-function context, that is, applied to function (10). Given the form of the latter, changes in the value of w_j can be *fully* decomposed using flexi-Fisher indexes, but not through "pure" Fisher-like indexes or elasticity-based indexes. However, it will be shown that a complete decomposition can be obtained with elasticity-based indexes when these are appropriately transformed.

The construction of elasticity-based indexes starts from total differentiation of (10):

$$\begin{aligned} dw_j &= \sum_i \frac{\partial w_j(.)}{\partial p_i} dp_i + \sum_k \frac{\partial w_j(.)}{\partial x_k} dx_k + \frac{\partial w_j(.)}{\partial t} t \qquad (11) \\ i &= D, X, M;\ j, k = K, L, \end{aligned}$$

Applying the same transformation as in (1) through (4) to (11) yields the following discrete-time decomposition:

$$\frac{w_{j,1}}{w_{j,0}} \cong \overline{\mathrm{W}}_{jD}\overline{\mathrm{W}}_{jX}\overline{\mathrm{W}}_{jM}\overline{\mathrm{W}}_{jK}\overline{\mathrm{W}}_{jL}\overline{\mathrm{W}}_{jT},$$

where $\overline{\mathrm{W}}_{ji} = (p_{i,1}/p_{i,0})^{\frac{1}{2}(\varepsilon_{ji,0}+\varepsilon_{ji,1})}$, $\overline{\mathrm{W}}_{jk} = (x_{k,1}/x_{k,0})^{\frac{1}{2}(\varepsilon_{jk,0}+\varepsilon_{jk,1})}$ and $\overline{\mathrm{W}}_{jT} = \exp\left[\frac{1}{2}(\varepsilon_{jT,0}+\varepsilon_{jT,1})\right]$ with ε's being elasticities:[8]

$$\begin{aligned}
\varepsilon_{ji} &= \partial \ln w_j/\partial \ln x_i = \delta_{ij}/s_j + s_i \\
\varepsilon_{jk} &= \partial \ln w_j/\partial \ln x_k = \begin{cases} \varphi_{jk}/s_j + s_k, & j \neq k \\ \varphi_{jj}/s_j + s_j - 1, & j = k \end{cases} \\
\varepsilon_{jT} &= \partial \ln w_j/\partial t = \varphi_{jt}/s_j + \left[\Sigma_i \delta_{it}\ln(p_i) + \Sigma_j \varphi_{jt}\ln(x_j) + \beta_t + \varphi_{tt}t\right].
\end{aligned}$$

$\overline{\mathrm{W}}_{ji}, \overline{\mathrm{W}}_{jk}$ and $\overline{\mathrm{W}}_{jT}$ are elasticity-based contribution indexes, which capture the impact of changes in p_i, x_j and time, respectively, on (nominal) marginal product of factor j between the two consecutive periods considered, in this case time 0 and time 1. $\overline{\mathrm{W}}_{jT}$ can be used as a measure of the contribution of technological progress to factor productivity growth.

To modify elasticity-based indexes, let us focus on $\overline{\mathrm{W}}_{ji}$. Its log is calculated as:

$$\begin{aligned}
\ln \overline{\mathrm{W}}_{ji} &= \frac{1}{2}(\varepsilon_{ji,0} + \varepsilon_{ji,1})\ln(p_{i,1}/p_{i,0}) \\
&= \left[\frac{1}{2}\delta_{ij}(1/s_{j,0} + 1/s_{j,1}) + \frac{1}{2}(s_{i,0} + s_{i,1})\right]\ln(p_{i,1}/p_{i,0}) \qquad (12)
\end{aligned}$$

where element $\frac{1}{2}(1/s_{j,0} + 1/s_{j,1})$ can be rewritten as:

$$\begin{aligned}
\frac{1}{2}(1/s_{j,0} + 1/s_{j,1}) &= \frac{1}{2}\left(\frac{s_{j,1}-s_{j,0}}{s_{j,0}}\frac{1}{s_{j,1}-s_{j,0}} + \frac{s_{j,1}-s_{j,0}}{s_{j,1}}\frac{1}{s_{j,1}-s_{j,0}}\right) \\
&= \frac{1}{2}\left(\frac{s_{j,1}-s_{j,0}}{s_{j,0}} + \frac{s_{j,1}-s_{j,0}}{s_{j,1}}\right)\frac{1}{s_{j,1}-s_{j,0}} \qquad (13)
\end{aligned}$$

Recall that $\frac{s_{j,1}-s_{j,0}}{s_{j,0}} \cong \ln(s_{j,1}/s_{j,0})$, but also $\frac{s_{j,1}-s_{j,0}}{s_{j,1}} \cong \ln(s_{j,1}/s_{j,0})$. However, when $s_{j,1} > s_{j,0}$, $\ln(s_{j,1}/s_{j,0})$ tends to underestimate $\frac{s_{j,1}-s_{j,0}}{s_{j,0}}$ and overestimate $\frac{s_{j,1}-s_{j,0}}{s_{j,1}}$ (the reverse is true when $s_{j,1} > s_{j,0}$). Hence the following expression holds as a good approximation:

$$\frac{1}{2}\left(\frac{s_{j,1}-s_{j,0}}{s_{j,0}} + \frac{s_{j,1}-s_{j,0}}{s_{j,1}}\right) \cong \ln(s_{j,1}/s_{j,0}). \qquad (14)$$

[8] See Kohli (1991) or Sfreddo (2001) for details.

Finally, inserting (14) and (13) into (12) yields:

$$\ln \overline{\mathrm{W}}_{ji} \cong \ln \widehat{\mathrm{W}}_{ji} = \left[\delta_{ij}\frac{\ln(s_{j,1}/s_{j,0})}{s_{j,1}-s_{j,0}} + \frac{1}{2}(s_{i,0}+s_{i,1})\right] \ln\left(p_{i,1}/p_{i,0}\right).$$

where $\widehat{\mathrm{W}}_{ji}$ is the modified elasticity-based contribution index.[9] [10]

Similarly,

$$\begin{aligned}
\ln \widehat{\mathrm{W}}_{jk} &= \begin{cases} \left[\varphi_{jk}\frac{\ln(s_{j,1}/s_{j,0})}{s_{j,1}-s_{j,0}} + \frac{1}{2}(s_{k,0}+s_{k,1})\right] \ln\left(x_{j,1}/x_{j,0}\right) & j \neq k \\ \left[\varphi_{jj}\frac{\ln(s_{j,1}/s_{j,0})}{s_{j,1}-s_{j,0}} + \frac{1}{2}(s_{j,0}+s_{j,1}) - 1\right] \ln\left(x_{j,1}/x_{j,0}\right) & j = k \end{cases} \\
\ln \widehat{\mathrm{W}}_{jT,t} &= \varphi_{jt}\frac{\ln(s_{j,t}/s_{j,t-1})}{s_{j,t}-s_{j,t-1}} + \\
&\quad \frac{1}{2}\left[\Sigma_i \delta_{it}(\ln p_{i,0} + \ln p_{i,1}) + \Sigma_j \varphi_{jt}(\ln x_{j,0} + \ln x_{j,1})\right] + \beta_t + \varphi_{tt} t,
\end{aligned}$$

where the modified elasticity-based indexes $\widehat{\mathrm{W}}_{jk}$ and $\widehat{\mathrm{W}}_{jT}$ are approximately equal to $\overline{\mathrm{W}}_{jk}$ and $\overline{\mathrm{W}}_{jT}$, respectively. It can be shown[11] that, when factor productivity is derived from a Translog GDP function, these indexes provide a complete decomposition of (nominal) factor-productivity growth. In our case:

$$\frac{w_{j,1}}{w_{j,0}} = \widehat{\mathrm{W}}_{jD}\widehat{\mathrm{W}}_{jX}\widehat{\mathrm{W}}_{jM}\widehat{\mathrm{W}}_{jK}\widehat{\mathrm{W}}_{jL}\widehat{\mathrm{W}}_{jT}, \tag{15}$$

where the equality holds exactly.

6 International-price effects and terms-of-trade effects

All the decomposition techniques presented so far make it possible to assess the contribution of import or export prices to changes in nominal marginal product, as well as the impact of other determinants, namely domestic prices, capital and labour endowment as well as technological progress. The aggregate effect of two or more determinants can be obtained by multiplying the corresponding indexes. This property allows one to assess the combined

[9] A hat ($\widehat{\ }$) indicates a modified elasticity-based index.

[10] Recall that s_M has a negative value.

[11] Refer to weighted-share indexes in Sfreddo (2001) for proof.

contribution of changes in import and export prices: their impact can be measured using flexi-Fisher indexes ($\mathrm{W}_{jX}\mathrm{W}_{jM}$), "pure" Fisher-like indexes, ($\mathrm{W'}_{jX}\mathrm{W'}_{jM}$), elasticity-based indexes ($\overline{\mathrm{W}}_{jX}\overline{\mathrm{W}}_{jM}$) or their modified form ($\widehat{\mathrm{W}}_{jX}\widehat{\mathrm{W}}_{jM}$).[12] While having different structure, they provide numerical results which differ only slightly, as will be shown in Section 8. (This is hardly surprising given that they all capture the same phenomenon using the same productivity function.)

One might be tempted to interpret the aggregate effect of changes in export and import prices as a terms-of-trade effect. However, we hesitate to do so. The reason is that an equiproportional increase in export and import prices, while leaving the terms of trade unaffected, generally has a non-neutral impact on factor marginal revenue: the impact of a change in export prices is generally not offset by the impact of an equiproportional change in import prices, and this is because usually $\varepsilon_{jX} \neq -\varepsilon_{jM}$. We find it preferable therefore to refer to this combined contribution as "international-price effect". Interestingly, this distinction reveals that the international-price effect does reflect differences in import-price and export-price elasticities, on one hand, and movements in the terms of trade, on the other. Moreover, these components can be identified and measured, and this is what will be done in the following paragraphs.

The terms-of-trade effect can be captured by considering what the net impact of the change in international prices would be if export-price elasticity were set to *minus* import-price elasticity. Alternatively, this effect could be assessed by measuring what the net impact of the change in international prices would be if import-price elasticity were equal to *minus* export-price elasticity. Taking the mean of the two measures and using average elasticities yields the following terms-of-trade effect $\overline{\mathrm{W}}_{jA}$ (in log):[13]

$$\begin{aligned}\ln \overline{\mathrm{W}}_{jA} &= \tfrac{1}{2}\left\{\tfrac{1}{2}\left[-(\varepsilon_{jM,1}+\varepsilon_{jM,0})\right]\ln(p_{X,1}/p_{X,0}) + \tfrac{1}{2}(\varepsilon_{jM,1}+\varepsilon_{jM,0})\ln(p_{M,1}/p_{M,0}) + \right.\\ &\quad \left. \tfrac{1}{2}(\varepsilon_{jX,1}+\varepsilon_{jX,0})\ln(p_{X,1}/p_{X,0}) + \tfrac{1}{2}\left[-(\varepsilon_{jX,1}+\varepsilon_{jX,0})\right]\ln(p_{M,1}/p_{M,0})\right\}\\ \ln \overline{\mathrm{W}}_{jA} &= \tfrac{1}{4}\left[(\varepsilon_{jX,1}+\varepsilon_{jX,0}) - (\varepsilon_{jM,1}+\varepsilon_{jM,0})\right]\ln\left(\frac{p_{X,1}/p_{M,1}}{p_{X,0}/p_{M,0}}\right). \qquad (16)\end{aligned}$$

[12] As noted above, indexes bearing no special sign have the to flexi-Fisher form, and those with an apostrophe refer to "pure" Fisher-like indexes. They can be constructed following the principles presented in Sections 2 and 3.

[13] Again, we use an upper bar ( ) to indicate that we adopt the approach based on elasticities.

Expression (16) implies that, in the absence of changes in the terms of trade, the terms-of-trade effect is neutral.

Deflating the international-price effect by the terms-of-trade contribution yields the elasticity-imbalance effect $\overline{\mathrm{W}}_{jB}$:

$$\overline{\mathrm{W}}_{jB} = \frac{\overline{\mathrm{W}}_{jX}\overline{\mathrm{W}}_{jM}}{\overline{\mathrm{W}}_{jA}}$$

or, in log:

$$\ln \overline{\mathrm{W}}_{jB} = \ln \overline{\mathrm{W}}_{jX} + \ln \overline{\mathrm{W}}_{jX} - \ln \overline{\mathrm{W}}_{jA}. \tag{17}$$

Recalling that $\overline{\mathrm{W}}_{ji} = (p_{i,1}/p_{i,0})^{\frac{1}{2}(\varepsilon_{ji,0}+\varepsilon_{ji,1})}$, $i = X, M$, it can be easily shown that the elasticity-imbalance effect (17) is (in log):

$$\ln \overline{\mathrm{W}}_{jB} = \tfrac{1}{4}\left[(\varepsilon_{jX,1} + \varepsilon_{jX,0}) + (\varepsilon_{jM,1} + \varepsilon_{jM,0})\right] \ln \left(\frac{p_{X,1}}{p_{X,0}}\frac{p_{M,1}}{p_{M,0}}\right). \tag{18}$$

Let us turn our attention to element $(\varepsilon_{jX,1} + \varepsilon_{jX,0}) + (\varepsilon_{jM,1} + \varepsilon_{jM,0})$ in expression (18). We have claimed that an equiproportional change in export and import prices has no impact on nominal productivity only if $\varepsilon_{jX} = -\varepsilon_{jM}$. It is therefore the difference between the right-hand and the left-hand side of the latter expression, i.e. $\varepsilon_{jX} - (-\varepsilon_{jM})$ or $\varepsilon_{jX} + \varepsilon_{jM}$, that captures the imbalance in elasticities. This is indeed what is measured by $\frac{1}{2}\left[(\varepsilon_{jX,1} + \varepsilon_{jX,0}) + (\varepsilon_{jM,1} + \varepsilon_{jM,0})\right]$.

Indexes $\overline{\mathrm{W}}_{jA}$ and $\overline{\mathrm{W}}_{jB}$ can be easily transformed into modified elasticity-based indexes $\widehat{\mathrm{W}}_{jA}$ and $\widehat{\mathrm{W}}_{jB}$, respectively, following the approach presented in Section 5. This yields:

$$\ln \widehat{\mathrm{W}}_{jA} = \frac{1}{2}\left[(\delta_{Xj} - \delta_{Mj})\frac{\ln(s_{j,1}/s_{j,0})}{s_{j,1} - s_{j,0}} + \frac{1}{2}(s_{X,0} + s_{X,1} - s_{M,0} - s_{M,1})\right] \ln \left(\frac{p_{X,1}/p_{M,1}}{p_{X,0}/p_{M,0}}\right).$$

and

$$\ln \widehat{\mathrm{W}}_{jB} = \frac{1}{2}\left[(\delta_{Xj} + \delta_{Mj})\frac{\ln(s_{j,1}/s_{j,0})}{s_{j,1} - s_{j,0}} + \frac{1}{2}(s_{X,0} + s_{X,1} + s_{M,0} + s_{M,1})\right] \ln \left(\frac{p_{X,1}}{p_{X,0}}\frac{p_{M,1}}{p_{M,0}}\right)$$

where $\ln(s_{j,1}/s_{j,0})/s_{j,1} - s_{j,0}$ can be replaced with its limit $(1/s_{j,0})$ when $s_{j,0} = s_{j,1}$. Notice, incidentally, that element $\frac{1}{2}(s_{X,0} + s_{X,1} + s_{M,0} + s_{M,1})$ is the average trade balance (s_M being negative).

Calculations of international-price contributions and their disaggregation into elasticity-imbalance and terms-of-trade effects will be carried out in Section 8.

7 Data construction and model estimation

When using a Translog GDP function, the decomposition of changes in factor productivity can be obtained only once the parameters of the functions have been estimated. The econometric estimation, in turn, requires series of price and quantity for capital, labour, domestic absorption, exports and imports, namely, w_K, w_L, p_D, p_X, p_M, x_K, x_L, y_D, y_X and y_M. These can be constructed using data from the national accounts and from other widely available macroeconomic databases.[14]

Prices for C, I G, X and M were obtained dividing current-price values by constant-price values. Constant-price aggregates were used as quantities. All prices were normalized to 1 in 1995 and quantities adjusted accordingly. Prices of C, I and G were then aggregated into the following domestic-price Törnqvist-like index p_D (normalized to 1 in 1995):

$$\ln\left(\frac{p_{D,t}}{p_{D,t-1}}\right) = \frac{1}{2}\sum_i (s_{i,t} + s_{i,t-1}) \ln\left(\frac{p_{i,t}}{p_{i,t-1}}\right), \qquad i = C, I, G,$$

where $s_{i,t} = (p_i q_i)/(\sum_h p_h q_h)$ is the GDP share of output i. Quantity y_D was calculated dividing the value of domestic absorption by its price p_D.[15]

Labour payments were obtained by assuming that self-employed labour is paid the same unit price as in the rest of the economy. The quantity of labour was assumed to be equal to the number of hours worked in the domestic economy. These were computed multiplying total employment by the average number of hours worked by employees. We calculated unit labour cost dividing labour payments by the quantity of labour. Unit labour cost was then normalized to 1 in 1995 and the quantity of labour adjusted to keep labour payments $w_L x_L$ unaffected.

We assume that capital stock grows in the whole economy at the same speed as in the business sector. Capital payments were calculated as a

[14] Data used to construct final series were drawn, with only a few exceptions, from the OECD on-line statistical databases.

[15] Prices p_D, p_X and p_M should be adjusted for indirect taxes and subsidies to ensure full compatibility with the producer optimization behaviour, as prices must reflect the net unit cost of imports and the net unit revenue of output produced. However, due to the general lack of relevant data, this treatment was not possible. Indeed, in some instances, the derivation of import duties by comparing different series or databases yielded negative values.

residual (GDP minus labour payments). Capital user cost was obtained by dividing capital payments by capital stock. It was then normalized to 1 in 1995; capital stock was adjusted accordingly.

This procedure ensures that $w_L x_L + w_K x_K = p_D y_D + p_X y_X + p_M y_M$ (y_M being a negative value).

The parameters of the complete system (6), (7) and (8) were estimated econometrically using non-linear three-stage least squares. Due to homogeneity, one output-supply equation and one factor-productivity equation was omitted.

The following instruments were used to correct for simultaneous-equation bias: population (in log) and capital stock (index, in log); household disposable income (as a ratio of GDP); general government's net lending (as a ratio of GDP); women share in total labour force; oil price (in national currency, per barrel, in log), US labour force (in log) and capital stock (index, in log); time index and time index square.

Since preliminary results revealed non-convexity of the profit function for all countries, convexity was imposed using the reparameterization technique introduced by Diewert and Wales (1987) and based on work of Lau (1978) and Wiley *et* al. (1973). Thus we normalized p_D, p_X, p_M, x_K and x_L to unity and reset t to 0 in the year where curvature was most violated, and redefined γ_{DD}, γ_{DX} and γ_{XX} as follows:

$$\begin{aligned}
\gamma_{DD} &= \tau_{DD}^2 - \alpha_D^2 + \alpha_D \\
\gamma_{DX} &= \tau_{DD}\tau_{DX} - \alpha_X \alpha_D \\
\gamma_{XX} &= \tau_{DX}^2 + \tau_{XX}^2 - \alpha_X^2 + \alpha_D.
\end{aligned}$$

The reparameterized GDP functions satisfied the curvature conditions over the whole period and for all countries.[16]

8 Results

The econometric estimation provides the necessary material to construct the entire set of contribution indexes. Confirming what was claimed above, (one

[16] For more details about the econometric estimation, see Kohli (1991).

plus) the factor-growth rate estimated econometrically

$$\frac{w_j(p_{D,t}, p_{X,t}, p_{M,t}, x_{K,t}, x_{L,t}, t)}{w_j(p_{D,t-1}, p_{X,t-1}, p_{M,t-1}, x_{K,t-1}, x_{L,t-1}, t-1)}$$

can be decomposed completely through flexi-Fisher and modified elasticity-based indexes. On the other hand, a statistical gap appears when using "pure" Fisher-like and elasticity-based indexes.[17]

Of course, the full decomposition no longer holds when one deals with *observed* values of w_j, i.e., with values which include the estimation residuals. The difference reflects optimization errors and temporary productivity shocks not accounted for by the exogenous variables. Far from being disturbing, the presence of this residual makes it possible to construct one additional index designed to capture short-run disturbances of factor productivity growth. It follows that, when using oberved movements in w_j, the complete decomposition becomes:

$$\frac{w_{j,t}}{w_{j,t-1}} = (\mathrm{W}_{KD} \cdot \mathrm{W}_{KX}, \cdot \mathrm{W}_{KM} \cdot \mathrm{W}_{KK} \cdot \mathrm{W}_{KL} \cdot \mathrm{W}_{KT}) \cdot \mathrm{W}_{SG} \cdot \mathrm{W}_{KE},$$

where W_E is the index capturing short-run disturbances (random or unexplained component) and W_{SG} measures the statistical gap (due to the index form selected).

A similar breakdown can be implemented using indexes of the type $\widehat{\mathrm{W}}_{jm}$, $\overline{\mathrm{W}}_{jm}$ or W'$_{jm}$ $(m = D, X, M, K, L, T, SG, E)$. Naturally, while the flexi-Fisher index W_{SG} and the modified-based index $\widehat{\mathrm{W}}_{SG}$ will necessarily be equal to 1 (the statistical gap being zero), this will be no longer true for their elasticity-based and "pure" Fisher-like counterparts $\overline{\mathrm{W}}_{SG}$ and W'$_{SG}$. For illustrative purposes, we have decomposed the change in (nominal) labour productivity in the United Kingdom for year 2000 using the four types of indexes. Interestingly, their values, reported in Table 1, reveal that numerical differences across classes of indexes are negligible and hence that, when a statistical gap exists, its index value is very close to one.

Table 2 to 5 reports the decomposition of capital and labour productivity movements using modified elasticity-based indexes for 10 OECD countries. Figures are expressed in annual geometric averages. Given the bulk of information produced, discussion will focus only on the overall picture.

[17] Hereafter, this gap will be indicated by subscript 'SG'.

Capital productivity is discussed in Table 2 and Table 3, the latter concerning more specifically international-price and terms-of-trade effects.The general impression the emerges from Table 2 is the presence of large cross-country differences. Unsurprisingly, growth in nominal capital productivity has been positive over the period 1970-2001 for all countries. This mainly reflects movements in domestic prices (see $\widehat{\mathrm{W}}_{KD}$) in all countries but Korea, where export prices seem to have been the main force explaining changes in capital revenue. Given the law of decreasing marginal returns, capital productivity has been driven down by the steady increase capital stock ($\widehat{\mathrm{W}}_{KK}$ is less than 1) in all countries, in contrast to the uneven effect of labour, which reflects the combined effect of the expansion of labour force and the decrease in the workweek length. The contribution of technological progress to productivity growth ($\widehat{\mathrm{W}}_{KT}$) is far from being uniform. In the majority of the remaining countries, technological progress has favoured capital at a rate of 1 to 4% per year. Japan and Switzerland are at opposite ends of the spectrum, their values even arousing suspicion about possible over- and under-estimation, respectively ($\widehat{\mathrm{W}}_{KT}$ = 1.1033 and 0.9855, respectively). Korea stands out with a high 7%.

Table 3 shows that movements in international prices have largely favoured capital (see $\widehat{\mathrm{W}}_{KXM}$) in Korea, United Kingdom, Switzerland and, to a lesser extent, Canada, while in France and Australia capital marginal revenue has been driven down. These contributions mainly reflect elasticity imbalances (captured by $\widehat{\mathrm{W}}_{KB}$), their impact being, in absolute value, stronger than the contribution of movements in the terms (measured by $\widehat{\mathrm{W}}_{KA}$).

On the labour side, Table 4 shows that, again, changes domestic prices are the main factor explaining movements in nominal productivity (see $\widehat{\mathrm{W}}_{LD}$). Labour productivity has largely benefitted from capital deepening (see $\widehat{\mathrm{W}}_{LK}$), at an annual rate of 1% to 3% for most of the sample, Japan being the exception (approx. 5%). Technological progress has favoured labour less than capital in all countries but Switzerland, as shown by $\widehat{\mathrm{W}}_{LT}$: in Japan, France and, only marginally, in New Zealand, this index is (puzzelingly) even less than one.

Finally, as is the case for capital, the decomposition of the international-price effect ($\widehat{\mathrm{W}}_{LXM}$) in the two components $\widehat{\mathrm{W}}_{LA}$ and $\widehat{\mathrm{W}}_{LB}$ reported in Table 5 reveals that the contribution of international prices to labour productivity is mainly driven by the elasticity-imbalance effect $\widehat{\mathrm{W}}_{LB}$. Interestingly, it appears that the elasticity-imbalance effect of labour and capital have opposite sign; Japan, where both are positive, is again an exception.

9 Conclusion

In this paper we presented three techniques to measure the contribution of major determinants to movements in factor productivity. One technique was further adapted to a GDP-function framework. This resulted in the construction of four types of contribution indexes, which were shown to yield very close values. Two indexes, namely the elasticity-based and the modified elasticity-based index, could be further developed in order to break down the combined impact of import and export prices into a terms-of-trade effect and an elasticity-imbalance effect. Of the elasticity-based and the modified elasticity-based techniques, only the latter allows for a complete decomposition of changes in factor productivity. This is therefore the one that was selected to carry out international comparisons.

Calculations revealed interesting and sometimes unexpected results.

The impact of international prices seems to have been driven mostly by imbalances between export-price and import-price elasticities on factor productivity. This confirms that, even keeping terms of trade constant, international prices can (and do) have a real impact on workers' and capital owners' welfare. In the context of wide swings in exchange rates, this phenomenon deserves to be looked into.

The negative impact of technological progress on factor productivity found for some countries is a somewhat puzzling result. Is it really the case that, at the margin, labour has been penalized by the passage of time in countries, like France, Japan or Sweden, where workers become more and more skilled and benefit from ever improving equipment? Or are these values the result of a misspecified model, which suffers from an unforgiving mismatch between reality and the assumption of perfect competition? Or is this the consequence of a purely econometric problem or an error-in-data problem?

While these points certainly deserve further investigation, they are an issue separate from the main methodological contribution of this paper:

the construction of decomposition indexes, which not only are easily implemented in an open-economy model but can be extended to fields that go beyond the study of productivity.

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Figure 1: Expansion of a 2-input production function and combinations of initial, final and intermediate productivity points

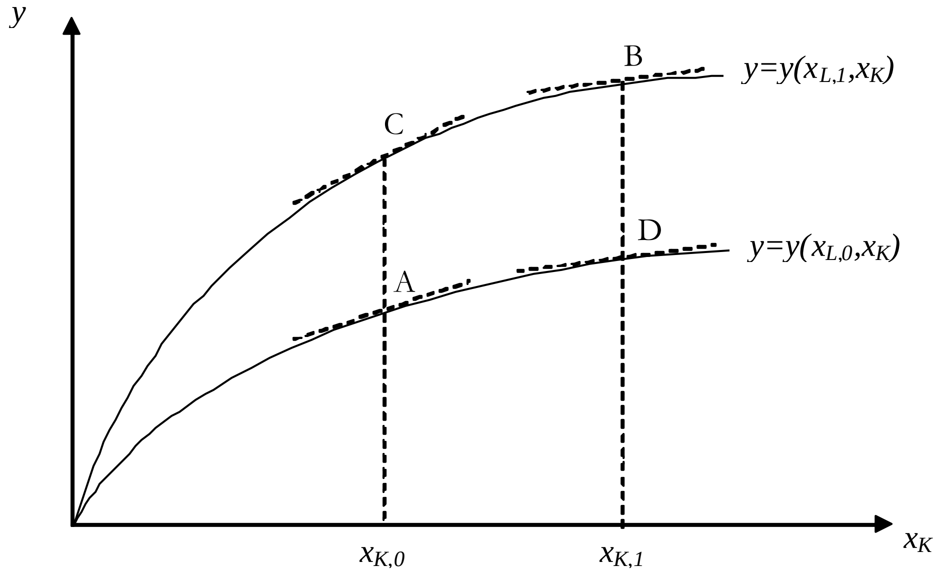

Figure 2: Expansion of a 3-input production function and combinations of initial, final and intermediate productivity points.

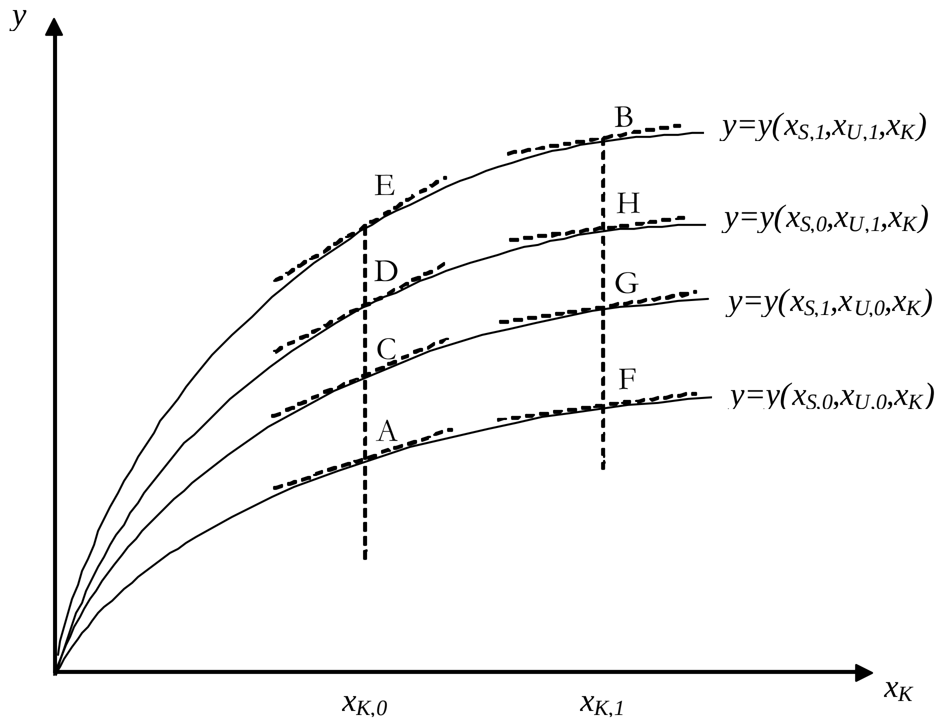

Table 1: Decomposition of change in labour marginal revenue, comparison of four indexes - United Kingdom, year 2000

Contribution of ($m =$)	Modified el.-based $\widehat{\mathrm{W}}_{Lm}$	Elasticity-based $\overline{\mathrm{W}}_{Lm}$	Flexi-fisher W_{Lm}	"pure" Fisher-like $\mathrm{W'}_{Lm}$
domestic prices (D)	1.01892027	1.0189203	1.01892035	1.01892035
export prices (X)	0.99597674	0.99597666	0.99597667	0.99597672
import prices (M)	1.00006195	1.00006197	1.000062	1.00006199
capital quantity (K)	1.01757457	1.01757458	1.01757459	1.01757459
labour quantity (L)	0.99846318	0.99846318	0.99846318	0.99846318
techn. progress (T)	1.00281424	1.0028142	1.00281418	1.00281425
random component (E)	1.02272496	1.02272496	1.02272496	1.02272496
international prices (XM)	0.99603844	0.99603839	0.99603841	0.99603846
terms of trade (A)	0.99873156	0.99873152	NA	NA
elasticity imbalance (B)	0.99730346	0.99730344	NA	NA
Statistical gap (SG)	1	1.00000007	1	0.99999989

Table 2: Decomposition of movements in capital marginal revenue contribution indexes, annual geometric averages

	$\frac{w_{K,t}}{w_{K,t-1}}$	$\widehat{\mathrm{W}}_{KD}$	$\widehat{\mathrm{W}}_{KX}$	$\widehat{\mathrm{W}}_{KM}$	$\widehat{\mathrm{W}}_{KK}$	$\widehat{\mathrm{W}}_{KL}$	$\widehat{\mathrm{W}}_{KT}$	$\widehat{\mathrm{W}}_{KE}$
Australia								
1971-1975	1.0673	1.1504	0.9610	1.0160	0.9740	1.0080	1.0034	0.9645
1976-1980	1.1225	1.1115	0.9719	1.0136	0.9796	1.0044	1.0045	1.0373
1981-1985	1.0736	1.0993	0.9869	1.0065	0.9753	1.0062	1.0059	0.9960
1986-1990	1.0508	1.0768	0.9922	1.0010	0.9768	1.0163	1.0072	0.9826
1991-1995	1.0268	1.0192	0.9995	1.0007	0.9881	1.0049	1.0083	1.0062
1996-2001	1.0285	1.0198	0.9965	1.0001	0.9815	1.0069	1.0105	1.0134
1971-2001	1.0600	1.0765	0.9850	1.0061	0.9793	1.0077	1.0068	1.0002
Canada								
1971-1975	1.0857	1.0642	0.9436	1.0771	0.9651	1.0213	1.0101	1.0082
1976-1980	1.0787	1.0452	0.9588	1.0624	0.9664	1.0223	1.0132	1.0121
1981-1985	1.0562	1.0426	0.9881	1.0266	0.9709	1.0087	1.0174	1.0023
1986-1990	1.0305	1.0245	0.9973	1.0001	0.9756	1.0204	1.0204	0.9928
1991-1995	1.0311	1.0127	0.9881	1.0280	0.9871	1.0020	1.0231	0.9906
1996-2001	1.0206	1.0092	0.9954	1.0086	0.9770	1.0174	1.0258	0.9879
1971-2001	1.0492	1.0321	0.9789	1.0326	0.9738	1.0154	1.0186	0.9986
France								
1971-1975	1.0194	1.1294	1.0039	0.9621	0.9189	0.9947	1.0344	0.9884
1976-1980	1.0674	1.1489	1.0051	0.9572	0.9349	0.9976	1.0356	0.9997
1981-1985	1.0689	1.1251	1.0068	0.9582	0.9516	0.9836	1.0364	1.0151
1986-1990	1.0518	1.0395	1.0000	1.0083	0.9554	1.0050	1.0330	1.0117
1991-1995	1.0057	1.0264	0.9991	1.0046	0.9667	0.9937	1.0289	0.9877
1996-2001	1.0052	1.0138	1.0008	0.9974	0.9716	1.0051	1.0249	0.9924
1971-2001	1.0350	1.0769	1.0026	0.9816	0.9504	0.9969	1.0320	0.9989
Japan								
1971-1975	0.9578	1.1047	1.0312	0.9558	0.8126	0.9844	1.1125	0.9884
1976-1980	1.0607	1.0594	1.0066	0.9714	0.8716	1.0285	1.1267	1.0138
1981-1985	1.0227	1.0221	0.9984	1.0011	0.8824	1.0150	1.1187	0.9990
1986-1990	1.0273	1.0119	0.9896	1.0238	0.8891	1.0167	1.0972	1.0103
1991-1995	0.9750	1.0085	0.9900	1.0142	0.9069	0.9842	1.0923	0.9876
1996-2001	0.9767	0.9929	0.9970	0.9969	0.9423	0.9883	1.0783	0.9856
1971-2001	1.0019	1.0313	1.0019	0.9937	0.8851	1.0022	1.1033	0.9970

Table 2 (cont.)

	$\frac{w_{K,t}}{w_{K,t-1}}$	$\widehat{W}_{KD}$	$\widehat{W}_{KX}$	$\widehat{W}_{KM}$	$\widehat{W}_{KK}$	$\widehat{W}_{KL}$	$\widehat{W}_{KT}$	$\widehat{W}_{KE}$
Korea								
1971-1975	1.3139	1.0505	1.1437	1.0020	0.9255	1.0246	1.0862	1.0595
1976-1980	1.0809	1.0619	1.1108	0.9971	0.9128	1.0185	1.0808	0.9145
1981-1985	1.1100	1.0280	1.0146	0.9960	0.9057	1.0120	1.0726	1.0586
1986-1990	1.0433	1.0229	1.0155	1.0009	0.9227	1.0266	1.0693	0.9907
1991-1995	1.0744	1.0367	1.0127	0.9977	0.9417	1.0159	1.0672	1.0046
1996-2001	1.0207	1.0202	0.9935	0.9923	0.9625	1.0074	1.0618	0.9858
1971-2001	1.1005	1.0361	1.0496	0.9975	0.9294	1.0172	1.0726	1.0006
New Zealand								
1971-1975	1.0465	1.1353	1.0344	0.9293	0.9681	1.0142	1.0003	0.9763
1976-1980	1.1231	1.1970	1.0536	0.9256	0.9867	1.0040	1.0035	0.9678
1981-1985	1.1711	1.1485	1.0361	0.9434	0.9785	1.0068	1.0067	1.0520
1986-1990	1.0747	1.0877	1.0109	1.0011	0.9802	0.9930	1.0095	0.9937
1991-1995	1.0441	1.0190	1.0014	1.0007	0.9919	1.0153	1.0129	1.0025
1996-2001	1.0261	1.0178	1.0141	0.9853	0.9857	1.0070	1.0162	1.0003
1971-2001	1.0780	1.0961	1.0246	0.9644	0.9820	1.0067	1.0084	0.9985
Sweden								
1971-1975	1.0767	1.0812	1.0440	0.9673	0.9385	0.9925	1.0388	1.0191
1976-1980	1.0729	1.0980	1.0394	0.9637	0.9567	0.9965	1.0406	0.9833
1981-1985	1.1156	1.0742	1.0402	0.9690	0.9677	1.0049	1.0392	1.0195
1986-1990	1.0504	1.0556	1.0140	0.9934	0.9527	1.0209	1.0377	0.9788
1991-1995	1.0412	1.0279	1.0186	0.9853	0.9754	0.9773	1.0388	1.0191
1996-2001	0.9938	1.0159	0.9975	0.9960	0.9600	1.0129	1.0376	0.9759
1971-2001	1.0556	1.0570	1.0245	0.9796	0.9585	1.0011	1.0387	0.9983
Switzerland								
1971-1975	1.0029	1.0447	1.0455	0.9803	0.9679	0.9951	0.9867	0.9856
1976-1980	1.0105	1.0159	1.0110	0.9914	0.9838	1.0009	0.9857	1.0225
1981-1985	1.0217	1.0193	1.0383	0.9866	0.9808	1.0063	0.9852	1.0062
1986-1990	1.0063	1.0124	1.0187	1.0018	0.9773	1.0163	0.9856	0.9949
1991-1995	0.9785	1.0082	1.0097	1.0075	0.9810	0.9990	0.9853	0.9880
1996-2001	0.9852	1.0016	1.0149	0.9937	0.9789	1.0044	0.9845	1.0076
1971-2001	1.0002	1.0164	1.0227	0.9935	0.9783	1.0037	0.9855	1.0009

Table 2 (cont.)

	$\frac{w_{K,t}}{w_{K,t-1}}$	$\widehat{W}_{KD}$	$\widehat{W}_{KX}$	$\widehat{W}_{KM}$	$\widehat{W}_{KK}$	$\widehat{W}_{KL}$	$\widehat{W}_{KT}$	$\widehat{W}_{KE}$
United Kingdom								
1971-1975	1.0881	1.0857	1.1539	0.8883	0.9805	0.9972	1.0251	0.9755
1976-1980	1.1782	1.0863	1.1614	0.9190	0.9852	0.9927	1.0233	1.0154
1981-1985	1.0857	1.0141	1.0826	0.9495	0.9878	0.9957	1.0213	1.0097
1986-1990	1.0448	1.0395	1.0148	0.9900	0.9789	1.0137	1.0182	1.0191
1991-1995	1.0415	1.0232	1.0360	0.9738	0.9798	0.9923	1.0182	1.0191
1996-2001	1.0059	1.0137	0.9870	1.0200	0.9728	1.0054	1.0164	0.9914
1971-2001	1.0705	1.0468	1.0678	0.9578	0.9806	0.9997	1.0205	0.9996
United States								
1971-1975	1.0685	1.0835	0.9674	1.0177	0.9688	1.0086	1.0053	1.0197
1976-1980	1.0684	1.0961	0.9798	1.0107	0.9694	1.0229	1.0067	0.9859
1981-1985	1.0623	1.0608	0.9962	0.9989	0.9733	1.0140	1.0082	1.0113
1986-1990	1.0396	1.0426	0.9951	1.0023	0.9796	1.0174	1.0099	0.9932
1991-1995	1.0365	1.0305	0.9976	1.0002	0.9840	1.0091	1.0116	1.0035
1996-2001	1.0133	1.0216	1.0022	0.9993	0.9720	1.0104	1.0138	0.9948
1971-2001	1.0468	1.0544	0.9901	1.0046	0.9744	1.0136	1.0094	1.0011

Table 3: International-price effect, terms-of-trade effect and elasticitity-imbalance effect on movements in capital marginal revenue, contribution indexes, annual geometric averages

	$\widehat{\mathrm{W}}_{KXM}$	$\widehat{\mathrm{W}}_{KA}$	$\widehat{\mathrm{W}}_{KB}$
Australia			
1971-1975	0.9764	0.9957	0.9806
1976-1980	0.9851	1.0039	0.9813
1981-1985	0.9933	1.0040	0.9894
1986-1990	0.9932	0.9974	0.9958
1991-1995	1.0002	1.0014	0.9988
1996-2001	0.9966	0.9989	0.9977
1971-2001	0.9910	1.0002	0.9908
Canada			
1971-1975	1.0164	0.9872	1.0295
1976-1980	1.0186	0.9905	1.0284
1981-1985	1.0143	1.0028	1.0116
1986-1990	0.9974	0.9963	1.0011
1991-1995	1.0157	1.0046	1.0111
1996-2001	1.0040	0.9993	1.0047
1971-2001	1.0108	0.9968	1.0140
France			
1971-1975	0.9659	0.9956	0.9701
1976-1980	0.9621	0.9953	0.9667
1981-1985	0.9647	0.9976	0.9671
1986-1990	1.0083	1.0048	1.0035
1991-1995	1.0036	1.0008	1.0029
1996-2001	0.9982	0.9998	0.9985
1971-2001	0.9841	0.9990	0.9851
Japan			
1971-1975	0.9857	0.9826	1.0031
1976-1980	0.9778	0.9771	1.0007
1981-1985	0.9996	0.9996	0.9999
1986-1990	1.0132	1.0139	0.9993
1991-1995	1.0041	1.0049	0.9992
1996-2001	0.9939	0.9941	0.9999
1971-2001	0.9956	0.9952	1.0003

Table 3 (cont.)

	$\widehat{W}_{KXM}$	$\widehat{W}_{KA}$	$\widehat{W}_{KB}$
Korea			
1971-1975	1.1460	0.9875	1.1605
1976-1980	1.1077	1.0022	1.1053
1981-1985	1.0374	1.0030	1.0343
1986-1990	1.0164	1.0124	1.0040
1991-1995	1.0104	0.9990	1.0113
1996-2001	0.9859	0.9761	1.0100
1971-2001	1.0470	0.9960	1.0513
New Zealand			
1971-1975	0.9613	0.9851	0.9758
1976-1980	0.9752	1.0062	0.9691
1981-1985	0.9775	0.9977	0.9797
1986-1990	1.0121	1.0146	0.9975
1991-1995	1.0020	1.0025	0.9995
1996-2001	0.9991	1.0031	0.9961
1971-2001	0.9881	1.0015	0.9865
Sweden			
1971-1975	1.0099	0.9978	1.0121
1976-1980	1.0017	0.9897	1.0121
1981-1985	1.0080	0.9981	1.0099
1986-1990	1.0073	1.0041	1.0033
1991-1995	1.0035	0.9979	1.0057
1996-2001	0.9935	0.9932	1.0003
1971-2001	1.0036	0.9967	1.0070
Switzerland			
1971-1975	1.0249	1.0058	1.0190
1976-1980	1.0023	0.9958	1.0066
1981-1985	1.0244	1.0091	1.0152
1986-1990	1.0205	1.0164	1.0040
1991-1995	1.0173	1.0192	0.9982
1996-2001	1.0085	1.0008	1.0077
1971-2001	1.0160	1.0076	1.0084

Table 3 (cont.)

	$\widehat{W}_{KXM}$	$\widehat{W}_{KA}$	$\widehat{W}_{KB}$
United Kingdom			
1971-1975	1.0250	0.9727	1.0538
1976-1980	1.0672	1.0209	1.0454
1981-1985	1.0279	1.0021	1.0258
1986-1990	1.0047	1.0002	1.0045
1991-1995	1.0089	0.9973	1.0116
1996-2001	1.0068	1.0132	0.9936
1971-2001	1.0227	1.0013	1.0213
United States			
1971-1975	0.9845	1.0095	0.9753
1976-1980	0.9903	1.0086	0.9819
1981-1985	0.9951	0.9952	1.0000
1986-1990	0.9974	1.0025	0.9949
1991-1995	0.9978	0.9993	0.9986
1996-2001	1.0015	0.9990	1.0025
1971-2001	0.9947	1.0022	0.9925

Table 4: Decomposition of movements in labour marginal revenue, contribution indexes, annual geometric averages

	$\frac{w_{L,t}}{w_{L,t-1}}$	$\widehat{\mathrm{W}}_{LD}$	$\widehat{\mathrm{W}}_{LX}$	$\widehat{\mathrm{W}}_{LM}$	$\widehat{\mathrm{W}}_{LK}$	$\widehat{\mathrm{W}}_{LL}$	$\widehat{\mathrm{W}}_{LT}$	$\widehat{\mathrm{W}}_{LE}$
Australia								
1971-1975	1.1617	1.1140	1.0511	0.9681	1.0151	0.9956	1.0007	1.0134
1976-1980	1.1011	1.0855	1.0442	0.9617	1.0128	0.9973	1.0017	0.9984
1981-1985	1.0911	1.0765	1.0224	0.9746	1.0165	0.9959	1.0032	1.0015
1986-1990	1.0578	1.0596	1.0150	0.9943	1.0166	0.9887	1.0045	0.9797
1991-1995	1.0360	1.0150	1.0014	0.9959	1.0091	0.9962	1.0057	1.0123
1996-2001	1.0396	1.0154	1.0113	0.9961	1.0145	0.9947	1.0079	0.9993
1971-2001	1.0790	1.0589	1.0237	0.9821	1.0141	0.9947	1.0041	1.0007
Canada								
1971-1975	1.1123	1.1110	1.0638	0.9333	1.0216	0.9873	0.9998	0.9999
1976-1980	1.0988	1.0776	1.0695	0.9323	1.0212	0.9865	1.0030	1.0121
1981-1985	1.0780	1.0779	1.0213	0.9720	1.0170	0.9950	1.0069	0.9888
1986-1990	1.0499	1.0441	1.0047	1.0000	1.0138	0.9886	1.0098	0.9889
1991-1995	1.0269	1.0225	1.0230	0.9672	1.0073	0.9985	1.0125	0.9967
1996-2001	1.0301	1.0159	1.0127	0.9865	1.0142	0.9896	1.0154	0.9959
1971-2001	1.0643	1.0563	1.0316	0.9656	1.0158	0.9909	1.0081	0.9970
France								
1971-1975	1.1508	1.0793	1.0212	0.9927	1.0492	1.0029	0.9937	1.0060
1976-1980	1.1415	1.0912	1.0237	0.9893	1.0370	1.0013	0.9943	1.0005
1981-1985	1.1164	1.0770	1.0255	0.9875	1.0263	1.0087	0.9946	0.9941
1986-1990	1.0435	1.0247	0.9998	1.0026	1.0272	0.9970	0.9928	0.9991
1991-1995	1.0320	1.0166	0.9975	1.0013	1.0229	1.0042	0.9900	0.9994
1996-2001	1.0300	1.0087	1.0019	0.9993	1.0228	0.9961	0.9870	1.0143
1971-2001	1.0826	1.0477	1.0112	0.9955	1.0306	1.0015	0.9919	1.0026
Japan								
1971-1975	1.1975	1.1062	1.0030	0.9969	1.0868	1.0052	0.9862	1.0049
1976-1980	1.0789	1.0603	1.0007	0.9968	1.0459	0.9909	0.9882	0.9959
1981-1985	1.0447	1.0224	0.9998	1.0001	1.0445	0.9948	0.9851	0.9983
1986-1990	1.0401	1.0120	0.9992	1.0020	1.0526	0.9929	0.9777	1.0046
1991-1995	1.0318	1.0086	0.9998	1.0001	1.0448	1.0072	0.9749	0.9975
1996-2001	1.0055	0.9928	0.9999	1.0001	1.0322	1.0065	0.9686	1.0065
1971-2001	1.0627	1.0317	1.0004	0.9994	1.0504	0.9998	0.9797	1.0014

Table 4 (cont.)

	$\frac{w_{L,t}}{w_{L,t-1}}$	$\widehat{W}_{LD}$	$\widehat{W}_{LX}$	$\widehat{W}_{LM}$	$\widehat{W}_{LK}$	$\widehat{W}_{LL}$	$\widehat{W}_{LT}$	$\widehat{W}_{LE}$
Korea								
1971-1975	1.2380	1.2845	1.0303	0.9224	1.0133	0.9956	1.0195	0.9860
1976-1980	1.2805	1.2701	1.0236	0.9458	1.0183	0.9964	1.0193	1.0070
1981-1985	1.1205	1.0900	1.0123	0.9795	1.0254	0.9969	1.0198	0.9946
1986-1990	1.1298	1.0647	1.0060	1.0034	1.0253	0.9919	1.0219	1.0115
1991-1995	1.1339	1.0978	1.0046	0.9916	1.0196	0.9949	1.0207	1.0014
1996-2001	1.0454	1.0472	0.9969	0.9794	1.0142	0.9974	1.0185	0.9924
1971-2001	1.1517	1.1353	1.0117	0.9703	1.0192	0.9956	1.0199	0.9986
New Zealand								
1971-1975	1.1430	1.0997	1.0213	0.9852	1.0192	0.9917	0.9871	1.0354
1976-1980	1.1510	1.1450	1.0353	0.9802	1.0078	0.9977	0.9902	0.9950
1981-1985	1.1049	1.1101	1.0248	0.9836	1.0137	0.9958	0.9936	0.9846
1986-1990	1.0945	1.0657	1.0072	1.0008	1.0148	1.0053	0.9967	1.0020
1991-1995	1.0128	1.0143	1.0009	1.0000	1.0067	0.9877	1.0002	1.0031
1996-2001	1.0300	1.0133	1.0102	0.9965	1.0127	0.9939	1.0036	0.9995
1971-2001	1.0862	1.0716	1.0163	0.9912	1.0125	0.9953	0.9955	1.0030
Sweden								
1971-1975	1.1227	1.0980	1.0158	0.9764	1.0362	1.0045	0.9898	1.0006
1976-1980	1.1298	1.1189	1.0163	0.9728	1.0244	1.0018	0.9911	1.0041
1981-1985	1.0791	1.0894	1.0185	0.9760	1.0195	0.9971	0.9907	0.9895
1986-1990	1.0875	1.0668	1.0069	0.9949	1.0318	0.9867	0.9904	1.0092
1991-1995	1.0417	1.0336	1.0095	0.9885	1.0159	1.0143	0.9912	0.9888
1996-2001	1.0454	1.0190	0.9987	0.9968	1.0284	0.9911	0.9908	1.0205
1971-2001	1.0826	1.0687	1.0105	0.9846	1.0261	0.9989	0.9907	1.0026
Switzerland								
1971-1975	1.1240	1.0948	0.9951	0.9903	1.0249	1.0032	1.0070	1.0062
1976-1980	1.0442	1.0360	0.9997	0.9955	1.0104	0.9998	1.0066	0.9958
1981-1985	1.0527	1.0454	1.0003	0.9928	1.0108	0.9965	1.0069	0.9997
1986-1990	1.0508	1.0322	1.0007	1.0010	1.0115	0.9920	1.0080	1.0048
1991-1995	1.0402	1.0227	1.0004	1.0037	1.0084	1.0003	1.0088	0.9953
1996-2001	1.0222	1.0059	1.0013	0.9967	1.0080	0.9984	1.0095	1.0022
1971-2001	1.0541	1.0381	0.9996	0.9967	1.0122	0.9984	1.0079	1.0007

Table 4 (cont.)

	$\frac{w_{L,t}}{w_{L,t-1}}$	$\widehat{W}_{LD}$	$\widehat{W}_{LX}$	$\widehat{W}_{LM}$	$\widehat{W}_{LK}$	$\widehat{W}_{LL}$	$\widehat{W}_{LT}$	$\widehat{W}_{LE}$
United Kingdom								
1971-1975	1.1807	1.1744	0.9723	1.0035	1.0102	1.0014	1.0111	1.0073
1976-1980	1.1632	1.1735	0.9737	1.0003	1.0078	1.0039	1.0095	0.9964
1981-1985	1.0874	1.0801	0.9861	1.0004	1.0072	1.0021	1.0078	1.0033
1986-1990	1.0817	1.0753	0.9960	1.0004	1.0121	0.9925	1.0062	0.9990
1991-1995	1.0523	1.0436	0.9927	1.0002	1.0119	1.0043	1.0048	0.9945
1996-2001	1.0510	1.0255	1.0028	0.9999	1.0165	0.9968	1.0031	1.0057
1971-2001	1.0999	1.0916	0.9877	1.0008	1.0111	1.0001	1.0069	1.0012
United States								
1971-1975	1.0776	1.0615	1.0287	0.9758	1.0167	0.9955	1.0031	0.9962
1976-1980	1.0873	1.0708	1.0204	0.9786	1.0165	0.9882	1.0046	1.0076
1981-1985	1.0613	1.0452	1.0036	1.0025	1.0148	0.9925	1.0060	0.9961
1986-1990	1.0442	1.0318	1.0053	0.9935	1.0117	0.9903	1.0078	1.0035
1991-1995	1.0342	1.0229	1.0029	0.9989	1.0094	0.9947	1.0095	0.9956
1996-2001	1.0419	1.0162	0.9972	1.0036	1.0170	0.9939	1.0117	1.0019
1971-2001	1.0571	1.0404	1.0092	0.9925	1.0144	0.9926	1.0073	1.0002

Table 5: International-price effect, terms-of-trade effect and elasticitity-imbalance effect on movements in labour marginal revenue, contribution indexes, annual geometric averages

	$\widehat{\mathrm{W}}_{LXM}$	$\widehat{\mathrm{W}}_{LA}$	$\widehat{\mathrm{W}}_{LB}$
Australia			
1971-1975	1.0176	1.0053	1.0123
1976-1980	1.0042	0.9934	1.0108
1981-1985	0.9964	0.9906	1.0059
1986-1990	1.0093	1.0071	1.0022
1991-1995	0.9973	0.9967	1.0006
1996-2001	1.0073	1.0056	1.0017
1971-2001	1.0054	0.9999	1.0054
Canada			
1971-1975	0.9929	1.0122	0.9809
1976-1980	0.9971	1.0132	0.9841
1981-1985	0.9927	0.9969	0.9958
1986-1990	1.0047	1.0052	0.9995
1991-1995	0.9894	0.9953	0.9941
1996-2001	0.9990	1.0015	0.9975
1971-2001	0.9961	1.0040	0.9921
France			
1971-1975	1.0137	0.9966	1.0172
1976-1980	1.0127	0.9963	1.0165
1981-1985	1.0127	0.9981	1.0146
1986-1990	1.0024	1.0039	0.9985
1991-1995	0.9988	1.0006	0.9982
1996-2001	1.0012	0.9998	1.0014
1971-2001	1.0067	0.9992	1.0075
Japan			
1971-1975	0.9999	0.9964	1.0097
1976-1980	0.9975	1.0023	1.0025
1981-1985	0.9999	1.0074	0.9869
1986-1990	1.0012	1.0015	0.9958
1991-1995	0.9999	0.9970	1.0161
1996-2001	1.0000	1.0009	1.0014
1971-2001	0.9997	1.0010	1.0017

Table 5 (cont.)

	$\widehat{W}_{LXM}$	$\widehat{W}_{LA}$	$\widehat{W}_{LB}$
Korea			
1971-1975	0.9503	0.9904	0.9596
1976-1980	0.9681	1.0016	0.9666
1981-1985	0.9915	1.0024	0.9892
1986-1990	1.0094	1.0102	0.9992
1991-1995	0.9962	0.9992	0.9970
1996-2001	0.9764	0.9797	0.9966
1971-2001	0.9816	0.9966	0.9849
New Zealand			
1971-1975	1.0062	0.9927	1.0135
1976-1980	1.0148	1.0024	1.0124
1981-1985	1.0079	0.9989	1.0090
1986-1990	1.0080	1.0057	1.0023
1991-1995	1.0010	1.0011	0.9999
1996-2001	1.0067	1.0015	1.0052
1971-2001	1.0074	1.0004	1.0070
Sweden			
1971-1975	0.9919	0.9991	0.9928
1976-1980	0.9887	0.9943	0.9944
1981-1985	0.9941	0.9990	0.9951
1986-1990	1.0018	1.0025	0.9993
1991-1995	0.9979	0.9987	0.9991
1996-2001	0.9955	0.9956	0.9999
1971-2001	0.9950	0.9981	0.9969
Switzerland			
1971-1975	0.9855	1.0007	0.9848
1976-1980	0.9953	0.9993	0.9960
1981-1985	0.9932	1.0017	0.9915
1986-1990	1.0017	1.0033	0.9984
1991-1995	1.0041	1.0038	1.0004
1996-2001	0.9980	1.0001	0.9979
1971-2001	0.9963	1.0014	0.9949

Table 5 (cont.)

	$\widehat{W}_{LXM}$	$\widehat{W}_{LA}$	$\widehat{W}_{LB}$
United Kingdom			
1971-1975	0.9757	1.0040	0.9718
1976-1980	0.9740	0.9977	0.9762
1981-1985	0.9864	0.9998	0.9867
1986-1990	0.9964	0.9998	0.9967
1991-1995	0.9929	1.0002	0.9927
1996-2001	1.0026	0.9984	1.0043
1971-2001	0.9884	0.9999	0.9885
United States			
1971-1975	1.0037	0.9907	1.0132
1976-1980	0.9986	0.9893	1.0093
1981-1985	1.0061	1.0061	1.0000
1986-1990	0.9987	0.9965	1.0022
1991-1995	1.0018	1.0011	1.0006
1996-2001	1.0008	1.0019	0.9989
1971-2001	1.0016	0.9977	1.0039