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**COMPUTER PRICE INDICES AND INTERNATIONAL GROWTH AND PRODUCTIVITY  
COMPARISONS**

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*\* The opinions expressed in this paper are at the sole responsibility of the author, and do not necessarily reflect those of the OECD or of the governments of its Member countries.*

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## 1 Introduction and conclusions

Recently, several articles and publications<sup>1</sup> have revived a discussion about the international comparability of the rates of economic growth and productivity. Each of these publications pointed to methodological differences between the United States and European countries in the computation of price indices for information and communication technology (ICT) products and asked whether some of the differences in measured growth performance reflect a statistical phenomenon rather than a real one.

The same question has been raised in the context of the OECD Growth project whose analytical conclusions rest on the comparability of the measured rates of economic growth between OECD countries. Several intermediate reports (e. g., Scarpetta et al. (2000)) have highlighted these measurement issues and underlined the need for a careful interpretation of cross-country comparisons.

This note aims at shedding additional light on some of these points. It does so by discussing the possible consequences for measures of economic growth of replacing one set of price indices by another one in the framework of national accounts. The note points out that the issue of ICT deflators cannot be discussed in isolation - any assessment of potential statistical biases has to take several other factors into account, in particular whether the products under consideration are final or intermediate products, whether they are imported or domestically produced and whether national accounts are set up with fixed or chain weighted index numbers. Another important point draws on the distinction between aggregate measures (such as total volume GDP) and disaggregate or component measures (such as volume growth of investment, or volume measures of output in a particular industry).

The paper reaches the following main conclusions:

- When price indices are adjusted in a national accounts framework, some or all of the resulting measurement effects can counter-balance each other at the aggregate level. Offsetting forces are at work when the products under consideration are intermediate products and/or imported from abroad.
- Empirical evidence for several OECD countries supports this conclusion and shows that the impact on aggregate measures of GDP volume growth of replacing one set of ICT deflators by another one is likely to be small. As a consequence, the impact on aggregate measures of labour productivity growth remains limited.
- Conversely, disaggregated measures of outputs, inputs and productivity are likely to be much more affected. An empirical assessment that simulates the effects of using the United States ICT price indices in other countries' investment series confirms this point. The simulation also explores different ways of transposing these price indices. For example, adjustments can be made for overall inflation or exchange rate shifts. It is found that results are quite sensitive to the choice between these methods.

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1. “America’s hedonism leaves Germany cold”; *Financial Times*, 4 September 2000 ; “Apples and Oranges”; *Lehman Brothers Global Weekly Economic Monitor*, September 2000; *Monthly Report of the Bundesbank*, August 2000; “The New Economy has arrived in Germany – but no one has noticed yet”; *Deutsche Bank Global Market Research*, 8. September 2000; Wadhvani, Sushil, “Monetary Challenges in a New Economy”; Speech delivered to the HSBC Global Investment Seminar, October 2000.

- A mixed picture arises with regard to measurement effects on multifactor productivity growth. When a different set of ICT deflators is used, the adjustments to MFP growth are not always large, although they can be quite important in absolute and relative terms as the case of Finland shows.
- Measures of the growth contribution of ICT capital are certainly strongly influenced by the choice of deflators: for a small sample of countries that do not use hedonically adjusted ICT price indices in their national statistics (Finland, Germany, Italy), the measured contribution of ICT capital to economic growth roughly doubles over the period under consideration.

## 2 Measurement of ICT prices<sup>2</sup>

Price indices are constructed by comparing prices of sampled products between two periods in time. Two conditions have to be fulfilled for this to yield reliable estimates: the products in the sample have to be representative of a whole product group and they should be comparable between the two periods. Rapid technical change means that neither condition easily holds in the case of ICT goods such as computers: models change very rapidly, and the price collector finds himself or herself in a position of comparing two non-identical products. And if only prices of those models that can be found in both periods are compared, there is a risk of using a non-representative sample.

In a situation where the price collector has to compare two different models, the fundamental question is: how much of an observed price change is due to quality change and how much is a true change in prices?

Consider the following example: in year 1, an old model costs 100; in year 2, a new model costs 90. How does one split the observed price change of 10 into a price and a quality component? What is missing here is the price that the old model would have fetched in year 2, had it still been on the market<sup>3</sup>. Suppose we knew that price, and suppose it is 80. Then it would be easy to state that the price change between the two periods is  $80-100 = -20$  and that the quality change equals  $+10$ .

|           | Year 1             | Year 2 |
|-----------|--------------------|--------|
| Old model | 100                | [80]   |
| New model | Does not exist yet | 90     |

But the price of the old model in year 2 is not known, and the price statistician, implicitly or explicitly, has to make some estimate. Simply ignoring the model change and calling  $-10$  the true price decline is tantamount to saying that there has been no improvement in quality, or that the price of the old model in year 2 would have been 90 as well. As a consequence, the fall in prices would have been understated by half. Thus, to get price changes right, a more informed estimate of the year 2 price of the old model is

2. For a full discussion of hedonic price indices see OECD (2001c).

3. This is a simplified example. Strictly speaking, looking for a price of the old model in year 2 is correct only if the price index uses expenditure weights of period 1, i.e., if it is formulated as a Laspeyres-type index. Under a Paasche price index, weights of period 2 are relevant, and one would seek a proxy for the price of the new model in year 1.

required. Such an estimate may come from expert advice, from “option pricing<sup>4</sup>”, or from some observation about the price at which the old model is traded on second-hand markets.

The hedonic method is a systematic way to obtain an informed estimate for the price of 80. Hedonic methods have been compared with the repackaging problem that arises with more common products: to compare a price quote for a 2-kilo box of oranges with one for a 1-kilo box, statistical agencies compute a price per kilo. If computers had only one characteristic, say processing speed, the price for a 1000 Mhz computer could be converted into a price per megahertz and then compared with the price per megahertz that was collected for a 500 Mhz computer. However, there are multiple computer box characteristics (speed, storage capacity, peripheral equipment, software etc.). By observing a sufficiently large number of computer models, it is possible to establish a systematic relationship between price and characteristics. Coefficients in a hedonic regression represent marginal prices for each of the characteristics. One can then infer a hypothetical price for the old computer model in year 2 by using the information about its technical characteristics (which are known from period 1) and so obtain an approximation to the true price change.

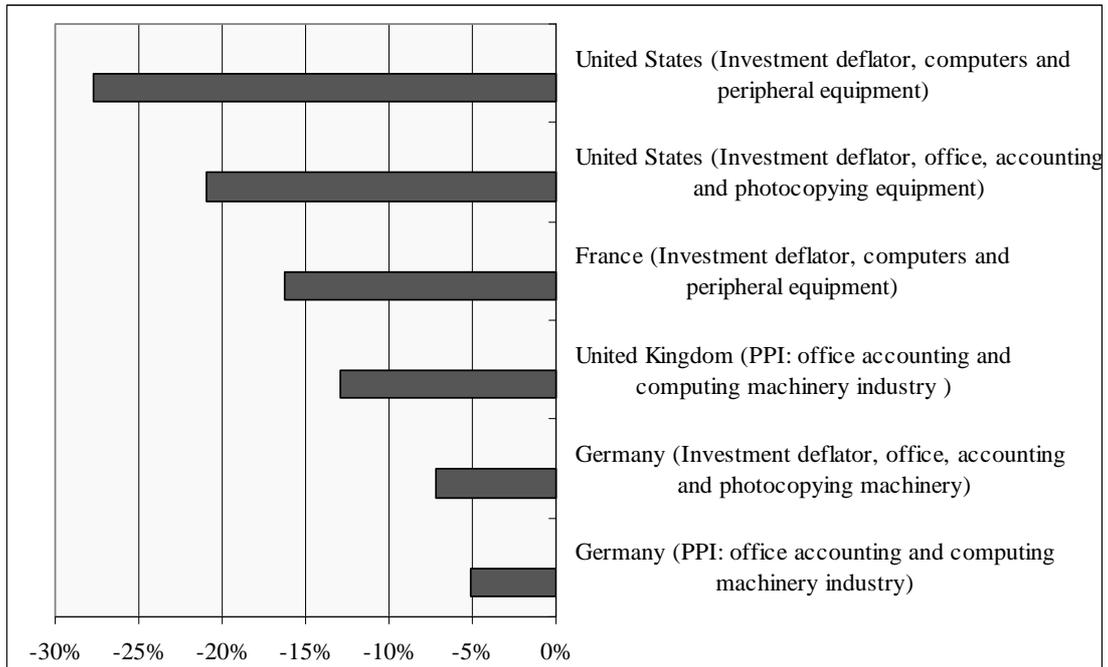
A number of countries use such hedonic methods, among them the United States who construct hedonic functions for different types of computers and peripheral equipment, semiconductors and software. Canada, Japan, France and some other countries have also developed their hedonic functions or adopted those of the United States. For ICT products, the hedonic method tends to yield price changes that drop more rapidly than price indices based on other estimates.

Figure 1 shows computer-related price indices (either producer price indices or investment deflators) for several countries. Both the United States and France employ hedonic price indices for ICT products, albeit not for the same range of products. No hedonic adjustment is carried out in the United Kingdom or Germany. One notes that, nonetheless, the UK producer price index falls comparatively fast<sup>5</sup>.

The cross-country variation in price decline has either been taken as a sign that conventional estimates understate true price changes, or as an argument to dismiss hedonic methods as producing unrealistically rapid price declines for some goods and thus overstate true price changes<sup>6</sup>. However, to date, few convincing arguments have been brought forward why hedonic methods should overstate price changes. If one accepts that the computer industry produces computing power, rather than computer ‘boxes’, the hedonic approach would seem to be much closer to the true price developments than some of its alternatives. A rising number of statistical offices recognise the usefulness of the hedonic approach, and a report by Eurostat (2001) qualifies the hedonic method as the preferred one in the field of computer and software price indices.

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4. Option pricing is a technique used, for example by the United Kingdom’s statistical office: If the difference between two models A and B is the inclusion of an extra characteristic (or option), for example a CD-ROM drive in a PC, this extra characteristic could be valued by its price when purchased separately. Thus, if B includes a CD-ROM drive, then its price can be reduced by the price of that drive to arrive at an estimate for the price of A, which didn’t have the CD-ROM, in period t. Clearly, this method is only possible when the quality difference can be described in this way and when a separate price for the option exists. Note that this method uses actual prices and not costs. In some cases, a separate price for the new option will not exist. In such cases the producer can be asked how much the new characteristic costs to produce. Note that in this method costs are used instead of prices, so that the value to the user is not taken into account. The method can be improved in this respect by including also the producer’s normal profit margin.
  5. This is an indication that the UK statistical office uses other methods to calculate quality change in computer models. It can also stem from a pricing practice where old models whose prices reflect rapid obsolescence, are kept in the sample as long as they are available.
  6. For a discussion of hedonic methods, see Triplett (1990).

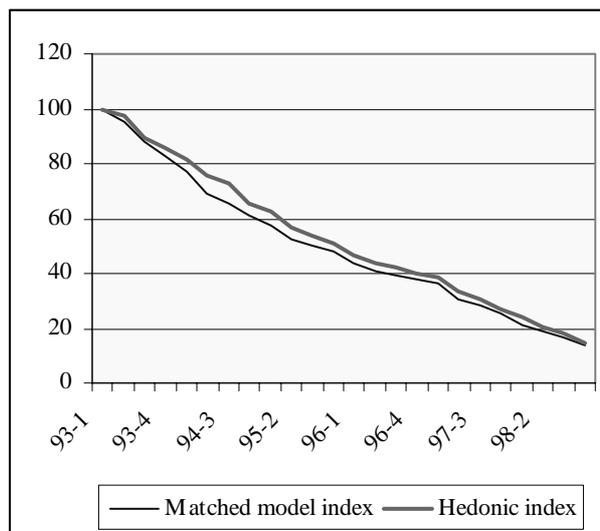
**Figure 1: Price indices for computers and office equipment**  
**Average annual rates of change, 1995-99**



Source: National sources and *OECD Indicators of Industrial Activity*.

A recent study by Aizcorbe et al. contrasts the widely held view that only hedonic functions generate steep price declines in high-technology goods. The authors use a very detailed and high-frequency (quarterly) data set for computers and semiconductors and apply a traditional matched-model technique to establish a price index. They compare their findings with a hedonic-based price index and find very similar trends in the 1990s, in particular an acceleration in the rate of decline in computer prices in the late 1990s.

**Figure 2 Hedonic and matched-model indices based on high-frequency, disaggregate data**  
**Personal desktop computers**



Source: Aizcorbe et al. (2000).

Figure 2 shows one result from the study by Aizcorbe et al. that relates to desktop computers. Over the period 1993-98, and based on quarterly observations, the price index based on 'traditional' matched model techniques fell by about 29% per year. Its hedonic counterpart fell by slightly less, 28.2% at annual rates. Similar results were found for notebook computers and microprocessors. This suggests that when very disaggregated data on prices and quantities of high-tech products are available at high frequency, matched model price measures will generally capture the rapid pace of quality change in these goods. The focus of the discussion then moves away from a comparison of methods (hedonics against matched models) towards one of the merits of collecting detailed and high frequency data over aggregate and less frequent data.

### 3 Impact on measured volume GDP

#### *3.1. Final or intermediate product?*

A first, and important distinction in the assessment of the effects of hedonic deflators is whether the product under consideration is used as an intermediate or a final product. In other words, is it a product that is delivered to other, downstream industries where it becomes part of another product (such as semiconductors that are delivered to a mobile phone factory) or is it a product that is bought by final consumers (such as a personal computer)?

To understand the importance of this distinction, consider a typical intermediate product, say semiconductors and suppose that they are exclusively sold to other industries, i.e., there are no exports. Next, suppose that a statistical office adjusts downwards its deflator for semiconductors. The measured rate of growth of volume gross output of the semiconductor industry will rise, and so will measured real value-added of the semiconductor industry<sup>7</sup>. But at the same time, the measure of real intermediate inputs will also rise for other industries, namely the ones that buy semiconductors: their combined measured real value-added will decline by just the amount that the semiconductor industry's real value added measure has increased. The economy-wide effect is zero - what has changed, are the measured contributions to growth by particular industries: the semiconductor industry will now feature a larger contribution than before and its downstream clients come out with a lower contribution to volume GDP growth than before. Such a shift in the measured contribution is, of course, an important change (because it tells a different story about the sources of growth). But it also shows that one cannot readily jump to conclusions about the macro-economic effects of the choice of price indices.

If on the other hand, a new deflator is used for a product that is mainly delivered to final demand, volume measures of aggregate final demand and GDP will be affected. This is certainly the case for personal computers, which are more often bought as investment goods or as durable consumer goods than as intermediate products. Suppose that computers are entirely final products, and suppose that their price index is changed from an annual decline of 5% to 15%. It would now seem straightforward to calculate the effect on measured volume GDP growth as the share of personal computers in total investment or private consumption times the 10 percentage point shift: thus, if personal computers account for 2% of private consumption expenditure, the measurement effect on total consumption is  $0.02 \times 0.1 = 0.002$  or 0.2% per year. Note, however, that the present calculation is only valid if all personal computers have been produced domestically - a rather unrealistic assumption for a large number of OECD countries. This gives rise to the second qualification regarding the impact of hedonic price indices, namely the role of imports.

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7. Note: the rate by which the volume value added measure changes is not the same as the one by which the volume gross output measure changes.

### 3.2. *Imported or domestically produced computers?*

The second important piece of information to assess the impact of a change in price indices on macro-economic growth and productivity is the degree to which the product under consideration is imported. Total constant price<sup>8</sup> GDP is the sum of private consumption ( $C$ ), investment ( $I$ ), government consumption ( $G$ ), exports ( $X$ ) minus imports ( $M$ ):

$$GDP = C + I + G + X - M \quad (1)$$

Suppose that the volume measure of investment and private consumption rises as a consequence of adjusting the deflator for computers. If parts or all of these products are imported, one also has to adjust the price index for imports and the measured rate of volume imports will go up. But imports enter the GDP calculation with a negative sign and so will partly or entirely offset the positive measurement effect from the other expenditure components. Thus, the use of a different deflator for certain products will almost certainly change the measured contributions of individual demand components to macro-economic growth but if the products under consideration are imported, these effects will be partly or entirely offsetting.

There is yet another possibility where imported products are used as intermediate inputs. Semiconductors, mentioned before, are a point in case. Adjusting (downwards) the price index for imports, and consequently upwards the volume index for imports leads to a *fall* in the measured rate of volume GDP growth, that is not counter-balanced by an increase in measured volume growth of investment or private consumption<sup>9</sup>. In this case, the absence of hedonic deflators in a country's national accounts implies an *overstatement* of real GDP growth (assuming that hedonic deflators represent a preferred measure). Note that this statement holds only if no other price index is changed at the same time – if the correction of the input price index leads also to a correction of the output price index, one faces again a situation of offsetting effects with no or very little impact on measured GDP growth.

### 3.3. *A quantitative assessment*

To obtain an order of magnitude for the impact of price adjustments of ICT products on the rate of change of volume GDP, a simple calculation was carried out (for details see Annex). It consisted in evaluating a 'multiplier' or coefficient by which price index adjustments of ICT products would carry over to measured GDP growth rates. Results and methodology are presented in the Annex. The 'multiplier' is the factor by which an adjustment to an ICT price index has to be multiplied to obtain a measure for its impact on volume GDP growth:

$$\begin{aligned} \% \text{ point adjustment to rate of volume GDP change} &= \\ &= \text{'multiplier'} \times \% \text{ point adjustment to ICT price index} \end{aligned}$$

This assessment is a simplified procedure. It should be noted that: (a) no statement is actually made about the size of a possible adjustment of the price index. The multiplier indicates only by how much measured GDP volume growth would rise or fall if price indices for ICT products are adjusted by any given rate for

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- 8 . Additivity between constant-price components of GDP of a given year only holds when national accounts are based on Laspeyres quantity indices, which is often the case. However, the additivity assumption is in no way essential for the discussion at hand and has only been used for simplicity.
- 9 . If imported semiconductors are added to inventories, rather than directly used as intermediate inputs, the rise in measured volume of inventories would offset the rise in measured volume of imports, and the effect on measured real GDP would again cancel out.

an individual country; (b) the multiplier itself is not a point estimate and is presented with an upper and a lower bound; (c) abstraction is made from index number issues (such as the ones outlined in section 3.4) because calculations are based on a ‘superlative’ Törnqvist index number formula.

The results point to only modest effects: even under the (unrealistic) upper bound of the ‘multiplier’, implications for measured GDP growth rates are likely to be small. For example, if output price indices of the office machinery and computer industry in Germany were adjusted downward by 10 percentage points per year, and applying the upper bound of the multiplier in Annex Table 1, this would result in a hypothetical upward adjustment of German GDP volume growth by  $0.009 \times 10\% = 0.09$  percentage points per year.

More systematic evidence that also takes into account index number effects (see next section) but for a smaller number of countries, and for the early 1990s only, arises from a simulation exercise for five OECD countries (Schreyer 2000b). The study uses a set of quality-adjusted price indices for computers, semiconductors, telecommunication equipment, communication services and computer services to assess the impact on measured final demand components and GDP in volume terms. The overall conclusion from this simulation is again one of comparatively small effects on measured GDP – because ICT products are imported and/or constitute intermediate inputs to the economy.

Similar, Lequiller (2001) examines the issue of a downward adjustment of computer and software price deflators and their effects on measured GDP growth in France empirically and finds a modest effect of +0.04% per year for the annual rate of growth between 1995 and 1998. Recently, Landefeld and Grimm (2000) reviewed the impact of hedonic price indices on aggregate volume growth in the United States. They find that only a small share of the increase in measured growth in the latter half of the 1990s is associated with the use of hedonic price indices. Landefeld and Grimm estimate that the quality change in personal computers adds, at most, one quarter of a percentage point to the estimate of annual real GDP growth over the period 1995-99. While higher than the Figure for France, this has to be put in proportion to a rate of real GDP growth of 4.15% per year in the United States.

### ***3.4. Index number formula***

Whenever price or quantity indices of two non-adjacent periods have to be compared, the question arises which period should be taken as a basis for comparison. One option is to choose the first or last observations as the base and carry out a direct comparison (‘fixed weight’ Laspeyres or Paasche index). Another option is to use the chain principle. Under the chain principle, the price or quantity change between two non-adjacent periods is calculated by linking the indices for consecutive periods. This choice matters little, as long as relative prices between goods remain stable. However, when there is a change in relative prices of the commodities that make up the index, Laspeyres fixed-weighted volume indices tend to place too much weight on goods or services for which relative prices have fallen and too little emphasis on items for which relative prices have risen. Chain weighted volume indices, on the other hand, successively reduce the weight of items whose relative prices fall and increase the weight of items whose relative prices rise. Generally, there will be a more rapid volume increase than average in those items whose relative prices fall. As a consequence, chain-weighted volume indices combine falling price weights with rising quantities and vice versa. Fixed weight volume indices, on the other hand, combine unchanged price weights with rising or falling quantities. This may lead to a ‘substitution bias’ that is potentially present in all fixed-based indices.

The difference between fixed and chain-weighted indices becomes highly visible when relative prices of underlying products change rapidly. This is precisely the case with hedonically adjusted computer price indices. In other words, using rapidly changing relative prices in a context of fixed-weight Laspeyres

quantity index numbers will lead to an *overstatement* of volume growth in periods after the base year. The issue is illustrated in the table below where the 1997-98 volume growth rate of GDP in the United States is calculated on the basis of different index number formulae. One is the official, chain-weighted volume index. It shows a growth rate of 4.3%. The rate of growth for the same year, based on a fixed-weight quantity index with 1995 price weights, amounts to 4.5%. This difference is still within bounds, given the relative proximity of the base year. However, when a 1990 price base is used, measured real GDP growth in 1998 is already 6.5% and the growth rate moves to a staggering 18.8% when based on 1980 prices.

**Table 1: Growth rate of volume GDP based on different index number formulae and base years**  
United States, 1997-98

|   |      |
|---|------|
| GDP growth rate based on chain (Fisher) volume index                  | 4.4  |
| GDP growth rate based on fixed-weight volume index<br>with base year: |      |
| 1995  | 4.5  |
| 1990  | 6.5  |
| 1980  | 18.8 |

Source: Whelan (2000).

What follows is that using hedonic price indices in a context of fixed-base Laspeyres index numbers almost certainly implies overstating volume GDP growth in years following the base year, and understating volume GDP growth in years prior to the base period. This means that it would be misleading to simply transpose price indices, say from the United States, to national accounts computations in other countries that do not use chain-weighted index numbers in their accounts.

To illustrate, consider again Table 2 with simulations for France. There are sizeable index number effects for investment and export growth: in essence, they correspond to the substitution bias that would have been caused by the use of fixed-weight Laspeyres index numbers. By using a chain-weighted ('superlative') index number, the overall effects on volume GDP growth from introducing more rapidly falling ICT prices are attenuated, and now amount to 0.13 percentage points per year.

**Table 2: Simulation of effects of quality adjustment  
France, 1985-96, percentage changes at annual rates**

|  | Private<br>consumption<br>expenditure | Government<br>expenditure | Investment | Exports | Imports | Total final<br>demand |
|--|---------------------------------------|---------------------------|------------|---------|---------|-----------------------|
| Fixed-weight (Laspeyres)<br>volume index, no quality<br>adjustment (A)   | 2.14                                  | 2.04                      | 1.53       | 4.28    | 4.28    | 2.01                  |
| Fixed-weight (Laspeyres)<br>volume index, full quality<br>adjustment (B) | 2.25                                  | 2.04                      | 2.44       | 4.86    | 4.95    | 2.22                  |
| Quality adjustment effect under<br>fixed weights (B-A)                   | 0.11                                  | 0.00                      | 0.91       | 0.58    | 0.67    | 0.21                  |
| Superlative (Fisher) volume<br>index, full quality adjustment (C)        | 2.18                                  | 2.03                      | 2.21       | 4.71    | 4.99    | 2.13                  |
| Index number effect (C-B)  | -0.07                                 | -0.01                     | -0.23      | -0.15   | 0.03    | -0.08                 |
| Total effect (C-A)   | 0.04                                  | -0.01                     | 0.68       | 0.43    | 0.71    | 0.13                  |

1. See source for full description of methodology.

Source : Schreyer (2000b).

#### 4 Impact on measured volume investment growth

Whereas the measurement effects of ICT deflators on aggregate GDP growth are likely to be small, there is little doubt that the international comparability of the rates of investment in computer capital is affected when traditional price indices deviate from hedonic price indices. Typically, the former fall less rapidly than the latter and the measured rate of volume investment growth will thus be slower under the former than under the latter. Because expenditure on computer capital goods presents a sizeable portion of investment in machinery and equipment and even of total investment, these indicators are likely to be affected as well.

Analytical studies have to take this issue into account. Schreyer (2000a) and OECD (2001a) use a 'harmonised' deflator for information and communication technology products and for software investment to adjust at least roughly for differences in price index methodology between countries. This remains an approximation, though, and cannot replace more systematic efforts by countries to use similar methodologies in the construction of their price indices. But the adjustment permits a comparison between investment measures constructed with national and those based on 'harmonised' deflators.

Thus, one way of assessing the effects of the choice of price index methodologies on measures of investment, output or productivity is to reconstruct the same measure with a different underlying deflator. In particular, it is instructive to replace national price indices by those used in the United States, as comparisons and discussions about measurement issues frequently focus on the comparison with the United States. However, there are several possibilities for transposing the US deflators to other countries' accounts for purposes of such a simulation. Here, three such possibilities were explored:

First, usage of the United States deflator, unadjusted for domestic inflation. This constitutes the most direct way of transposing a price index from one country to another. The underlying hypothesis is that nominal prices of ICT products change at the same rate in different countries: a 20% fall of computer prices in the United States translates into a 20% decline of the same price index in Italy. Letting  $p_{ICT}^{US}$  be the price index of the ICT product in the United States, and  $\tilde{p}_{ICT}^{Other}$  the 'harmonised' price index for the same product group in another country, the usage of the United States deflator, unadjusted for domestic inflation implies:  $\Delta \ln(\tilde{p}_{ICT}^{Other}) = \Delta \ln(p_{ICT}^{US})$ . Arguably, this simple transposition assumes away the fact that different countries may experience different changes in the overall price level. In this case, one would not expect the same nominal rate of price change between countries and it would seem preferable to control for economy-wide inflation. The second measure represents such an adjustment.

Second, usage of the United States deflator, adjusted for domestic inflation. To control for domestic inflation in the construction of a harmonised price index, the following assumption is made: the relative price change of the ICT product under consideration should be the same across countries. The relative price is expressed as the price index of the ICT product divided by the price index for non-ICT products ( $p_{ICT}^{US} / p_N^{US}$ ,  $p_{ICT}^{Other} / p_N^{Other}$ ). The rate of change of the 'harmonised' price index of a country other than the United States is then given by:  $\Delta \ln(\tilde{p}_{ICT}^{Other}) = \Delta \ln(p_N^{Other}) + \Delta \ln(p_{ICT}^{US}) - \Delta \ln(p_N^{US})$ . Thus, if ICT prices in the United States rise by 10 percentage points per year less than prices for non-ICT goods, this carries over to other countries and makes the 'harmonised' deflator independent of the overall price level that prevails in the different countries.

A third way of constructing a 'harmonised' deflator uses an exchange rate adjustment. This is a plausible approach if the ICT product is internationally traded and/or imported into the country under consideration. One problem is that shifts in exchange rates are not always fully passed on to domestic consumers. To the

extent that this is not the case, exchange rate adjustments may under- or overstate the price change in domestic currencies. One notes that the exchange rate adjustment implicitly reflects cross-country differences in overall inflation, as long as exchange rates are floating and responsive to changes in a country's price level. More formally, the adjusted price change in a country is given by:  $\Delta \ln(\tilde{p}_{ICT}^{Other}) = \Delta \ln(p_{ICT}^{US}) + \Delta \ln(e_{US}^{Other})$  where  $e_{US}^{Other}$  is the bilateral exchange rate between the country under consideration and the United States. In some countries (for example Australia) this method is used to 'import' the United States' price index for personal computers into national accounts

Table 3 presents results of such a comparison. It shows the average annual growth rate of volume investment in the business sector of several OECD countries. Alternative measures reflect different price indices for the three ICT capital goods that form part of aggregate investment: software, information technology hardware and communication technology. Three types of 'harmonised' deflators were used in comparison but they have in common that they all are based on the national United States deflator for these products (see Box 2).

**Table 3 Gross fixed capital formation: alternative deflators for ICT assets**  
Törnqvist volume index, percentage changes at annual rates, 1990-99

|               | Based on:         |   |   |  |
|---------------|-------------------|---|---|--|
|               | National deflator | United States deflator, adjusted for domestic inflation | United States deflator, unadjusted for domestic inflation | United States deflator, adjusted for exchange rate movements |
| Australia     | 4.3%              | 3.8%  | 4.1%  | 3.7%   |
| Canada        | 3.6%              | 3.9%  | 4.0%  | 3.8%   |
| Finland       | -1.8%             | -0.2%   | -0.4%   | -1.0%  |
| France        | 3.8%              | 4.2%  | 4.0%  | 3.9%   |
| Germany*      | 0.3%              | 0.6%  | 0.8%  | 0.6%   |
| Italy         | 1.8%              | 2.7%  | 3.0%  | 2.2%   |
| Japan         | -2.2%             | -1.9%   | -1.9%   | -1.8%  |
| United States | 7.4%              | -   | -   | -  |

\*1991-99

Source: based on OECD (2001a).

**Table 4: Gross fixed capital formation: index number effect**  
 Volume indices, percentage change at annual rate 1995-99  
 Based on United States deflator, adjusted for domestic inflation

|               | Flexible-weight<br>index (1) | Fixed-weight<br>index (2) | Index number<br>effect: (2) - (1) |
|---------------|------------------------------|---------------------------|-----------------------------------|
| Australia     | 7.3%                         | 7.6%                      | 0.3%                              |
| Canada        | 9.3%                         | 9.7%                      | 0.4%                              |
| Finland       | 10.4%                        | 10.6%                     | 0.2%                              |
| France        | 8.3%                         | 8.7%                      | 0.4%                              |
| Germany       | 5.0%                         | 5.3%                      | 0.3%                              |
| Italy         | 6.4%                         | 6.8%                      | 0.4%                              |
| Japan         | 0.9%                         | 1.1%                      | 0.3%                              |
| United States | 10.7%                        | 12.3%                     | 1.6%                              |

*Note: Flexible-weight index represents a Törnqvist formula; the fixed weight index represents a Laspeyres-type quantity index with 1995 price weights.*

*Source: based on OECD (2001a).*

Several conclusions can be drawn from this comparison:

- first, the use of the United States deflators in other countries does not automatically raise these countries' measures of volume investment growth. Little impact or even a downward adjustment is observed in those countries whose national deflator is also based on a hedonic methodology, such as Australia, Japan, Canada and France. Conversely, simulated adjustments are more important for those countries that do not use hedonic prices in their national statistics. In the sample in Table 3, these are Finland, Germany and Italy;
- second, the size of the adjustment varies considerably with the specific type of adjustment methodology – for example whether the United States deflator is or is not adjusted for exchange rate movements. The difference between alternative harmonised deflators can be as large as the difference between the national and any of the harmonised deflators;
- third, the effects simulated in Table 3 reflect the use of a flexible-weight index number (Törnqvist index). This will tend to produce smaller differences between national and harmonised deflator than a comparison based on a fixed-weight index number. To elaborate on this point, consider Table 4. It shows the rate of change of volume investment per year, based on one of the harmonised deflators, but with two different index number formulae. The 'flexible-weight' column stands for the results based on a Törnqvist index number whose weights are averages of the years under comparison. The 'fixed-weight' column stands for a Laspeyres-type quantity index with weights for each type of investment good fixed in the year 1995. Because national accounts base years are typically updated every five years, 1995 represents a plausible choice for the base year. As one would expect, the rates of investment growth are higher under the fixed-weight formula for all countries. The difference is particularly accentuated for the United States where large investment in ICT assets were accompanied by large changes in relative prices;
- fourth, while the use of hedonic deflators can have a noticeable impact on measured rates of volume investment, it is also apparent that the basic patterns and ranking of countries

with respect to their investment activity hardly changes with a different deflator; In particular, a sizeable gap remains between volume investment growth in the United States and other countries throughout the 1990s, and different types of price indices cannot account for this discrepancy.

## 5 Impact on aggregate productivity measures

To the extent that a change in price indices affects the volume growth of gross output and value-added by industry, it will also affect the rate of labour productivity growth. If measures of aggregate volume GDP growth change, so will measures of aggregate labour productivity and the growth rate of per-capita income. Given that the quantitative impact of hedonic measures on GDP volume changes is likely to be small, aggregate labour productivity growth measures will only be affected by the same small degree.

The picture is more complicated when it comes to measures of multi-factor productivity (MFP). Typically, MFP growth is measured residually, in the simplest case by subtracting the weighted growth rates of labour ( $L$ ) and capital inputs ( $K$ ) from the growth rate of real value-added ( $Q$ ). The current-price shares of labour and capital in value-added ( $s_L, s_K$ ) form the appropriate weights:

$$\Delta \ln(MFP) = \Delta \ln(Q) - s_L \Delta \ln(L) - s_K \Delta \ln(K) . \quad (2)$$

The above expression shows that the adjustment of a price index for capital goods (such as computers) has two effects. One, it may affect the rate of volume output growth,  $Q$ . If this effect is positive, this will raise measured MFP growth. At the same time, however, a downward adjustment of investment goods prices will raise measured volume growth of investment, and consequently, the growth rate of capital input  $K$ . This *reduces* measured MFP growth because a larger quantity of primary inputs is recorded in the production of output. The net effect on measured MFP growth is, *a priori*, unclear. However, at the aggregate level, the net effect is likely to be negative, especially if computers (or any other investment good whose price index is adjusted downwards) are exclusively or mainly imported. In this case, measured volume growth of GDP remains unchanged (see discussion above) but measured capital input will rise, and measured MFP growth will decline.

For some quantitative indications, consider Table 5. It reproduces measures of multi-factor productivity for the total business sector under two different assumptions regarding the price indices of ICT capital goods. It should first be noted that only the capital services measure was adjusted, not the measure of output, and in this sense, Table 5 is only a partial assessment of the effects of hedonic price indices on MFP growth rates. However, this is of secondary importance here because the adjustments shown in the table are small. As the omitted adjustments of output growth would influence MFP measures with the opposite sign from the influence of the adjusted capital measure, the net overall effect on MFP growth would be even smaller than shown below.

**Table 5: Multi-factor productivity: effects of ICT deflators**  
Percentage change at annual rate, 1995-99

| With capital service measures based on: |   |                    |
|---|---|--------------------|
|   | United States<br>deflators, adjusted<br>for domestic<br>inflation | National deflators |
| Australia                               | 2.0%  | 1.8%               |
| Canada                                  | 1.1%  | 1.2%               |
| Finland                                 | 3.4%  | 3.8%               |
| France                                  | 0.8%  | 0.9%               |
| Germany                                 | 0.8%  | 0.9%               |
| Italy                                   | 0.1%  | 0.3%               |
| Japan                                   | 0.5%  | 0.6%               |
| United States                           | 1.3%  | 1.3%               |

Source: based on OECD (2001a).

For several countries, the switch from national to ‘harmonised’ ICT deflators reduces measured MFP growth, the most visible case being Finland. This fall in measured MFP simply means that a larger share of output growth has been attributed to capital, and away from ‘disembodied’ technical change that the MFP measure reflects. This is consistent with the underlying adjustment: a more rapidly falling price index for ICT capital goods is equivalent to a larger volume of quality-adjusted capital input: technology is shifted from the ‘disembodied’ MFP representation to a contribution embodied in capital goods<sup>10</sup>. Not surprisingly, the effects on aggregate measures of MFP growth are quite small for Australia, Canada, France and Japan, as these countries use hedonically-adjusted price indices in their national statistics. On the other hand, measurement effects are limited for Germany – a country that does not use rapidly declining deflators based on hedonic methods. For obvious reasons, effects are zero for the United States.

Growth accounting studies such as Jorgenson and Stiroh (2000), Oliner and Sichel (2000), Cette et al. (2000) or OECD (2001a) have identified the contribution of ICT capital to output growth. They do so by measuring ICT capital and its income share separately. In this case, the changes shown in Table 5 would exclusively be due to a modified ICT capital measure and/or ICT income share. This can be seen by re-writing equation (2) in a growth accounting context, where contributions of labour, capital and MFP to output growth are identified:

$$\Delta \ln(Q) = s_L \Delta \ln(L) + s_K \Delta \ln(K) + \Delta \ln(MFP). \quad (3)$$

When the contribution of ICT capital is identified separately, this becomes

$$\Delta \ln(Q) = s_L \Delta \ln(L) + s_K^{Other} \Delta \ln(K^{Other}) + s_K^{ICT} \Delta \ln(K^{ICT}) + \Delta \ln(MFP). \quad (4)$$

where  $s_K^{ICT}$  and  $\Delta \ln(K^{ICT})$  are the income share and the rate of change of ICT capital, and  $s_K$  and  $\Delta \ln(K^{Other})$  are the income share and the rate of change of non-ICT capital. The table below reproduces results from an OECD study to assess the contribution of ICT capital to output growth. Thus, the data

10. See Bassanini et al. (2000) and OECD(2001b) for a discussion of embodied and disembodied technical change and MFP measures.

correspond to the term  $s_K \Delta \ln(K)$  in expression (4). These contributions are presented on the basis of the national and a harmonised deflator (adjusted for domestic inflation). The difference shown in the third column corresponds to the adjustment to the measured growth contribution, when price indices are changed. These differences, expressed as percentage points, are equal to the differences between the two MFP measures in Table 5. However, whereas the same adjustment effect may be comparatively small when the focus is on the MFP measure, it can be large in the context of a growth contribution. For example, measured MFP growth for Germany would be adjusted by about 0.1 percentage points, when a harmonised ICT deflator is applied. This seems a modest adjustment to a 0.9% growth rate of MFP. However, it is a large modification to a growth contribution of ICT capital over the same period 1995-99 that is adjusted upwards from 0.19 to 0.29 percentage points. In the case of Finland, both the MFP adjustment and the adjustment to the growth contribution are significant in absolute and relative terms.

**Table 6: Growth contribution of ICT capital: effects of ICT deflators**  
Percentage changes at annual rate, 1995-99

|           | United States<br>deflators, adjusted<br>for domestic<br>inflation (1) | National deflators<br>(2) | Difference<br>(1)-(2) |
|-----------|---|---------------------------|-----------------------|
| Australia | 0.61  | 0.79                      | -0.18                 |
| Finland   | 0.58  | 0.22                      | 0.36                  |
| France    | 0.35  | 0.27                      | 0.08                  |
| Germany   | 0.29  | 0.19                      | 0.10                  |
| Italy     | 0.32  | 0.16                      | 0.16                  |
| Japan     | 0.33  | 0.28                      | 0.05                  |

Source: OECD (2001a).

In conclusion, a mixed picture arises with regard to measurement effects on MFP growth. Adjustments are not necessarily large in countries that do not use hedonic deflators but they can be quite important in absolute and relative terms as the case of Finland shows. At the same time, measures of the growth contribution of ICT capital are strongly influenced by the choice of deflators: for those countries in the sample that do not use hedonically adjusted ICT price indices in their national statistics (Finland, Germany, Italy), the measured contribution of ICT capital to economic growth roughly doubles over the period under consideration.

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## ANNEX: ASSESSING THE EFFECTS OF PRICE ADJUSTMENTS ON VOLUME CHANGES OF GDP

**Preliminary remarks.** An evaluation of the effects on the measured growth rate of GDP of an adjustment of the price index of one product can be carried out either by looking at the expenditure or at the production side of national accounts. Consider the production side first. Given that the rate of growth of aggregate GDP or value-added is a weighted average of the rates of value-added change by industry, it would appear simple enough to adjust the constant-price value-added measure of the relevant industry (for example the computer industry) and then multiply the new rate of value-added growth by the industry's share in total value added to obtain a measure for the adjusted overall rate of growth. For two reasons, this is only a partial solution.

First, quality-adjusted price indices for computers are always indices to deflate measures of nominal gross output and their identification with price changes of value-added may be inappropriate because they do not take into account the price changes of intermediate inputs. A preferred price index for value-added is based on some form of 'double-deflation' method, combining deflators of gross output and intermediate inputs. In the present context, this point is of importance as many high-tech industries consume intermediate ICT products whose price changes may in turn be overstated. However, correction for this bias in intermediate goods prices increases the price index of value-added (or reduces the volume index of value-added) of an industry, because intermediate inputs enter measures of value-added with a negative sign. Thus, both output and input prices have to be adjusted to assess the full impact on measured value-added and labour productivity<sup>11</sup>.

Second, inter-industry flows of products have to be considered. Adjustment of one industry's gross output prices may imply adjustment of another industry's intermediate input prices when the former supplies goods to the latter. This is the point made in the main text, namely the degree to which a product is used as an intermediate input in the production of other goods. If the price adjustment is for a product that is delivered to another industry, measures of value-added growth of both industries are affected and effects go in the opposite direction. Semiconductors are a case in point: they are largely intermediate goods (except when exported) and a quality-adjustment of semiconductor output prices will increase measured productivity in the semiconductor industry but reduce the measured productivity growth in semiconductor using industries. On the other extreme, adjustment of output prices of an industry that delivers exclusively to final demand will fully carry over to aggregate GDP measures. The full assessment of inter-industry versus aggregate effects of measurement biases requires a broad set of information on flows of intermediate inputs between industries, which can only be obtained from input-output tables. If only aggregate effects are to be evaluated, a preferred methodology is to examine effects on final demand and its components: private consumption, investment, government consumption and net exports. This is essentially the approach followed here, although a full assessment requires detailed data on demand components by products – a set of information that is not directly available from national accounts data at the international level. Some approximations are therefore necessary, as described below.

**Methodology.** In a simple accounting framework, current-price GDP is the sum of final demand components (*FD*: comprising private and government consumption, capital formation and exports) minus imports (*M*):

$$GDP_t = FD_t - M_t$$

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11 . See Triplett (1996) for an assessment of adjusting input and output prices for the United States computer industry.

Some of the final demand and some of the import expenditure relates to those products whose prices one wants to adjust. In line with the present paper, call them ICT products, so that all other products are non-ICT ones, indexed with a superscript  $N$ :

$$GDP_t = FD_t^N + FD_t^{ICT} - M_t^N - M_t^{ICT}$$

The logarithmic rate of change of volume GDP can be represented as a weighted average of the rate of change of volume final demand and volume imports<sup>12</sup>. Weights are in current prices, representing the ratio of final demand to total GDP and the ratio of imports to GDP. To distinguish volume from current-price series, the former are denoted with small letters, the latter with capital letters:

$$\frac{d \ln(gdp_t)}{dt} = \frac{FD_t^N}{GDP_t} \cdot \frac{d \ln(fd_t^N)}{dt} + \frac{FD_t^{ICT}}{GDP_t} \cdot \frac{d \ln(fd_t^{ICT})}{dt} - \frac{M_t^N}{GDP_t} \cdot \frac{d \ln(m_t^N)}{dt} - \frac{M_t^{ICT}}{GDP_t} \cdot \frac{d \ln(m_t^{ICT})}{dt}$$

Applying a different price index to ICT products is tantamount to using a different rate of volume growth of the ICT components in final demand and import components. The adjusted volume rate of change is marked with a tilde. It is then possible to express the change in the measure of the aggregate volume GDP growth as follows.

$$\frac{d \ln(gdp_t)}{dt} - \frac{d \ln(gd\tilde{p}_t)}{dt} = \frac{FD_t^{ICT}}{GDP_t} \cdot \left( \frac{d \ln(fd_t^{ICT})}{dt} - \frac{d \ln(\tilde{f}d_t^{ICT})}{dt} \right) - \frac{M_t^{ICT}}{GDP_t} \cdot \left( \frac{d \ln(m_t^{ICT})}{dt} - \frac{d \ln(\tilde{m}_t^{ICT})}{dt} \right)$$

Thus, the percentage point change in overall volume GDP depends on the adjustment of the volume growth measures of ICT final demand and imports, each weighted with their current-price coefficient. Another assumption is needed to simplify calculations: the price adjustment for the ICT product be independent of its use. In other words, the reasonable hypothesis is made that there is only one deflator for one product, independent of whether this product is part of imports or one of the components of final demand. Accepting this assumption implies that the percentage point change in the measured quantity (the adjustment) of final demand and import are of the same size. For example, a 10 percentage point upward adjustment of the annual rate of volume growth in computer final demand implies a 10 percentage point upward adjustment of the rate of volume growth in ICT imports:

$$\left( \frac{d \ln(\tilde{f}d_t^{ICT})}{dt} - \frac{d \ln(\tilde{m}_t^{ICT})}{dt} \right) = \left( \frac{d \ln(m_t^{ICT})}{dt} - \frac{d \ln(\tilde{m}_t^{ICT})}{dt} \right)$$

Now, the effect on measured GDP growth reads as:

$$\frac{d \ln(gdp_t)}{dt} - \frac{d \ln(gd\tilde{p}_t)}{dt} = \left( \frac{FD_t^{ICT}}{GDP_t} - \frac{M_t^{ICT}}{GDP_t} \right) \cdot \left( \frac{d \ln(fd_t^{ICT})}{dt} - \frac{d \ln(\tilde{f}d_t^{ICT})}{dt} \right)$$

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12. This is a representation with a continuous-time Divisia index. In practice, other index number formulae are used in national accounts, in particular (fixed or chain-weighted) Laspeyres type quantity indices. However, for ease of exposition, the Divisia formulation is retained here. For a fuller treatment with different types of index number formulae, see Schreyer (2000b).

This expression is the basis for the quantitative assessment of the impact of an adjustment of the price index of ICT products. It can be interpreted as follows. The effect on GDP measurement has two components:

- The first component states by how much the price (and therefore the quantity) rate of change of the ICT product is adjusted. This is the second term on the right hand side of the equation above;
- The second component (the term in the first bracket on the right hand side of the equation) acts as a multiplier to the quantity adjustment. Before interpreting this multiplier, it is practical to explicitly formulate a supply and demand balance for the ICT product. For this purpose note that at the level of individual products, (and different from the aggregate picture), intermediate consumption ( $IC_t^{ICT}$ ) has to be introduced. Total supply of the ICT product is the sum of domestic gross output of the ICT product ( $Q_t^{ICT}$ ) and imports ( $M_t^{ICT}$ ). Demand is the sum of final demand ( $FD_t^{ICT}$ ) and intermediate consumption:

$$Q_t^{ICT} + M_t^{ICT} = IC_t^{ICT} + FD_t^{ICT} \text{ or}$$

$$FD_t^{ICT} - M_t^{ICT} = Q_t^{ICT} - IC_t^{ICT}$$

It is now straightforward to interpret the multiplier above which:

- equals zero (no impact on aggregate GDP) if final demand equals imports of the ICT products  $FD_t^{ICT} = M_t^{ICT}$ . This implies that domestic production is just enough to cover intermediate consumption ( $Q_t^{ICT} = IC_t^{ICT}$ ), or, as a special case, when there is no domestic production and intermediate consumption at all;
- will be largest (and positive) in size when imports are zero, i.e., when the ICT product is produced only domestically ( $FD_t^{ICT} = Q_t^{ICT} - IC_t^{ICT}$ );
- will be negative when imports exceed final demand ( $FD_t^{ICT} < M_t^{ICT}$ ). This occurs when intermediate demand for the ICT product exceeds domestic supply ( $Q_t^{ICT} < IC_t^{ICT}$ ). Some of the intermediate demand has to be satisfied by imports. The negative multiplier is largest in absolute terms when the product is exclusively used for intermediate consumption, and when there is no domestic output:  $M_t^{ICT} = IC_t^{ICT}$ .

**Implementation.** To obtain a quantitative picture of the orders of magnitude involved, we measure the sign and size of the multiplier, as described above. In principle, the relevant data is contained in detailed national accounts expenditure statistics. In practice, not enough product detail is readily available at the international level, and two additional sources have been used.

The first source is the OECD STAN database, which provides time series for total domestic output and imports of relevant industries. The focus here is on the office accounting equipment and computing machinery industry (30 ISIC Rev.3), and on the radio, TV, and communication equipment industry (32, ISIC Rev.3). The STAN database reflects an activity classification, not a detailed product classification and to the extent that the product composition within activities varies between countries, this may limit

international comparability. However, comparability is sufficient to establish an order of magnitude for the multiplier defined above.

STAN provides information on the supply side of ICT producing industries. To complete the supply-demand balance, a split between deliveries to intermediate and final consumption is needed. Final demand can then be computed residually, the supply-demand balance is established, and it is possible to compute the multiplier that has to be applied to an adjustment of price indices. In principle, national supply-use and input-output tables provide information on the share of intermediate consumption in total deliveries. However, those tables are not available for all countries represented in the STAN database and where they exist, comparability between the databases cannot be ensured. Thus, as a first approximation, upper and lower bounds are defined. The lower bound is the case where all supply goes to intermediate consumption (no final consumption), the upper bound is the case where all supply goes to final consumption (no intermediate consumption). An intermediate, point estimate is also produced with a 30% ratio of intermediate consumption in total supply. This corresponds approximately to the share observed in supply-use tables of the United States, the United Kingdom, France and Japan.

**Results.** The table below shows estimates for the multiplier described above. First, it is useful to re-state its interpretation: the data in the table below represent the factor by which an adjustment of the volume or price indices of the office machinery or the communication equipment machinery industry output translates into the rate of change of total GDP. For example, the figure of 0.011 for France (office, accounting and computing machinery, upper bound) states that a 10 percentage point upward adjustment of the volume index of this industry (or a 10 percentage point downward adjustment of the price index) would lead to a  $0.011 * 10\% = 0.11$  percentage point shift in the GDP growth rate.

Not surprisingly, the lower bound estimates all produce negative multipliers. This reflects the case of imported intermediate products: when their price index is adjusted downwards, this translates into a negative effect on measured volume GDP change. Generally, effects appear to be small: even under the unrealistic assumption of no deliveries to intermediate consumption, the largest multiplier for the computer industry is 0.026, implying a 0.2 percentage point upward adjustment for a 10 percentage point downward revision of prices. The point estimates, by definition lower than the upper bound, represent a more realistic value of the share of intermediate consumption in total demand. However, the Korean, the Finnish and the Japanese multiplier for communication equipment show higher multiplier values, reflecting the large role that the consumer electronics industry plays in Korea and the role that the communication equipment industry plays in Finland and Japan.

**Annex Table 1: Estimates of multipliers**

| <b>Office, accounting and computing machinery</b>    |  |   |   |
|--|--|---|---|
|  | Upper bound: no<br>intermediate<br>consumption | Point estimate:<br>intermediate<br>consumption<br>equals 30% of<br>total supply | Lower bound:<br>intermediate<br>consumption<br>equals 100% of<br>total supply |
| Italy  | 0.005  | 0.002   | -0.005  |
| Denmark  | 0.007  | 0.002   | -0.010  |
| Germany  | 0.009  | 0.004   | -0.008  |
| Finland  | 0.010  | 0.003   | -0.014  |
| France   | 0.011  | 0.006   | -0.007  |
| Canada   | 0.012  | 0.004   | -0.015  |
| United States  | 0.016  | 0.010   | -0.004  |
| Japan  | 0.024  | 0.016   | -0.002  |
| Korea  | 0.026  | 0.015   | -0.010  |
| United Kingdom                                       | 0.026  | 0.016   | -0.009  |
| <b>Radio, television and communication equipment</b> |  |   |   |
|  | Upper bound: no<br>intermediate<br>consumption | Point estimate:<br>intermediate<br>consumption<br>equals 30% of<br>total supply | Lower bound:<br>intermediate<br>consumption<br>equals 100% of<br>total supply |
| Italy  | 0.012  | 0.007   | -0.005  |
| Germany  | 0.017  | 0.010   | -0.006  |
| Denmark  | 0.018  | 0.010   | -0.007  |
| France   | 0.020  | 0.012   | -0.006  |
| United Kingdom                                       | 0.028  | 0.017   | -0.008  |
| Canada   | 0.030  | 0.018   | -0.010  |
| United States  | 0.031  | 0.021   | -0.003  |
| Japan  | 0.054  | 0.037   | -0.002  |
| Korea  | 0.152  | 0.103   | -0.012  |
| Finland  | 0.085  | 0.058   | -0.007  |