

## COMPUTER PRICE INDICES AND INTERNATIONAL GROWTH AND PRODUCTIVITY COMPARISONS

BY PAUL SCHREYER

*OECD Statistics Directorate*

Methodologies to derive price indices for information and communication technology (ICT) products vary between national statistical offices. This may lead to significant differences in measured price changes for these products and there has been concern about the international comparability of volume growth rates of GDP between several OECD countries. This article discusses the possible consequences for measures of economic growth of replacing one set of price indices by another one in the framework of national accounts. It is argued that the issue of ICT deflators cannot be dealt with in isolation and several other factors have to be taken into account, in particular whether ICT products 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. Overall, results point to modest effects at the aggregate GDP level but may be more significant when it comes to component measures such as volume growth of investment, or of output in a particular industry.

### 1. INTRODUCTION

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 U.S. 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. Analytical studies of growth comparisons in OECD countries (e.g. Scarpetta *et al.*, 2000) have also highlighted these measurement issues.

This article aims at shedding additional light on some of these points. It discusses the possible consequences for measures of economic growth of replacing one set of price indices by another one in the framework of national accounts. Thereby, 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. Conclusions will also be different between aggregate measures such as total volume GDP and component measures such as volume growth of investment, or volume measures of output in a particular industry.

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

<sup>1</sup>“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.

The paper starts out with a brief discussion of ICT price measurement (Section 2), and then goes on to discuss the impact of a change in deflators on measured volume GDP (Section 3), volume investment growth (Section 4), and productivity measures (Section 5). Some conclusions are offered in Section 6.

## 2. MEASUREMENT OF ICT PRICES

Price indices are constructed by comparing prices of sampled products between two periods in time.<sup>2</sup> At least two conditions have to be fulfilled 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. When technical change is fast, neither condition holds easily. In the case of ICT goods, 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.

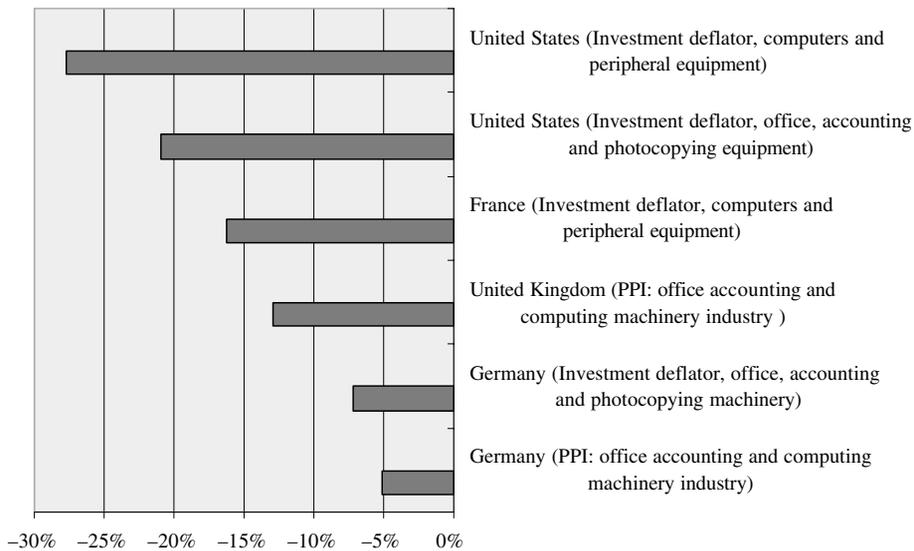
When faced with a price comparison of two different models, the question is how much of an observed price change is due to quality change and how much is a true change in prices? Implicitly or explicitly, an assumption is made of how much a new model would have cost in the first period and/or how much the old model cost in the second period. Such an estimate may come from expert advice, from “option pricing,”<sup>3</sup> or from some observation about the price at which the old model is traded on second-hand markets. The hedonic method is another, systematic way to obtain an informed estimate for the missing price(s).<sup>4</sup>

A number of countries use such hedonic methods, among them the U.S., who construct hedonic functions for different types of computers and peripheral equipment, semiconductors and software. Canada, Japan, France, Australia and some other countries have also developed hedonic functions or adopted those of

<sup>2</sup>For a full discussion of hedonic price indices see OECD (2002).

<sup>3</sup>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 also including the producer’s normal profit margin.

<sup>4</sup>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 the second period by using the information about its technical characteristics (which are known from period 1) and so obtain an approximation to the true price change.



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

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*.

the U.S. 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 U.S. 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 U.K. or Germany. One notes that, nonetheless, the U.K. producer price index falls comparatively fast. This is an indication that the U.K. statistical office uses other methods to calculate quality change in computer models such as option pricing, or expert opinions to determine quality change. A comparatively rapid fall in hardware prices 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.

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>5</sup> However, to date, few convincing arguments have been brought forward as to 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 recognize the usefulness of the hedonic approach,

<sup>5</sup>For a discussion of hedonic methods, see Triplett (1990).

and a report by Eurostat (2001) qualifies the hedonic method as the preferred one in the field of computer and software price indices.

A recent study by Aizcorbe, Corrado, and Doms (2000) 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.<sup>6</sup> 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) toward 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. 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 may change analysts' assessment of the sectoral 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

<sup>6</sup>For example, for desktop computers, Aizcorbe *et al.* (2000) find that over the period 1993–98, and based on quarterly observations, the price index based on “traditional” matched model techniques fell by about 29 percent per year. Its hedonic counterpart fell by slightly less, 28.2 percent at annual rates. Similar results were found for notebook computers and microprocessors.

<sup>7</sup>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.

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 percent to 15 percent. 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 percent of private consumption expenditure, the measurement effect on total consumption is  $0.02 \times 0.1 = 0.002$  or 0.2 percent 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.

### 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. 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>8</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, we carry out a simple calculation.

<sup>8</sup>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.

It consists in evaluating a “multiplier” or coefficient by which price index adjustments of ICT products would carry over to measured GDP growth rates. 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 ( $M$ ):

$$(1) \quad GDP_t = FD_t - M_t$$

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

$$(2) \quad GDP_t = FD_t^N + FD_t^{ICT} - M_t^N - M_t^{ICT}$$

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>9</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:

$$(3) \quad \frac{d \ln(gdp_t)}{dt} = \frac{FD_t^N}{GDP_t} \cdot \frac{d \ln(fd_t^N)}{dt} + \frac{FD_t^{ICT}}{GDP_t} \cdot \frac{d \ln(fd_t^{ICT})}{dt} \\ - \frac{M_t^N}{GDP_t} \cdot \frac{d \ln(m_t^N)}{dt} - \frac{M_t^{ICT}}{GDP_t} \cdot \frac{d \ln(m_t^{ICT})}{dt}$$

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.

$$(4) \quad \frac{d \ln(gdp_t)}{dt} - \frac{d \ln(gd\tilde{p}_t)}{dt} = \frac{FD_t^{ICT}}{GDP_t} \cdot \left( \frac{d \ln(fd_t^{ICT})}{dt} - \frac{d \ln(\tilde{f}d_t^{ICT})}{dt} \right) \\ - \frac{M_t^{ICT}}{GDP_t} \cdot \left( \frac{d \ln(m_t^{ICT})}{dt} - \frac{d \ln(\tilde{m}_t^{ICT})}{dt} \right)$$

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 has to be independent of its use. In other words, the 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 changes in the measured quantity (the adjustment) of

<sup>9</sup>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 (2001).

final demand and import are of the same size:

$$(5) \quad \left( \frac{d \ln (f d_t^{ICT})}{dt} - \frac{d \ln (f \tilde{d}_t^{ICT})}{dt} \right) = \left( \frac{d \ln (m_t^{ICT})}{dt} - \frac{d \ln (\tilde{m}_t^{ICT})}{dt} \right).$$

Now, the effect on measured GDP growth reads as:

$$(6) \quad \frac{d \ln (g d p_t)}{dt} - \frac{d \ln (g d \tilde{p}_t)}{dt} = \left( \frac{F D_t^{ICT}}{G D P_t} - \frac{M_t^{ICT}}{G D P_t} \right) \cdot \left( \frac{d \ln (f d_t^{ICT})}{dt} - \frac{d \ln (f \tilde{d}_t^{ICT})}{dt} \right).$$

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 equation (6).

The second component (first bracket on the right hand side of equation (6)) 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, 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:  $Q_t^{ICT} + M_t^{ICT} = IC_t^{ICT} + FD_t^{ICT}$  or  $FD_t^{ICT} - M_t^{ICT} = Q_t^{ICT} - IC_t^{ICT}$ .

It is now straightforward to interpret the multiplier above. The multiplier:

- 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;
- is largest (and positive) in size when imports are zero, i.e. when the ICT product is produced only domestically ( $FD_t^{ICT} = Q_t^{ICT} - IC_t^{ICT}$ );
- is 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:  $M_t^{ICT} = IC_t^{ICT}$ .

We now turn to measuring the sign and size of the multiplier, as described above. In principle, the relevant data are contained in detailed national accounts expenditure statistics. In practice, not enough product detail is readily available at the international level, and an additional source had to be used.<sup>10</sup> Also, to

<sup>10</sup>The OECD STAN database 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.

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 always available 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 percent ratio of intermediate consumption in total supply. This corresponds approximately to the share observed in supply–use tables of the U.S., the U.K., France and Japan.

Table 1 shows estimates for the multiplier described above, i.e. 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  $0.011 \times 10\% = 0.11$  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.

Overall, 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 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.

This assessment remains 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; (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

TABLE 1  
ESTIMATES OF MULTIPLIERS

|  | Upper Bound:<br>No 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 |
|--|--|---|---|
| <i>Office, accounting and computing machinery</i>    |  |   |   |
| 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  |
| U.S.   | 0.016  | 0.010   | -0.004  |
| Japan  | 0.024  | 0.016   | -0.002  |
| Korea  | 0.026  | 0.015   | -0.010  |
| U.K.   | 0.026  | 0.016   | -0.009  |
| <i>Radio, television and communication equipment</i> |  |   |   |
| 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  |
| U.K.   | 0.028  | 0.017   | -0.008  |
| Canada   | 0.030  | 0.018   | -0.010  |
| U.S.   | 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  |

(such as the ones outlined in Section 3.4) because calculations are based on a “superlative” Törnqvist index number formula.

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, 2001). The study uses a set of quality-adjusted price indices for computers, semi-conductors, 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 percent 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 U.S. 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 percent per year in the U.S.

#### 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,<sup>11</sup> 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 U.S., 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.

<sup>11</sup>The issue has been well illustrated by Whelan (2000), who computes alternative rates of the 1997–98 volume growth GDP in the U.S. One is the official, chain-weighted volume index. It shows a growth rate of 4.3 percent. The rate of growth for the same year, based on a fixed-weight quantity index with 1995 price weights, amounts to 4.5 percent. 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 percent and the growth rate moves to a staggering 18.8 percent when based on 1980 prices.

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<br>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<br>under fixed weights (B – A)                 | 0.11                                  | 0.00                      | 0.91       | 0.58    | 0.67    | 0.21                     |
| Superlative (Fisher) volume<br>index, full quality adjust-<br>ment (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                     |

*Note:* See source for full description of methodology.

*Source:* Schreyer (2001).

#### 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 rate 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 (2000) and Colecchia and Schreyer (2001) use a “harmonized” 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 “harmonized” 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 U.S., as comparisons and discussions about measurement issues frequently focus on the comparison with the U.S. However, one has to keep in mind that replacing one country’s price index by that of another country implies assuming away differences in the composition of ICT production or consumption as well as differences in market structure and competition. Both can have significant impact on the aggregate ICT

price index, and the use of “harmonized” deflators remains at best an approximation to a lower bound of a true price change. Also, there are several possibilities for transposing the U.S. deflators to other countries’ accounts for, the purposes of such a simulation. Here, three such possibilities were explored.

First, usage of the U.S. 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 percent fall of computer prices in the U.S. translates into a 20 percent decline of the same price index in Italy. Letting  $p_{ICT}^{US}$  be the price index of the ICT product in the U.S., and  $\tilde{p}_{ICT}^{Other}$  the “harmonized” price index for the same product group in another country, the usage of the U.S. deflator, unadjusted for domestic inflation implies:  $\Delta \ln(\tilde{p}_{ICT}^{Other}) = \Delta \ln(p_{ICT}^{U.S.})$ . 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 U.S. deflator, adjusted for domestic inflation. To control for domestic inflation in the construction of a harmonized 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 ( $p_{ICT}^{U.S.}/p_N^{U.S.}, p_{ICT}^{Other}/p_N^{Other}$ ). The rate of change of the “harmonized” price index of a country other than the U.S. is then given by:  $\Delta \ln(\tilde{p}_{ICT}^{Other}) = \Delta \ln(p_N^{Other}) + \Delta \ln(p_{ICT}^{U.S.}) - \Delta \ln(p_N^{U.S.})$ . Thus, if ICT prices in the U.S. rise by 10 percentage points per year less than prices for non-ICT goods, this carries over to other countries and makes the “harmonized” deflator independent of the overall price level that prevails in the different countries.

A third way of constructing a “harmonized” 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:  $\Delta \ln(\tilde{p}_{ICT}^{Other}) = \Delta \ln(p_{ICT}^{U.S.}) + \Delta \ln(e_{U.S.}^{Other})$  where  $e_{U.S.}^{Other}$  is the bilateral exchange rate between the country under consideration and the U.S. In some countries (for example, Australia) this method is used to “import” the U.S.’s 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 “harmonized” deflators

TABLE 3

PRIVATE NON-RESIDENTIAL GROSS FIXED CAPITAL FORMATION WITH ALTERNATIVE DEFLATORS FOR ICT ASSETS. TÖRNQVIST VOLUME INDEX, PERCENTAGE CHANGES AT ANNUAL RATES, 1990–99

|           | National Deflator | U.S. Deflator, Adjusted for Domestic Inflation | U.S. Deflator, Unadjusted for Domestic Inflation | U.S. Deflator, Adjusted for Exchange Rate Movements |
|-----------|-------------------|--|--|---|
| Australia | 4.2               | 3.9  | 4.0  | 3.6   |
| Canada    | 4.0               | 4.0  | 4.1  | 3.9   |
| Finland   | -1.8              | -0.1   | -0.4   | -1.0  |
| France    | 0.9               | 1.1  | 1.1  | 1.0   |
| Germany*  | 2.4               | 2.8  | 2.9  | 2.7   |
| Italy     | 1.8               | 2.8  | 3.0  | 2.2   |
| Japan     | -2.2              | -1.8   | -1.9   | -1.8  |
| U.K.      | 3.4               | 4.5  | 4.5  | 4.4   |
| U.S.      | 7.6               | –  | –  | –   |

\* 1991–99.

Source: Author's calculations, based on Colecchia and Schreyer (2001).

were used in comparison but they have in common that they all are based on the national U.S. deflator for these products.

Table 3 shows that the use of the U.S. 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. Also, the size of the adjustment varies considerably with the specific type of adjustment methodology—for example, whether the U.S. deflator is or is not adjusted for exchange rate movements. The difference between alternative harmonized deflators can be as large as the difference between the national and any of the harmonized deflators.

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 harmonized 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 harmonized 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 U.S. where large investments in ICT assets were accompanied by large changes in relative prices.

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                          | 7.9                       | 0.6                               |
| Canada    | 9.1                          | 10.9                      | 1.8                               |
| Finland   | 10.6                         | 10.9                      | 0.3                               |
| France    | 5.0                          | 5.5                       | 0.5                               |
| Germany*  | 5.5                          | 6.0                       | 0.5                               |
| Italy     | 6.6                          | 7.3                       | 0.6                               |
| Japan     | 1.1                          | 1.6                       | 0.5                               |
| U.K.      | 9.3                          | 10.2                      | 0.9                               |
| U.S.      | 11.1                         | 11.6                      | 0.5                               |

\* 1991–99.

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

*Source:* Author's calculations, based on Colecchia and Schreyer (2001).

## 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 labor productivity growth. If measures of aggregate volume GDP growth change, so will measures of aggregate labor 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 labor 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 labor ( $L$ ) and capital inputs ( $K$ ) from the growth rate of real value-added ( $Q$ ). The current-price shares of labor and capital in value-added ( $s_L, s_K$ ) form the appropriate weights:

$$(7) \quad \frac{d \ln \text{MFP}}{dt} = \frac{d \ln Q}{dt} - s_L \frac{d \ln L}{dt} - s_K \frac{d \ln K}{dt}$$

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

TABLE 5  
 MULTI-FACTOR PRODUCTIVITY: EFFECTS OF ICT  
 DEFLATORS. PERCENTAGE CHANGE AT ANNUAL  
 RATE, 1990–99

|           | U.S. Deflators,<br>Adjusted for<br>Domestic Inflation | National<br>Deflators |
|-----------|---|-----------------------|
| Australia | 1.0   | 1.0                   |
| Canada    | 1.1   | 1.1                   |
| Finland   | 2.9   | 3.2                   |
| France    | 0.8   | 0.9                   |
| Germany*  | 0.4   | 0.6                   |
| Italy     | 0.9   | 1.0                   |
| Japan     | -0.3  | -0.2                  |
| U.K.      | 1.0   | 1.2                   |
| U.S.      | 1.0   | 1.0                   |

\* 1991–00

*Source:* Author’s calculations, based on Colechia and Schreyer (2001).

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.

For several countries, the switch from national to “harmonized” 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>12</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 U.S.

<sup>12</sup>See Bassanini *et al.* (2000) and OECD (2002) for a discussion of embodied and disembodied technical change and MFP measures.

## 6. CONCLUSIONS

This paper examines some of the implications of replacing a set of ICT price indices by another one where the latter falls by more (or rises by less) than the former. We look at implications for measured volume growth of GDP, investment, productivity and the growth contributions of ICT capital. The following main conclusions are reached.

When price indices are adjusted in a national accounts framework, some or all of the resulting measurement effects can counterbalance 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 labor 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 U.S. 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.

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 U.S. and other countries throughout the 1990s, and different types of price indices cannot account for this discrepancy.

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.

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