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Computer prices: How good is the quality adjustment?

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Introduction

1 Correctly assessing changes in computer prices is a key issue in determining levels of real investment and therefore the real level of a country's capital stock because of the large proportion of investment now going to computers. This paper has been prompted by concerns about the extent to which the overall quality improvements in computers, as identified using hedonic techniques, may be overestimated. The consequences would be that the decline in computer prices would be overstated and so the estimated increase in the volume of computers in the national accounts would also be stronger than is really justified.

2 It is clear that there have been significant advances achieved over the past decade or so in terms of systematically measuring changes in the quality of computers and therefore in more accurately measuring changes in their prices. It is also clear that those responsible for measuring computer prices through the use of hedonic techniques are fully aware of the limitations of their art, which depends on assumptions about the major characteristics underlying the price changes in computers (Cartwright, 1986). The question which needs to be examined is whether the existing assumptions are adequate in current circumstances or whether the range of characteristics typically used in existing hedonic approaches needs to be modified. The answer to this question is influenced to a large extent by what is perceived as being measured when one talks about the "volume of computers". For example, in the case of a PC being used as an investment good, is it just the PC hardware itself or is it the potential of the PC to be useful in producing output?

3 To give an indication of the potential impact on national accounts of any changes in the methods used to assess quality changes in computers, a rough estimate is made of the sensitivity of the volume of private investment on equipment to differences in the rate of change of computer prices, using Australian national accounts data as the basis[2].

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[1] The author is a staff member of the OECD Statistics Directorate. The views expressed are those of the author and do not necessarily reflect those of the OECD Secretariat.

[2] The author wishes to thank the ABS for supplying the unpublished estimates from the Australian national accounts on which these indicative calculations are based.

Scope of this paper

4 A further point of interest is whether a special case exists for examining whether "cost" or "value" is the appropriate measure for computers in capital stock because it can be argued that computers are different from most other investment items. The main reason is that the theoretical increase in their potential output, as measured by the increases in their input characteristics, is unlikely to ever be realised in practice. In other words, computers now have a high level of built-in redundancy in the form of features which will never be used by a large proportion of users and so are different from most other items of capital equipment. For example, a decade or so ago word processors were purpose built and were able to be used for other purposes only with some difficulty, if at all. Now, someone wanting a word processor has to buy a PC (or similar) which will handle word processing as well as all other computer type functions such as spreadsheets, databases, e-mail etc, even if the purchaser has no intention of using any of these additional features. Further, software is very often designed to be all things to all users, and so offers features which are seldom, if ever, used by many users.

5 The main reason for raising this issue is to clarify that the central theme of this paper does not depend on which of the "cost" or "value" of computers is considered most appropriate for measuring the volume of computers in investment, and therefore in capital stock. In fact, it may be worthwhile revisiting this issue (in another paper) given the number of features which are unique to computers amongst capital goods items. However, because it does not impact on the conclusions in this paper, this issue is not discussed any further here.

Measuring "pure" price change

6 In producing price indexes, such as the consumer price index (CPI), the general aim is to measure as far as possible only the actual price changes which are occurring. The effects of quality changes which may also be influencing the overall rate of price changes have to be identified and then excluded. The traditional method of adjusting for quality changes in price indexes is commonly referred to as the "matched model" method. As the name suggests, it involves identifying "pure" price changes by pricing identical models from one period to the next, so that no quality differences are present to affect the observed price changes.

7 Traditionally, when a new model is introduced, it is linked into the current level of the existing price index by pricing both the new and the old model in the same period and assuming that the difference between their price levels reflects the difference in quality. In effect, the price movements of the new model are used to extrapolate forward from the price level recorded for the old model in the overlap period. The validity of this procedure is based on the following assumptions:

. there are relatively minor quality differences between the old and the new models;

. there are no significant price changes occurring in their own right

in conjunction with the introduction of the new model; and

. the difference in the level of prices for the old and new models fully reflects quality differences.

8 However, the assumptions underlying the matched model procedure break down when a product is subject to rapid quality change, which is often associated with the frequent introduction of new models. Two products which are particularly affected by this breakdown in these assumptions are motor vehicles and computers. In both these cases, there has been rapid quality change and it is very common for price changes to be introduced at the same time as a new model which further complicates the process of separating the quality change from the "pure" price change.

9 A method commonly used to adjust for quality change in motor vehicles is to ask the relevant manufacturer to identify the costs associated with each of the changes made between the old and the new models. The sum of these costs is then used to adjust the price of the new model back to a basis of "constant quality" comparable with the old model. However, the validity of this procedure is fairly dependent on the assumption being met of relatively small changes occurring between models. Once significant changes do occur, the link between the "price" which can be identified for each element of quality change and the actual overall quality change breaks down.

Hedonic price indexes

10 Even greater problems than those associated with motor vehicles became evident from the 1970s onwards for prices statisticians and national accountants. The cause was the rapid quality improvement occurring in computers. In fact, the assumptions underlying the matched-model method completely broke down in the case of computers. Rapid advances in technology resulted in new models being both more powerful (ie, higher quality) and often less expensive than the model they replaced. In the mid 1980s, the US Bureau of Economic Analysis (BEA), in conjunction with IBM, released the results of some very innovative and detailed investigations into deriving quality adjusted price indexes for mainframe computers and associated peripherals (disk drives, printers and displays). They were based on hedonic methods of adjusting for quality change which attempted to overcome the shortcomings associated with the traditional "matched-model" method of handling quality adjustments in price indexes of computer equipment. The quality change identified through the hedonic approach was far greater than that allowed for at that time in national accounts investment deflators in countries world wide.

11 While hedonic price indexes provide a means of assessing quality improvements in computers, it is important to recognise that they are only an approximation to the ideal. Their formal definition provides some important background to the main issue in this paper: "A hedonic function is a relation between prices of varieties or models of goods - or services - and the quantities of characteristics contained in them[3]." Selecting the most appropriate characteristics to include in the hedonic function is critical in

obtaining a satisfactory result from the process. One shortcoming, which is the major focus of this paper, is that the hedonic functions for computers are based on assumptions about the characteristics which physically underlie computer hardware.

12 As the above definition implies, hedonic price indexes impute changes in the (output) price of a good by aggregating the prices imputed for each of the major characteristics identified. While hedonic price indexes are similar to input price indexes, which are often used as deflators in some parts of the national accounts, they differ in one significant respect. Rather than being based on the prices of actual inputs, the first step in producing a hedonic index is to identify the major characteristics which contribute to the usefulness of the product and therefore to its final price. Regression techniques are then used to identify the relationships between those characteristics and the final output price observed for different models of the good being priced. In practice, the characteristics used in the hedonic regressions are those for which some quantifiable feature can be explicitly identified.

Do hedonic price indexes for computers take all essential characteristics into account?

13 The main aim in this discussion is to determine whether or not all relevant characteristics of computers are being taken into account in the hedonic approach. One important characteristic which appears to be missing from the hedonic approaches used so far in this field is software. The question which needs to be examined is whether or not omitting software characteristic(s) from the hedonic approach is likely to have a significant impact on the results. The answer partly depends on identifying what is required for a computer to be useful as an investment good and therefore as a component of capital stock.

14 Computer hardware is useless as an investment good without the associated operating system(s) and software and there would be no market for computer hardware if it were not for the software which enables computers to produce useful output. Therefore, it is necessary to look at "computers" as a general package (processor, memory, storage capacity etc and software). The current hedonic approaches quite reasonably assume that computers, as part of capital investment, can produce useful output. However, because only the hardware characteristics of computers are being explicitly included in the hedonic regressions, the software characteristics are being taken into account implicitly in some way.

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[3] The New Palgrave: A Dictionary of Economics, Vol. 2

In practice, a key assumption underlying the hedonic approach to measuring price changes for investment in computers must be that the quality changes identified for hardware are also applicable to software generally. Is this a valid assumption? A number of issues need to be examined before this question can be answered.

15 The types of features used to estimate changes in computer prices using a hedonic approach are the major characteristics such as processing speed, capacity, etc. Once they have been identified, implicit prices are imputed for different computers for all relevant periods based on these characteristics. However, the use of measures such as processing speed assumes a constant relationship between the price and volume underlying this characteristic and the output (eg, the "PC package") for which prices and quantity changes are being estimated. In a field such as computers where technology is evolving extremely rapidly, this assumption is unlikely to hold in practice, especially in the longer term. Despite the spectacular increases over the past couple of decades in the number of features offered in (and the underlying complexity of) the non-hardware components such as operating systems and software, several factors indicate that the gains now being realised in software are not on the same scale as those in hardware. Also, the increasing size and complexity of operating systems and software are likely to be resulting in increasing relative inefficiencies between the hardware and software. In particular, the increased requirements imposed by modern software will be using up some part of the increased capacity of the hardware as imputed by the (incomplete) set of price indicators for hardware characteristics in the hedonic approach. For example, the operating systems on PCs and the more sophisticated software, such as spreadsheets (now with their associated graphics capabilities), word processing programs, and databases, have become increasingly complex. The latest software designed to run on the bigger, faster hardware is using up a significant part of the increased disk storage available on PCs. Also, the greater complexity means that some part of the increased computer speed is diverted from the task of processing to handling the software itself.

16 It may have been reasonable to assume that improvements in hardware and software were similar when mainframes were dominating computer sales and there was a rapid transition to more and more sophisticated programming languages. It may have even been a reasonable assumption for many years as PCs became more sophisticated and the features available in spreadsheets, word processing packages and data bases expanded very rapidly. However, in recent years, the developments in much of the existing PC software have often tended to be in adding functions at the margin rather than in making any fundamental changes to the features available. In addition, as noted above, a significant part of the hardware improvements is being taken up in catering for more complex software. Producers of many types of goods often upgrade their products regularly to stimulate demand for them. In most cases,such products are going to be used for broadly the same purpose as previously and the additional features are at the margin rather than incorporating fundamental changes. Software for computers is a prime example of such a process. Therefore, the assumption that the overall output price for computers, particularly PCs, used as investment goods can be estimated hedonically by using the prices of the hardware characteristics would be less valid now than it was up to about the early 1990s.

17 A further issue discounting the existence of a direct link between quality changes in hardware and software is that it is possible for operational problems to

arise with computers because new hardware is in advance of software. For example, as an extreme example of software developments lagging behind hardware inputs, currently-installed operating systems often do not have built-in drivers for all new hardware components. These must then be installed using manufacturer supplied disks. A common result is incompatibilities - and resulting inefficiencies - between the hardware and software components which had been integrated into the previous hardware environment.

18 To summarise, it seems fairly clear that there have been ongoing improvements in the quality of software. However, the improvements in quality of the latest and more complex versions of software commonly available for many years (such as spreadsheets and word processing packages) are unlikely to have kept pace with the rapid improvements identified in hardware by the hedonic approach. The result is that a significant proportion of current software is of relatively lower utility than in the past compared with the magnitude of the improvements in the capability of the hardware on which it is operating. Therefore, the overall quality of a computer package (hardware and all the associated software) has not been rising as rapidly as that of the hardware input characteristics on which the hedonic estimates of quality improvement are based. As a result, the quality adjustments being used in the estimation of the price deflators for computer investment are being overstated which leads to the price falls in computer investment also being overstated. In turn, the investment volume estimates based on those deflators are overstated and this distortion in the investment estimates then feeds into the capital stock estimates.

19 It would be possible to argue at length over the above proposition regarding the relative improvements in existing software and hardware, without reaching a satisfactory conclusion. The issue can really only be resolved by resorting to the same techniques as those used for the hardware. In other words, it is necessary to empirically test these propositions using hedonic methods.

20 If it is accepted that there is a case for empirically investigating the extent to which the improvements in existing software are lagging those in hardware, then it is also necessary to take some other software issues into account. In particular, it would be important to examine the extent to which completely new software packages (as distinct from upgrades of existing software) are impacting on the overall rate of improvement in software quality. It is possible that the quality improvements associated with completely new software may be as spectacular as those in hardware. As is the case with hardware, the only practical method available to investigate this issue is to use a hedonic approach.

21 Including software as one of the characteristics in the hedonic approach to measuring computer prices will obviously be difficult and time consuming. However, it seems critical to make an attempt to do so because of the potential distortions in the hedonically measured computer prices at the present time caused by omitting software. It is important to note that this is not a criticism of using hedonic indexes as such in deflating computer investment. It seems very clear that significant gains have been realised by doing so, but there is scope for even further gains in accuracy by including software as part of the overall hedonic approach in this field.

The impact of the computer quality adjustment

22 The impact of using the hedonic price indexes for computers is significant. For example, the table below demonstrates some of the effects of the rapid decline in computer prices on the investment estimates recorded in the Australian national accounts (in which all expenditures on computer hardware are deflated using a hedonic price index). It shows the share of computers within private investment on equipment and within total public investment from the mid 1980s to the mid 1990s.

Share of computers in investment

	Computers as a percentage of:			
	Private investment on equipment		Total public investment	
Year ended June	Current price values	Volumes	Current price values	Volumes
1985	14	6	10	4
1986	11	6	9	4
1987	11	7	8	5
1988	10	8	8	5
1989	10	9	7	6
1990	9	9	6	6
1991	10	12	6	7
1992	10	14	5	7
1993	10	16	5	7
1994	9	18	4	7
1995	9	21	4	7
1996	9	23	4	11

23 In both cases there is a significant decline in the shares recorded for current price (ie, nominal) expenditures during the eleven years. However, in volume terms, there is a very large increase in the computer share of overall investment, reflecting the rapid decline in computer prices over the past decade or so. In interpreting the increases in the volume shares above, it is important to note that volume measures in the Australian national accounts currently use a fixed base Laspeyres formula, with the base year being the financial year ended June 1990. The impact from using some form of chain volume measure rather than the fixed base volume estimates would be to reduce the rapid increase in the computer share of the totals. However, it would still be the case that the shares in nominal terms and in volume terms would diverge significantly between the mid 1980s and the mid 1990s, with the large quality adjustment currently being applied to computers being a major contributor.

24 The next table shows the differences which would be observed in private investment on equipment in the Australian national accounts under two different assumptions relating to a lower rate of decline in the computer price deflator (ie, a

lower quality adjustment). The two assumptions are:

. the computer investment deflators fall at half of their current observed rate each year; and

. the computer investment deflators do not change over the 11 years shown.

25 Note that the estimates for the annual average growth in volumes based on this second assumption (ie, no change in the computer deflator) are provided simply to indicate the sensitivity of the volumes to different assumptions - it is not being suggested that this is a realistic assumption to make about computer prices.

26 One aspect of interest is that, in Australia, most computer equipment is imported. Therefore, there will be little impact on the volume of gross domestic product from any modifications being made to the computer price deflator. The largest impacts will be observed in private investment on equipment, in imports of goods and, to a lesser extent, in public investment. Smaller impacts would be seen in final consumption expenditures. Given that the estimates shown are only indicative of the sensitivity of alternative rates of change in the computer deflator, they have been confined to private investment on equipment.

27 As noted above, the volume measures in the Australian national accounts currently use a fixed base Laspeyres formula. The impact from using some form of chain volume index rather than the fixed base index would be to reduce the differences shown under the two sets of assumptions relating to the rate of increase in the computer price index.

28 The average annual growth rates are calculated for the various periods using the compound growth formula.

29 As can be seen from the table, halving the rate of decline in the computer price deflator would reduce the overall growth rate in the volume of private investment on equipment between 1985 and 1996 by about 25 per cent. A much larger impact is observed between 1990 and 1996, where, under this assumption, the growth rate would be reduced by about 40 per cent.

Average annual growth rates
Private investment on equipment

Year ended June	Actual estimates		Volumes based on assumption that:	
	Current price values	Volumes	Computer prices change at half current rate	Computer prices do not change
1985 to 1996	7.2%	3.7%	2.7%	1.9%
1985 to 1990	10.2%	3.5%	3.2%	2.7%
1990 to 1996	4.7%	3.8%	2.2%	1.3%

Summary

30 This paper has been produced in response to concerns that the existing hedonic price indexes for computers do not take account of the potentially different rates of quality change in hardware and software, particularly for PCs.

31 The most common method used to derive capital stock estimates is the "perpetual inventory method", or PIM. The implications of any shortcomings in the investment volume estimates is that the volume estimates recorded in the (PIM-based) capital stock will suffer from similar shortcomings. For significant components of investment, such as computers, it is critical that any potential distortions introduced into volume estimates via the deflation process should be minimised as far as possible. While it is currently impossible to quantify any such effects, the brief sensitivity analysis above shows that their impact on the growth in the Australian national accounts volume estimates is unlikely to be huge, but it could be non-trivial.

32 Extending the hedonic approach to take software into account would be a useful exercise. It would be a significant step in further refining investment, and therefore capital stock, volume estimates.

REFERENCES

BERNDT E.R. and GRILICHES Z., (1993), "Price Indexes for Microcomputers: An Exploratory Study", in M.F. Foss, M. Manser and A.H. Young (eds), *Price Measurements and Their Uses*, Studies in Income and Wealth, Vol. 57, pp. 63-93, University of Chicago Press, for the National Bureau of Economic Research, Chicago.

CARTWRIGHT D.W., (1986), "Improved Deflation of Purchases of Computers", in *Survey of Current Business, March 1986*, Bureau of Economic Analysis, Washington, D.C.

COLE R., CHUN Y.C., BARGUIN-STOLLEMAN J.A., DULBERGER E., HELVACIAN N., and HODGE J.H., (1986), "Quality -Adjusted Price Indexes for Computer Processors and Selected Peripheral Equipment", in *Survey of Current Business, January 1986*, Bureau of Economic Analysis, Washington, D.C.

MOREAU A., (1996), "Methodology of the Price Index for Microcomputers and Printers in France", in *OECD Proceedings: Industry Productivity, International Comparison and Measurement Issues*, pp 99-118, OECD, Paris.

SCHREYER P., (1996), "Quality Adjustment of Price Indices in Information and Communication Technology Industries: Simulation of Effects on Measured Real Output in Five OECD Countries", in *OECD Proceedings: Industry Productivity, International Comparison and Measurement Issues*, pp 159-180, OECD, Paris.

TRIPLETT J.E., (1983), "Concepts of Quality in Input and Output Price Measures: A Resolution of the User Value-Resource Cost Debate", in M.F. Foss (ed), *The U.S. National Income and Product Accounts: Selected Topics*. Conference on Research in Income and Wealth; Studies in Income and Wealth, Vol. 47, pp. 269-311, University of Chicago Press, for the National Bureau of Economic Research, Chicago.

TRIPLETT J.E., (1987), "Hedonic Functions and Hedonic Indices", in John Eatwell, M. Milgate and P. Newman (eds), The New Palgrave: A Dictionary of Economics, Vol. 2, pp 630-634, The Macmillan Press, London.

TRIPLETT J.E., (1996), "High-tech Industry Productivity and Hedonic Price Indexes", in *OECD Proceedings: Industry Productivity, International Comparison and Measurement Issues*, pp 119-142, OECD, Paris.