A Note on the Impact of Hedonics and Computers on Real GDP

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THERE has been recent speculation about the impact of the use of hedonic price indexes in the measurement of real computer hardware and software expenditures in the U.S. national income and product accounts (NIPA's) and on the extent to which their use may be responsible both for the pickup in real gross domestic product (GDP) and productivity growth and for the continued low rate of measured inflation in the United States since 1995. Strong growth in computer sales and rapid declines in computer prices have made a significant contribution to economic growth; because measured growth depends on prices, if the declines in computer prices are overstated, the contribution of computers to real GDP will be overstated. This issue is central to the debate over the performance of the U.S. economy relative to that of other countries and to the debate over whether the pickup in the U.S. economy in the latter half of the 1990's represents a fundamental change in the structure of the economy or whether it is due to changes in measurement.

A review of the data shows that only a small share of the increase in measured growth in the latter half of the 1990's is associated with the use of hedonic price indexes. In addition, there is no evidence of an overstatement in the decline in computer prices. Hedonic price indexes for computers produce results that are quite robust and that are virtually the same as those produced by a carefully constructed traditional price index for computers.

The perception that the use of hedonic price indexes is largely responsible for the pickup in measured U.S. growth appears, in part, to be founded on misunderstandings about the nature of hedonic price indexes, the extent to which they are used in the accounts, the possible discontinuities in BEA's time series due to the introduction of hedonic price indexes, the importance of using chain-type indexes in computing real GDP and prices, the robustness of hedonic price estimates, the differences between hedonic price and traditional price measures, and the impact of BEA's methodology for deflating computer software. In addition, the perceptions about the relative impacts of these computer measurement issues on economic growth do not consider other measurement issues that probably impart a negative bias to measured economic growth.

What are hedonic price indexes?

Despite their unfortunate name, hedonic price indexes are simply statistical tools for developing standardized per unit prices for goods, such as computers, whose quality and characteristics are changing rapidly. Just as traditional price indexes measure the change in the price of strawberries by holding fixed the weight of the strawberries in a box rather than by the price per box, computers need to—at a minimum—be priced by holding fixed the computing power in the computer box. Traditional price indexes are well adapted to measuring the price of relatively standardized products, but they encounter problems—in terms of data requirements and methods—when the characteristics, market shares, and prices of a class of products are changing rapidly. Hedonic price indexes are one means of addressing these empirical and methodological problems.

Traditional price indexes use the "matched model" method to measure the relative change in the price of a market basket of goods, holding its quality and characteristics constant. The constancy of quality and characteristics is maintained by sample design, and great efforts are made at the Bureau of Labor Statistics (BLS) to ensure that exactly the same set of items is priced each month.

Hedonic price indexes developed at BLS and elsewhere use a statistical model that employs a regression of the prices of a basket of goods on a set of qualities or characteristics of those goods. Using the statistical relationship between observed price changes and changes in the characteristics and qualities of the goods, a hedonic price index is then

developed that measures relative price changes while holding quality and characteristics constant. Thus, the hedonic price index is doing the same thing statistically that a matched-model price index does through sample design.[1]

How widespread and important is the use of hedonic techniques?

The use of hedonic price indexes is increasing, and the components that are deflated by hedonic techniques account for 18 percent of GDP. For most of these components, the impact of using hedonic techniques is small because the matched models used earlier picked up most of the quality changes. For example, the introduction of hedonic price indexes by BLS slightly raised the rate of price increase for VCR's and for rent but slightly lowered it for televisions.

The main area in which the use of hedonic price indexes has had a large impact is in computers and peripheral equipment, whose quality-adjusted prices have been falling at an average annual rate of about 24 percent in recent years. In 1998, the components for which hedonic price indexes were used contributed a negative 0.2 percentage point to the 1.3-percentage-point increase in the GDP price index; however, among these components, computers and peripheral equipment contributed a negative 0.4 percentage point and thus more than accounted for the negative contribution.

Discontinuities

In December 1985, BEA introduced quality-adjusted price indexes for computers and peripherals that were developed using hedonic techniques. Prior to the development of the hedonic-based indexes, the price index for computers was held constant at the base period value of 100; this treatment, which differed from that for most other NIPA price indexes for goods, faced increasing skepticism in a period of declining prices and increasing capabilities of computers and computer systems. Working with IBM, BEA developed hedonic price indexes for computers and peripherals that were designed to capture the equivalent of the price per unit of computing power through the use of multiple regressions that explained the differences in the prices of computers and peripherals of different types and vintages as functions of their characteristics. The first index covered 1969–85, and BEA later developed estimates back to 1959; before 1959, computers were of little importance and were not separately identified in the NIPA's, thereby minimizing the discontinuity. When the estimates of computer software prices were introduced, they also extended back to 1959.[2]

Thus, when one looks—as several authors have—at the difference between the real GDP growth rate in 1973–95 and that in 1995–99, the pickup in the later period cannot be attributed to discontinuities (table 1). For 1973–95, real GDP grew at an average annual rate of 2.8 percent, and private fixed investment in computers and software accounted for 0.2 percentage point of that growth. In 1995–99, real GDP grew at an average annual rate of 4.2 percent, and computers and software accounted for 0.7 percentage point of that growth.[3] In other words, the real GDP growth rate in 1995–99 was 1.4 percentage points more than that in 1973–95, and computers and software contributed 0.4 percentage point to that difference, a significant share but not nearly enough to explain the overall increase in growth.

Table 1.—Contributions of Private Fixed Investment in Computers and Software to Percent Changes in Real GDP

[Average annual rates]

	Real GDP (percent change)	Contributions (percentage points)		
		Computers	Software	Sum
1973-95	2.78	.16	.08	.24
1995-99	4.15	.37	.31	.68
Difference	1.37	.21	.23	.44

Chain-type weights versus fixed weights

Comparisons of U.S. growth rates with those of other countries are also affected by the choice of weighting methodology. Although the introduction of hedonic price indexes for computers raised the measured rate of real GDP growth (relative to the previous assumption of no price change), the concurrent adoption of chain-type price and quantity indexes lowered it (relative to the previous fixed-weight methodology used by the United States and currently used by most other countries). BEA introduced chain-type weights to measure real GDP and prices in 1995 in order to

1. In practice, statistical agencies employ a mix of hedonic and matched-model techniques to produce hedonic estimates. For example, BLS uses the results from hedonic regressions to adjust for quality differences between the prices of models going out of production and the prices of new models replacing them in the sample. The results from the monthly price surveys are then used to produce the relevant producer price and consumer price indexes.

2. BEA now uses detailed BLS price indexes for computers, peripherals, parts and for some types of software; these indexes are aggregated using BEA chain weights to produce chain-type price indexes.

3. The contribution of final sales of computers and software—which also includes personal consumption expenditures, exports, imports, and government—was also 0.7 percent, as imports largely offset the other components.

eliminate the bias associated with using fixed weights. Chain-type indexes use adjacent period weights to construct an index for each period–annual percent changes in real GDP for 1997–98, for example, are calculated using weights from 1997 and 1998—and the indexes for each period are chained (multiplied) together to form a time series that allows for changes in relative prices and the composition of output over time.[4] In contrast, fixed-weighted measures are calculated with a single set of weights over time.

In the index number literature, it has been long recognized that output measures that use fixed-price weights of a single period tend to misstate growth as one moves away from the base period. This tendency, often called substitution bias, reflects the fact that the commodities for which output grows rapidly tend to be those for which prices increase less than average or decline. Using past prices to weight these goods places too high a weight on their growth and overstates real GDP growth. When chain-type indexes are used, the goods with rapid growth tend to receive lower weights, and growth in real GDP is reduced. For example, the replacement of the fixed-weight price index with the chain-type price index in 1995 reduced the average annual rate of growth of real GDP during the economic expansion in 1991:I–1995:II by 0.5 percentage point. (Roughly three-fifths of this reduction reflected falling computer prices, and the rest reflected changes in the relative prices of other goods and services.)

As the United States found, a system with fixed weights puts too high a weight on those goods and services—such as computers—whose prices are falling and thus overstates real GDP growth for recent periods. Moreover, some observers may be assessing the impact of introducing quality-adjusted prices for computers into other countries' estimates without realizing that most other countries use fixed-weighted systems.

Most countries periodically update their weights, but even periodic updating of fixed weights does not adequately address substitution bias when there are significant changes in relative prices or when the period between updates is long. Most of these countries plan to move to chain-type price indexes, as recommended by the international system of guidelines on national accounting in the 1993 System of National Accounts. If the U.S. experience is any guide, the introduction of a chain index at the same time as the introduction of a hedonic price index for computers will moderate the impact of the computer price index and may even significantly offset it by eliminating the substitution bias associated with noncomputer goods whose prices are falling. This offset will be especially important for countries that are not large producers of computers and computer components; indeed, if a country is a large importer of these goods, there could be almost no net impact on GDP. In such a case, introduction of a falling price for computers will raise real investment, but this rise will be offset by a corresponding increase in real imports, which is subtracted in calculating GDP.

Robustness

As is the case with any statistical method, the results from hedonic regressions are subject to error, but the hedonic indexes for computers appear to produce consistent results. A recent survey of the literature by Ernst Berndt and Neal Rappaport (2000) suggests a fairly robust central tendency among hedonic estimates of computer prices over time. Table 2 compares the rates of decline of computer prices reported by a number of authors for a wide variety of time periods and types of computers. The estimated rates of decline in quality-adjusted prices range from 14 percent per annum to

Table 2.—Hedonic Studies of Computer Prices

Author [1]	Computer type	Time period	Prices: Annual rates of change
Chow	mainframe	1960–65	–21
Triplett	mainframe	1953–72	–27
Cole et al.	mainframe	1972–84	–19
Cartwright	mainframe	1972–84	–14
Gordon	mainframe	1951–84	–22
Cohen	personal computer	1982–87	–25 to –27
Berndt and Griliches	personal computer	1982–89	–23 to –25
Berndt, Griliches, and Rappaport	mobile personal computer desktop personal computer	1989–92 1989–92	–23 to –24 –31 to –32
Nelson, Tanguy, and Patterson	desktop personal computer laptop personal computer	1984–91 1990–98	–18 to –25 –40
Chwelos	desktop personal computer personal computer	1992–98 1976–83	–32 to –35 –18
Berndt and Rappaport [2]	personal computer personal computer personal computer	1983–89 1989–94 1994–99	–18 –32 –39
Aizcorbe, Corrado, and Doms	desktop personal computer notebook personal computer personal computer, weighted average. [3]	1994:IV-1998:IV 1994:IV-1998:IV 1994:IV-1998:IV	–31 –26 –30
BEA price index	personal computer	1994:IV-1998:IV	–32

1. See "Bibliography" for more complete citations.
2. Results reported for "all pooled" regression, (Berndt and Rappaport 2000).
3. Weights are 0.75 for desktops, 0.25 for notebooks.

4. The chain-type indexes that BEA uses are described in the price index literature as Fisher Ideal indexes. These indexes, which are the geometric means of Paasche and Laspeyres chain-type indexes, have the characteristic of minimizing substitution bias, which the Paasche and Laspeyres indexes do not. For a more complete discussion, see Parker and Triplett (1996).

40 percent per annum, depending on the time period and on the type of computer examined. The range narrows when similar time periods are examined; for example, the results for personal computers (PC's) for the latter half of the 1990's cluster around an average annual rate of decline of between 30 percent and 40 percent.

Berndt and Rappaport also evaluated the impact of using varying parameters over time to address a long-standing concern about hedonics—that the estimated coefficients of performance characteristics are unstable over time. They attempted to overcome this problem by estimating individual-year regressions and using methods analogous to the construction of Paasche and Laspeyres chain-type indexes to construct price-index time series; this was done separately for mobile and desktop PC's.[5] Their approach produced four price indexes; the mean of the four alternative (time varying) indexes was a 39.8-percent rate of decline in the prices of PC's in 1995–99, 6.5 percentage points more than the 33.3-percent average rate of decline in the BEA hedonic price index for PC's over the same period (table 3).

Table 3.—Price Indexes for Computers: Average Annual Rates of Decline, 1995-99

	Percent
NIPA private fixed investment:	
Computers and peripheral equipment	–24.2
Personal computers	–33.3
Berndt and Rappaport [1]:	
Desktop personal computers, unit prices	–8.7
Mobile personal computers, unit prices	–4.6
Personal computers, mean of alternative hedonic indexes	–39.8

1. Source: Berndt and Rappaport 2000.

Relation to traditional price measures

One of the principal obstacles to estimating the impact of hedonic price indexes for computers is the lack of traditionally measured price indexes for computers. Fortunately, two recent, but very different, studies—the aforementioned study by Berndt and Rappaport and one by Ana Aizcorbe, Carol Corrado, and Mark Doms (2000)—provide some new price information. Berndt and Rappaport estimated the average unit prices for computers and found an 8.7-percent annual rate of decline for desktop PC's and a 4.6-percent annual rate of decline for mobile PC's in 1995–99 (table 3). Although such an index makes no allowance for the increased computing power, storage capacity, speed, or graphics capability over this period, it allows the calculation of a crude measure of the contribution of quality change to the growth in real GDP. If we assume that desktop PC's account for three-fourths of the market and that mobile PC's account for one-fourth, the average rate of decline in unit prices for PC's was 7.7 percent, compared with a 33.3-percent rate of decline in BEA's hedonic price index, a difference of 25.6 percentage points. If we weight this difference using the weight for computers and peripherals from the NIPA's, the quality change in PC's adds, at most, one-quarter of a percentage point to the estimate of average annual real GDP growth over the period.[6]

This "what-if" exercise using unit prices may provide a rough estimate of the impact of quality change for computers, but a more instructive exercise is to compare the hedonic price index to a traditional matched-model price index, such as the one recently constructed by Aizcorbe et al. They collected quarterly data on PC prices and sales to construct a chain-weighted price index for PC's in which the weights were current-dollar shares for each period; no explicit adjustments were made to reflect quality differences across models. They found that the decline in the prices of PC's with Pentium I processors when Pentium II processors were being introduced, the decline in the prices of PC's with Pentium II processors when Celeron processors were introduced, and so on, represented the price reductions that were necessary to make the older units competitive with the newer higher quality units. The price indexes that they constructed are remarkably close to the corresponding hedonic price indexes (table 4). Their estimates of the average annual rates of price decline in 1994:IV–1998:IV were 30.6 percent for desktop computers and 24.6 percent for notebook comput-

5. Laspeyres indexes are price indexes that use past-period weights to measure changes in relative prices, whereas Paasche indexes are price indexes that use current-period weights. For a description of these indexes and other indexes, see Jack T. Triplett (1992).

6. This calculation implicitly assumes no increase in the number of PC's in equipment investment from 1995 to 1999.

Table 4.—Price Indexes for Computers: Average Annual Rates of Decline, 1994:IV to 1998:IV

	Percent	
	Traditional	Hedonic
NIPA Private fixed investment:		
Computers and peripheral equipment	.....	–23.7
Personal computers	.....	–32.5
Aizcorbe et al. [1]:		
Desktop personal computers	–30.6	–31.0
Notebook computers	–24.6	–26.3
Weighted average [2]	–29.1	–29.8

1. Source: Aizcorbe et al. 2000.
2. Weights are 0.75 for desktops, 0.25 for notebooks.

ers. Their estimates of hedonic price indexes for the same period showed a 31.0-percent average annual rate of decline for desktop computers and a 26.3-percent average annual rate of decline for notebook computers. BEA's price index for personal computers declined at an average annual rate of 32.5 percent over the same period.

Software prices

BEA uses a hedonic price index (as well as a matched-model index) in the estimation of real prepackaged software investment for 1985–93, but this index declines more slowly than BEA's computer price index, and its impact is largely offset by BEA's use of cost-based estimates in constructing the price indexes for the other two components of software-custom software and own-account software (charts 1 and 2). BEA's price index for custom software is a weighted average of the prepackaged-software index and a cost-based price index; the price index for own-account software is a pure cost-based index. (A paper describing BEA's methodology for software is on BEA's Web site at <www.bea.doc.gov>.) By construction, BEA's cost-based indexes assume roughly zero growth in multifactor productivity A number of observers have questioned this conservative methodology, but until BEA is able to obtain better indexes, the contribution of software investment to real GDP growth is likely to be little different than its contribution to current-dollar GDP growth, so the net impact of hedonics on software prices is minimal.

Other factors

Although much attention has recently been focused on whether real GDP growth in the latter half of the 1990's has been overstated as a result of the use of hedonic-based price estimates for computers and peripherals and for computer software, there are other reasons to suspect that growth—especially that related to high-tech innovations—has been understated. First, a number of the industries that are heavy users of the new information technology, such as education and certain financial services, are deflated using cost-based indexes or by input and partial output extrapolators. As noted above, if nominal output is deflated by total cost indexes, there is roughly zero multifactor productivity growth, or if real output is extrapolated by labor inputs, there is no labor productivity growth (and if capital inputs grow faster than labor inputs, there is negative multifactor productivity growth). Recently, BEA replaced its input extrapolation for banking services with a new BLS banking services index; this replacement raised real GDP growth rates in recent years by an average of 0.05 percentage point. If similar indexes were introduced into the remaining 20 percent of GDP that is still estimated using cost and input-based indexes, real GDP growth might be revised up substantially.

CHART 1

Chain-Type Price Indexes for Private Fixed Investment in Computers and Peripherals and in Computer Software, Average Annual Rates of Change

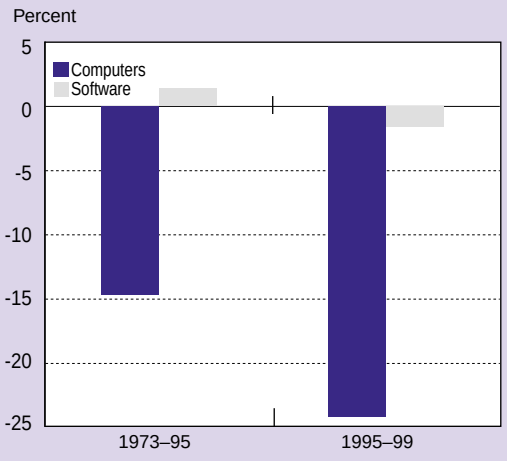

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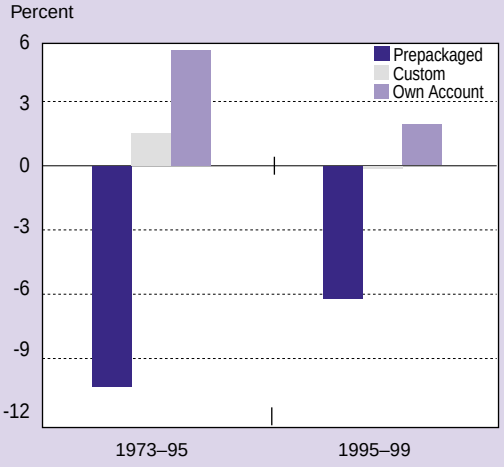
CHART 2

Price Indexes for Private Fixed Investment in Computer Software by Type, Average Annual Rates of Change



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