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Fisher Ideal Indexes in the National Income and Product Accounts

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Students and researchers selecting tables on the Bureau of Economic Analysis'(BEA) Internet site may be surprised to discover an array of unfamiliar quantity and price indexes in the national income and product accounts. The new method represented in the tables by Fisher Ideal quantity and price indexes was introduced by the bureau during a period of time when users were becoming increasingly dependent on electronic media for data as well as explanatory information. Unfortunately the method changes in the national income and product accounts have received little or no attention from economists in academia. However, the new approach has important implications for the measurement of economic growth and the interpretation of real-dollar estimates of gross domestic product (GDP) and its components.

The purpose of this article is to review several aspects of the bureau's 10th comprehensive revision as reported in various issues of the *Survey of Current Business*. I discuss the impact of substitution bias on the measurement of economic growth under the old method, then show that with the new method there is no longer a fixed base year because the Fisher Ideal indexes are chain-type annual-weighted quantity and price indexes that are in effect rebased each year. The new methodology has resulted in chained dollar estimates of GDP and its components that are not additive in real-dollar terms; I discuss the impact of this inconsistency on the analysis of contributions to growth.[1]

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IMPACT OF SUBSTITUTION BIAS ON MEASURING ECONOMIC GROWTH

The new method used in the 10th comprehensive revision was designed to provide an accurate characterization of changes in economic activity that would not be subject to change every time the accounts were adjusted for a new base year with different relative prices. It is commonly known that conspicuous changes in relative prices and subsequent alterations in purchasing patterns have the potential to distort estimated growth rates. In particular, a significant decline in relative prices from fixed base-year weights results in understatements of growth for periods before the base year and overstatements of growth for periods after the base year. The impact of a change in the base year affects the computation of growth rates because higher rates of expenditures for a good often occur expressly because the relative price of the good is decreasing. Thus, when the relative price of a good is decreasing, but growth is measured using an earlier (higher) price, output of this good will receive an unwarranted high weight and the economic growth rate will be biased upward.

In previous comprehensive revisions, changes in the base year had only a minor effect on the measurement of economic growth because relative price movements had been small.[2] However, after the introduction of the bureau's new price index for computer memory chips and microprocessors, the effect of recent decreases in the relative price of computer equipment became evident. Lower computer prices resulted in a 1.5 percentage point decrease in the contribution of computer equipment to economic growth from 1982 to 1987, when 1982 output was measured with 1987 prices. Landefeld and Parker (1995) reported that the old methodology understated growth in real GDP during the five economic expansions from 1960 to 1990 by .5 percentage points. At the same time, growth after 1987 was overestimated by .5 percentage points. Thus the relative strength of the current economic expansion may have been overstated by 1 percentage point as a result of using the old fixed-weight method.

The BEA new method, based on geometric means, is designed to reduce the bias that occurs when expenditure patterns are altered in response to broad trends in relative prices (referred to as upper-level substitution bias). In contrast, Boskin et al. (1998) reported that the Bureau of Labor Statistics' (BLS) consumer price index (CPI) emphasized a bias called component level bias that is defined as substitution at a lower level of aggregation, such as consumers substituting between different brands of a particular good. The BLS is currently evaluating whether geometric means should be used for some or all of the components of the CPI (BLS 1998).[3]

CALCULATION OF FISHER IDEAL QUANTITY INDEXES AND CHAINED DOLLAR ESTIMATES

I begin with the definition of a Laspeyres quantity index Q^L as a ratio of aggregates for periods 0 and 1, that is,

$$Q^L = \frac{\sum p_0 q_1}{\sum p_0 q_0}, \tag{1}$$

where p_0 and p_1 are prices, and q_0 and q_1 are quantities in each period, and the subscript i (representing the number of different goods) is dropped for ease of exposition. The Laspeyres index may be rewritten as a weighted average of a ratio of quantities so that an equivalent expression is

$$Q^L = \sum\left(\frac{p_0 q_0}{\sum p_0 q_0}\right) \times \frac{q_1}{q_0}. \tag{1′}$$

The ratio q_1/q_0 is a quantity relative, and the shares of current dollar output in base-year dollars are referred to as price weights.

Alternatively, a Paasche quantity index Q^P can be defined as the ratio of two aggregates.

$$Q^P = \frac{\sum p_1 q_1}{\sum p_1 q_0}, \tag{2}$$

or as the weighted average of quantity relatives,

$$Q^P = \sum\left(\frac{p_1 q_0}{\sum p_1 q_0}\right) \times \frac{q_1}{q_0}. \tag{2′}$$

Expressions (1) and (2) illustrate that when a quantity index is constructed between two time periods, the Laspeyres index uses the prices of the first period as weights whereas the Paasche index uses the prices of the second period. As a general rule, expressions (1′) and (2′) correspond to value weights that are easier to use with source data, so these will be used here to illustrate the problem of upper-level substitution bias.

Consider the following hypothetical data for two goods:

	t_0	t_1
good 1:	p = \$7, q = 1	p = \$7, q = 1
good 2:	p = \$5, q = 1	p = \$1, q = 10.

For the period t_0 to t_1, the quantity of good 2 increases from 1 to 10 as its price decreases from \$5 to \$1, but the price and quantity for good 1 are unchanged. Using equations (1′) and (2′) to calculate the Laspeyres and Paasche indexes for year t_1 one finds

$$Q^L = (.583)(1) + (.416)(10) = 4.743$$
$$Q^P = (.875)(1) + (.125)(10) = 2.125,$$

that is, the Laspeyres index suggests stronger growth from t_0 to t_1. Although each of the four price weights is different, it is easy to see the bias caused by the dramatic decrease in the price of good 2. The large weight on the quantity of good 2 in the Laspeyres index (\$5/\$12 = .416) overestimates the effect of its 10-fold increase in quantity whereas the small weight in the Paasche index ($1/$8 = .125) underestimates growth. In general, the difference between a Laspeyres and Paasche index will depend on the dispersion of the price weights and quantity relatives and the correlation between movements of the individual prices and quantities.

Prior to the 10th comprehensive revision, GDP and its components were measured using Laspeyres indexes with weights from a single base year (1987). To alleviate the bias caused by changes in relative prices, the BEA undertook a multiyear plan (completed in 1996) to replace all fixed-weight 1987 series with Fisher Ideal quantity indexes that use price weights from two consecutive years to avoid substitution bias. *Fisher Ideal indexes* are defined as the geometric mean of a Laspeyres and a Paasche index so that the Fisher Ideal quantity index is defined as

$$Q^F = (Q^L \times Q^P)^{1/2}, \quad (3)$$

where the Laspeyres component uses weights from the first year, and the Paasche component uses weights from the second year.[4] Because the Fisher Ideal index is the geometric mean of the Laspeyres and Paasche indexes, its value will be between the upper bound of the Laspeyres and the lower bound of the Paasche. Thus the use of annual weights reduces the upper-level substitution bias.[5]

To illustrate how the annual-weighted Fisher Ideal quantity indexes are chained together to form a time series, consider the following value matrix formed by using prices and quantities from a hypothetical economy for years 0, 1, and 2:

$$\begin{array}{lll} \Sigma p_0 q_0 & \Sigma p_0 q_1 & \Sigma p_0 q_2 \\ \Sigma p_1 q_0 & \Sigma p_1 q_1 & \Sigma p_1 q_2 \\ \Sigma p_2 q_0 & \Sigma p_2 q_1 & \Sigma p_2 q_2. \end{array}$$

If each item in the first row of the value matrix were divided by $\Sigma p_0 q_0$, the result would be quantity indexes that use prices from year 0 as weights. Similarly, dividing each item in the second row by $\Sigma p_1 q_0$ would produce quantity indexes using prices from year 1 as weights. Now consider the submatrix formed from the first two columns and rows, as in a comparison of years 0 and 1.

$$\begin{array}{ll} \Sigma p_0 q_0 & \Sigma p_0 q_1 \\ \Sigma p_1 q_0 & \Sigma p_1 q_1. \end{array}$$

The first and second rows of the submatrix, respectively, can be used to form Laspeyres and Paasche quantity indexes based on annual prices for years 0 and 1, where the first element of each row is equal to one. In a like manner, consider the submatrix from the second and third columns and rows.

$$\begin{array}{ll} \Sigma p_1 q_1 & \Sigma p_1 q_2 \\ \Sigma p_2 q_1 & \Sigma p_2 q_2. \end{array}$$

The rows of this submatrix can be used to find Laspeyres and Paasche quantity indexes based on annual prices for years 1 and 2, if the first row is divided by

TABLE 1
Nominal GDP and GDP in Chained (1992) Dollars

Year	Nominal GDP ($)	Quantity index	GDP in chained (1992) dollars
1992	6,244.4 billion	100.00	6,244.4 billion
1993	6,558.1 billion	102.32	6,389.6 billion
1994	6,947.0 billion	105.87	6,610.7 billion

Source: Bureau of Economic Analysis (August 1997, Tables 1–3). Download from STAT-USA,State of the Nation database.

$\Sigma p_1 q_1$ and the second row by $\Sigma p_2 q_1$. Thus, the first two rows and then the second two rows and so on can be used to form Fisher Ideal indexes that do not have a fixed base but must be chained together to form a time series. In effect, the Fisher Ideal indexes are link indexes that show the percentage change in real GDP from one year to the next based on weights from the two successive years. The chained time series may denote any year as having a value of 100 although it is not a fixed base in the sense of the Laspeyres index that uses fixed weights from the fixed base year.

Data in Table 1 can be used to illustrate how the link indexes are combined to form a time series for the GDP quantity index. The BEA chose to express quantity and price indexes for 1992 as equal to 100 because 1992 is the latest year for which data will not be subject to review until the next comprehensive revision. From Table 1, the Fisher Ideal index using price weights from 1992 for the Laspeyres component and 1993 for the Paasche component has a value of 102.32, so that growth was 2.32 percent between 1992 and 1993. A Fisher Ideal link index using price weights from 1993 and 1994 would have been 103.47, meaning that growth from 1993 to 1994 was 3.47 percent. Because 1992 is chosen to have the value 100, the GDP quantity index for 1993 is 102.32 (that is, 2.3 percent more than the 1992 value of 100), and the GDP quantity index for 1994 is 105.87 (that is, 3.47 percent more than the 1993 value of 102.32). Comparing the value of the GDP quantity index for 1994 to the base-year value of 100, growth was 5.87 percent for the two-year period. That is, the growth rates from 1992–1993 and 1993–1994 are chained together to find growth from the base year as $1.0232 \times 1.0347 = 1.0587$, or a 5.87 percent increase.[6]

Table 2 reproduces some of the quantity and price indexes presented in Table 7.1 of a recent issue of the *Survey of Current Business*, showing four indexes for each component. One helpful characteristic of the Fisher Ideal quantity and price indexes is that for any two years the ratio of nominal GDP is equal to the ratio of the quantity indexes multiplied by the ratio of the price indexes. This characteristic, known as the factor reversal test, can be illustrated using the indexes from Table 2 and nominal GDP for 1996 and 1997, which are $7,636.0 billion and $8,079.9 billion, respectively. Then the factor reversal property is written as

TABLE 2
Quantity and Prices Indexes for Gross Domestic Product (1992 = 100)

	1996	1997	Seasonally adjusted 1997IV	1998Ir
Gross Domestic Product				
Current dollars	122.29	129.39	131.76	133.94
Chain-type quantity index	110.95	115.12	116.58	118.12
Chain-type price index	110.22	112.45	113.07	113.40
Implicit price deflator	110.21	112.40	113.01	113.34
Personal Consumption Expenditures				
Current dollars	123.41	130.00	132.18	134.32
Chain-type quantity index	111.71	115.35	116.74	118.46
Chain-type price index	110.47	112.71	113.24	113.39
Implicit price deflator	110.47	112.70	113.23	113.31
Gross Private Domestic Investment				
Current dollars	141.26	157.19	162.45	159.69
Chain-type quantity index	135.26	151.44	156.53	153.46
Chain-type price index	104.50	104.13	104.10	104.06
Implicit price deflator	104.43	103.79	103.78	103.95

Note: Data were obtained from Table 7.1, *Survey of Current Business,* May 1998,and from Internet transmission of final GDP estimates,Department of Commerce, June 25,1998.

$$\frac{\$8{,}079.9}{\$7{,}636.0} = \frac{115.12}{110.95} \times \frac{112.45}{110.22},$$

$$\text{or } 1.058 = 1.037 \times 1.020.$$

In other words, Fisher Ideal quantity and price indexes can be interpreted as showing that the rate of change of real GDP plus the rate of change of the price level equals the rate of change of nominal GDP.[7]

CHARACTERISTICS OF CHAINED DOLLAR ESTIMATES

Because the Fisher Ideal quantity index uses annual weights from adjacent years, it has the desirable characteristic of unbiasedness. In addition, as illustrated above, quantity indexes provide a direct method of calculating percentage growth for real GDP or a component without ever using a dollar value. Thus the index number approach to measuring growth emphasizes that real GDP is most appropriately considered an analytical concept rather than a series that is derived from adding up “real dollars.”

However, for many purposes, users will seek a dollar value for real GDP or its components in place of the base-year 1987 series. In order to calculate real GDP in dollars, it is only necessary to note that for any two years the ratio of the quantity indexes must equal the ratio of real GDPs. Hence if the quantity index for the year t is known, real GDP for the year t in chained (1992) dollars can be found as

$$\text{real GDP}_t = \frac{Q_t \times \text{base-year GDP}}{100},$$

where base-year GDP is in current dollars (same as real for the base year), and 100 is the quantity index in the base year. Using the GDP numbers from Table 1, GDP for 1993 in chained (1992) dollars is [(102.32)($6,244.4 billion)/100], or $6,389.6 billion. Similarly, the chained (1992) value for any GDP component can be extrapolated from the quantity index for the component. For example, from Table 2, the quantity index is 111.71 for personal consumption expenditures in 1996. If current dollar personal consumption in 1992 is $4,219.8 billion, the chained (1992) dollar estimate for consumption in 1996 is [(111.71 × $4219.8 billion)/100] = $4,713.9 billion. However, the phrase chained (1992) dollars can be misleading because in effect the index is rebased each year, as described above.

Finally, it is important to note that because the calculation of chained dollar estimates uses geometric averaging of prices from any two adjacent years as well as prices from 1992, chained dollar estimates of GDP and its components derived from the Fisher Ideal quantity indexes are not additively consistent. That is to say, the sum of chained dollar estimates of the components of GDP (for example at the highest level of aggregation, consumption, investment, government spending and net exports) will not necessarily be the exact sum of GDP as an independently calculated aggregate. Similarly, chained dollar estimates of an intermediate aggregate such as personal consumption expenditures will not be the exact sum of its detailed components (durable goods, nondurable goods, and services).[8] To acknowledge the loss of additivity, chained dollar tables now include a residual entry, where the residual is defined as the difference between GDP or a component and the sum of the most detailed components of the table. Because the residual can be traced to price weights that are not the same as the base year, it can be expected that the residuals will be small for years close to1992 (when the annual weights will likely be close in value to the 1992 weights). However, the size of residuals will increase dramatically for periods far from 1992.[9]

When analyzing the change of an individual component over time, either chained dollar estimates or a quantity index can be used. However when analyzing the contribution of various components to the growth in real GDP, calculations using chained dollar estimates may produce results that differ significantly from those calculated using quantity indexes because of the loss of additivity. Indeed, the bureau cautions against using the chained (1992) dollar estimates before 1982 for analysis across components or for analyzing components whose prices are rapidly changing.

To guard against inappropriate use of the chained dollar estimates, the bureau now publishes tables that provide contributions of the major GDP components to changes in real GDP using specific formulas that are based on detailed prices and quantity components before and after the base year. However, an approach more readily accessible to users is to select an appropriate midpoint for a time period of interest and calculate the contribution of components using contemporaneous chained dollar estimates that correspond to the midpoint. For example, consider using 1994III as a midpoint for the economic expansion that began in 1991I. Current dollar GDP for 1994III was $6,986.50 billion, and quantity indexes for 1991I, 1994III, and 1998I are 96.85, 106.17, and 118.12, respectively. Then the chained (1994III) dollar estimate for GDP for 1991I can be found as [($6,986.50 billion)(96.85)/(106.17)] = $6,373.20 billion. The chained (1994III) dollar estimate for GDP for 1998I is [($6,986.50 billion)(118.12)/(106.17)] = $7,772.87 billion. Chained (1994III) dollar estimates for personal consumption expenditures, investment, government spending, exports, and imports can also be extrapolated from their current dollar levels using quantity indexes for each component. Using this approach, Table 3 presents the percentage contribution of each component to the change in GDP from 1991I–1998I. For comparison, the table also presents the contributions of components for 1975I–1980II and 1982III–1990II, using 1977III and 1986III as the respective midpoints, as well as contributions calculated from chained (1992) dollars.

Generally speaking, the contribution of personal consumption expenditures to growth in GDP rose from 57 percent for the 1975I–1980II period to 65–69 percent in the 1980s and 1990s. In contemporaneous dollar terms, investment spending contributed more to GDP for 1975I–1980II (35.4 percent) than for 1982III–1990II (18.4 percent). Most recently, whereas the relative price of the computer component of producers' durable equipment has decreased, investment spending in the current expansion is as strong as in the 1975I–1980II

TABLE 3
Component Contributions to Real GDP Using Midpoints of Expansions or Chained (1992) Dollars

	1975I–1980II (1977III = 100)	1982III–1990II (1986III = 100)	1991I–1998I (1994III = 100)
GDP	100.0	100.0	100.0
Consumption	57.0	65.4	69.0
	(59.5)	(67.6)	(68.9)
Investment	35.4	18.4	36.1
	(23.9)	(16.6)	(36.7)
Government	8.0	18.8	0.0
	(9.5)	(18.4)	(0.0)
Exports	14.9	18.1	30.2
	(13.5)	(16.6)	(31.4)
Imports	–15.6	–20.2	–43.1
	(–11.1)	(–19.1)	(–45.3)
Residual	.4	–.5	7.6
	(4.7)	(–.1)	(8.3)

Notes: Numbers are percentage contribution of components to growth in real GDP based on chained dollars of the midpoint year, except for numbers in parentheses, which are calculated from chained (1992) dollars. Columns using chained (1977III) and chained (1986III) dollars are from J. S. Landefeld and R. P. Parker (1997, Table 3). Department of Commerce estimates may be in million-dollar precision. Other numbers are the author's calculations.

expansion. The contribution of investment spending was 36.1 percent using the contemporaneous prices of 1994III as the midpoint of the current expansion but 36.7 percent using the (higher) earlier prices of the chained (1992) dollar estimates. Finally, Table 3 shows the significant effect of increases in foreign trade and a dramatic decline in the contribution of government spending for 1991I–1998I.[10]

CONCLUDING REMARKS

With its move to chained annual-weighted indexes that progressively update the base year, the Bureau of Economic Analysis may have produced a final rewrite of the economic record. As a result of the new method, the long-term growth rate for the U.S. economy from 1929–1987 has been revised upward from 3.0 percent to 3.4 percent per year. Economic activity during periods of time such as the post-World War II demobilization has been recharacterized, because new calculations based on low postwar prices for defense equipment show that the drop in real GDP from 1944 to 1947 was 13 percent instead of 25 percent (Landefeld and Parker 1997). Recently, the new methodology has suggested that economic growth was 13 percent higher for the period 1960–1987 but 3 percent lower for the period 1987–1992.

The new approach is also appropriate for measuring short-run fluctuations in economic activity, and, in fact, its most significant application may be in the analysis of business cycle conditions. For example, application of the annual-weighted indexes to the unusually brief contraction that began in 1980II resulted in lengthening the downturn to include an additional quarter, and during the subsequent expansion, the average quarterly growth rate was found to be 8.1 percent instead of 6.9 percent. However, this revision was the only instance in which the timing of a business cycle was altered. In general, the new method has eliminated the tendency of comprehensive revisions to dampen the historical business-cycle record, because it will no longer be the case that the record of past business cycles is recalculated using prices of another period. In other words, the use of a single base-year fixed-weight measure of real GDP had meant that there was an *a priori* bias toward understating growth for periods before the base while overstating growth for periods after the base. Adoption of the Fisher Ideal indexes that use contemporaneous price weights will result in more accurate measurement of the depth of contractions and strength of expansions.

In summary, the new chain-type measures of real GDP produce unbiased estimates of economic growth because they are constructed using price weights that change continually as prices in the economy change. The new method has or will soon be incorporated into other data series such as the Federal Reserve's index of industrial production and the Bureau of Labor Statistics' annual and quarterly measures of multifactor and labor productivity to reduce bias in these series. Taken together, these developments may hold the promise of improving the analysis of critical economic relationships, such as the long-term potential for noninflationary growth. Progress toward a better understanding of such relationships will more than offset the loss of familiar teaching tools.

NOTES

1. The new method has been received skeptically by the business community, in part because the loss of additivity of components measured in chained dollars creates computational and forecasting problems for users. For example, see Lowenstein (1995) and Prakken and Guirl (1995). Another significant aspect of the 10th comprehensive revision is the introduction of a new series for government investment that provides a consistent treatment of fixed assets whether purchased by the public or private sector. Accordingly, the series formerly called government purchases has been replaced by a series called government consumption expenditures and gross investment. For details, see Donahoe et al. (1996), Triplett (1992),and Young (1992).
2. Beginning in the 1970s, there were pronounced movements in the relative prices of food and energy, but upward trends have been followed by downward trends so that over long periods of time there has been little bias from the food and energy sectors.
3. There has been much discussion of lower component-level bias in the consumer price index, such as Boskin et al. (1998). Boskin and Jorgenson (1997) note that the component consumer price indexes are used as inputs by the BEA, so that the consumer price index bias flows into the price data of the national income and product accounts, resulting in lower estimates of real consumption expenditures and subsequently an understatement of the growth of real GDP.
4. Diewert (1976) showed that the Fisher Ideal price index is a superlative index that approximates a true cost-of-living index. For additional reference, see Stone and Paris (1952).
5. We focus here on the computation of annual quantity indexes. Quarterly estimates use annual weights centered between adjacent years, except for the tail when data are not yet available. To compute Fisher Ideal price indexes, use the formulas in the text, but interchange the *p*s and *q*s.
6. The ability of an index to be consistent from period to period is called transitivity. The Laspeyres index always displays transitivity whereas the Fisher Ideal index is transitive when growth rates are calculated by chaining.
7. In the previous method, the implicit price deflator was a Paasche index,and the price and quantity estimates met the factor reversal test for comparisons using the base year. As a result of the new method, the implicit price deflator will now be defined as the ratio of current output to chained dollar output multiplied by 100. Because the weights used to aggregate the detailed prices for each measure are the same, the new implicit price deflator will be the same as the chain-type price index for all but the most recent estimates. Thus, the new implicit price deflator is no longer distorted by shifts in the composition of output.
8. Using the previous method, quantities were found primarily by deflation of reported values and then weighted by base-year prices so that all base-year 1987 dollar estimates were additive. It is well known that achieving the desirable objectives of unbiasedness and transitivity may mean the loss of additivity.
9. Residuals for 1929–48 averaged more than 8 percent of GDP, with especially large residuals during World War II, when government spending nearly doubled and prices were controlled. Residuals average approximately 1.5 percent of GDP for the period 1949–81 and less than .1 percent of GDP for the period 1982–96.
10. Estimates of annual GDP for 1942–62 in chained (1952) dollars and annual GDP for 1962–82 in chained (1972) dollars are found in Landefeld and Parker (1997, Table 5–6).

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