PRODUCTIVITY MEASUREMENT WITH

CHANGING-WEIGHT INDEXES OF OUTPUTS AND INPUTS

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This paper examines the use of changing weight indexes of inputs and outputs in productivity measurement[1]. The U.S. Bureau of Labor Statistics (BLS) productivity measurement program has for many years preferred changing-weight indexes to fixed-weight indexes. The paper examines the reasons for this preference and how it has been implemented over time.

The paper examines this broad problem as follows. The next section of the paper, section 1, discusses weighting schemes for input indexes, from the viewpoint of the general logic for selecting an input index method and also by drawing on the theoretical literature relating to input measurement. Section 2 treats output indexes in a parallel fashion. In both sections, it is concluded that changing-weight indexes are preferable to fixed-weight indexes. The third section explores several important practical issues that a statistical organization must resolve before implementing one of the changing-weight index forms and explores the tension between the ideal methods favored in the theoretical literature and the practical requirements of an on-going statistical program. This section also examines the issue of which output concept—for example, value added or gross output—is appropriate for industries and sectors of the economy. Section 4 describes how BLS has implemented its choice of changing-weight indexes for productivity data. Section 5 is an analysis of the effects of the BLS changing-weight indexes on trends in selected input, output, and productivity series. The final section of this paper, section 6, summarizes the main results of the paper. It also offers a few observations on international comparisons of productivity trends.

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[1] We are happy to acknowledge the contributions to this paper made by our colleagues John Glaser, Bill Gullickson, Margaret Johnson, Kent Kunze, Phyllis Otto, Larry Rosenblum, and Clayton Waring. In addition, Charles Hulten and participants in the May 1996 OECD Expert Workshop on Productivity made valuable comments on an earlier draft.

1. INPUT INDEXES

In 1983, BLS introduced its first measures of trends in multifactor productivity (MFP--also referred to frequently as total factor productivity or TFP). These data were for three major sectors of the U.S. economy, the private business sector, the private nonfarm business sector and manufacturing; they covered the years 1948 to 1981. The input measures included were capital services and labor. An annually-chained Tornqvist index was used both to aggregate detailed capital services inputs into a single index of total capital input and to aggregate capital and labor inputs. (The Tornqvist index is a specific changing-weight index which has been termed a superlative index by several index number theorists; see especially Diewert (1976).) This work was published in a BLS bulletin (BLS 1983). These data have been updated, roughly annually, since 1983; to our knowledge this was the first time that a national statistical office in the United States used a superlative index in the preparation of an official, periodically published, set of data.

This section discusses the reasons for selecting a changing-weight index, and specifically the Tornqvist index, for preparing input series for use in calculating productivity. There is also some discussion of the general merits of a changing-weight index compared to a fixed-weight index. The section concludes with a brief discussion of the Fisher Ideal index.

Before discussing the theoretical literature on changing-weight indexes, we make some introductory comments suggesting that changing-weight indexes have a strong intuitive appeal. (Later we discuss the foundations of changing-weight indexes in the index-number literature and in production theory.) Let us compare a changing-weight index with one type of fixed-weight index. As our example, we will select an index that makes use of the following fixed-weight method: the weight for each input is its price, in a base year, or equivalently the weight is each input's share of input costs in the base year when the index is constructed by weighting together quantity indexes of individual inputs. These weights are kept constant over a number of years. Note that constant weights ignore possible changes in the relative use of inputs that would be expected when relative prices change. For example, if the price of capital were to increase sharply relative to the price of labor, enterprises would be likely to begin using relatively more labor (workers may be hired, shifts increased or hours per shift increased) and relatively less capital (investment in equipment may be cut back or existing plant or office space leased to new renters). In this example, two changes take place, as regards capital: there is an increase in the relative price of capital and a decrease in the relative quantity of capital. The two changes have opposite effects on the share of capital in input costs and, as a result, capital’s share could rise, fall, or remain constant. With base-year share weights, the weight for capital must remain constant. In this example, fixed weights fail to capture fully the effects of the input-mix decisions we would expect managers to make. Further, the resulting input index is dependent on the specific base year selected for the price (or share) weights. A changing-weight index does not suffer from these problems.

In the literature on productivity measurement, the Tornqvist index is the changing-weight index that has been most frequently examined and used. The Tornqvist index, which was developed in the 1930s at the Bank of Finland (Tornqvist 1936), makes use of logarithms for comparing two entities (e.g., two countries or two firms) or for comparing a variable pertaining to the same entity at two points in time. When used to compare inputs for two time periods, in the context of productivity measurement, it employs an average of cost-share weights for the two periods being considered. The index number is computed after first determining a logarithmic change (or rate of proportional change), as follows:

$$\ln X_t - \ln X_{t-1} = \sum_i \left[s_i \left(\ln x_{i_t} - \ln x_{i_{t-1}} \right) \right]$$

where x_i designates inputs, where n inputs (1…i….n) are being considered, where the two time periods are t and t-1, and where the cost share weights s_i are computed as:

$$s_i = \frac{1}{2}\left[\left\{\frac{c_{i_t} x_{i_t}}{\sum_i \left(c_{i_t} x_{i_t}\right)}\right\} + \left\{\frac{c_{i_{t-1}} x_{i_{t-1}}}{\sum_i \left(c_{i_{t-1}} x_{i_{t-1}}\right)}\right\}\right]$$

where c_i is the unit cost of the input. The exponential of this logarithmic change yields an index number.

The literature on the theory of index numbers has shown that the Tornqvist index of inputs has a number of desirable properties. In particular, an important article by Diewert (1976) demonstrated that the Tornqvist index is an exact index for (i.e., is consistent with) a "translog" structure of production. (The translog, or transcendental logarithmic, form is discussed below.) The underlying conditions assumed in making this demonstration are quite general, as is demonstrated in an important paper by Caves, Christensen, and Diewert (1982); nonetheless, certain limitations are associated with the demonstration.[2]

The literature that examines the merits of specific input index methods frequently makes use of production functions, the structure relating the production of an output to the use of one or many inputs. Dale Jorgenson and a

[2] For example, Caves, Christensen and Diewert (CCD) show that the theorem setting forth this result for the Tornqvist input index does not require optimizing behavior with respect to outputs nor does it require linear homogeneity. On the other hand, the theorem does require the assumption of cost minimizing behavior and it assumes that positive amounts of all inputs are used at both periods of time. In addition, the underlying translog distance functions (distance functions are used by CCD in deriving a very general production structure) must be assumed to have identical coefficients for the second order input terms. CCD make their demonstration in terms of indexes comparing two different firms rather than to comparisons of one economic entity at two points of time; however, it applies also to the latter case. For a complete description of the assumptions needed under this theorem, see CCD, especially pages 1393—99. For further examination of exact and superlative indexes used in aggregation of inputs and outputs in production theory, see Diewert (1976), Denny and Fuss (1983) and Diewert (1992). For a broader discussion of this literature, see Morrison (1993). Several of these studies focus on the relative merits of the Tornqvist and the Fisher indexes.

number of collaborators have explored the properties of various production functions, with a view to determining those most suitable for the study of productivity and to selecting an appropriate input index method. Jorgenson and his collaborators have carefully examined and set forth the properties of the translog production function, which presents output as a transcendental or, more specifically, exponential function of the logarithms of inputs.[3] The merits of the translog production function include the fact that it places fewer restrictions on input (and also output) relationships than other functions. It is noteworthy that the translog function allows the elasticities of substitution among inputs to vary as input proportions vary, unlike some other production functions including the Cobb-Douglas function and constant elasticity of substitution functions (Christensen, Jorgenson, and Lau (1973).)

Tornqvist indexes can be used to combine indexes of broadly-defined inputs such as capital, labor and purchased intermediate inputs into indexes of total inputs. They can also appropriately be used for combining detailed inputs—such as specific types of capital, labor, or intermediate inputs—into aggregate indexes for each type of input. For example, an aggregate index for capital can be developed through Tornqvist-aggregation of detailed types of capital inputs. The productivity literature generally recommends identifying inputs at the finest

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[3] For example, Gollop and Jorgenson (1980)[G-J], have set forth a very general production function for a sector or an industry, as follows:

$$Z_i = F^i(W_i, K_i, L_i, t).$$

In this formulation , Z_i is the output of the sector; W_i , K_i , and L_i are inputs of intermediate inputs, capital, and labor respectively; t is time; and is an index denoting a particular sector. They then proceed to present the translog production function for a sector. See G-J, p. 25. In empirical work on productivity, it is often assumed that a translog production function is characterized by constant returns to scale. For more detailed discussion of this approach , including a careful justification of the use of the translog in productivity measurement, see for example G-J, pp. 17-28.

possible level of detail and then aggregating, using cost-share weights for each detailed type, to more broadly-defined inputs, such as total capital or total intermediate input. The cost share weights are developed using prices, or estimates of prices, of the detailed inputs.

Several additional comments on input aggregation are appropriate. In the literature on capital aggregation, a classic article by Hall and Jorgenson (1967) sets forth the formulae for estimating implicit rental prices of capital. Other researchers, including Jorgenson, have explained how these rental prices can be used to aggregate detailed types of capital input for use in measurement of productivity. A similar approach has been followed in other studies with respect to labor input (Jorgenson, Gollop, and Fraumeni 1987; Jorgenson and Fraumeni 1989; BLS, 1993, Labor Composition and U.S. Productivity Growth, especially Appendix A; Dean, Kunze and Rosenblum 1988; Rosenblum et al (1990).)

The literature on input aggregation for productivity measurement purposes builds on micro-economic theory. It makes use of the concept of the elasticity of output with respect to inputs and, often, the assumptions of competitive output and input markets, and in some applications the assumption of constant returns to scale. While a careful examination of these assumptions is not necessary for purposes of the present paper, it should be noted that they are critical to the input aggregation procedures often used, by BLS and by other researchers, and that these assumptions have been challenged. It should be noted specifically that the use of cost-share weights for input aggregation generally requires competitive input markets.[4] In addition, the use of implicit rental prices of capital for estimation of capital service flows is predicated on the additional assumption of long-run equilibrium in capital goods markets.

The Tornqvist index method is not the only index method that could be used to implement the general idea of calculating indexes for broad input categories by aggregation from finely-defined inputs. Nor is it the only procedure that can be used to implement the general preference for changing-weight over fixed-weight indexes. Other index methods could be used. However, the Tornqvist index method has been preferred by many researchers in the area of productivity measurement and analysis, because of the desirable properties outlined above.

Another frequently-discussed index method for aggregating inputs is the Fisher Ideal index. The Fisher Ideal quantity index is the geometric mean of the Laspeyres and Paasche quantity indexes. In productivity studies, the Fisher index has been used less frequently than the Tornqvist. Some recent work has emphasized the merits of the Fisher index. In addition, the adoption of the Fisher index by the BEA for the measurement of real GDP and its main components may add to the popularity of this index.

Diewert, in his 1992 paper, examined both the Tornqvist and the Fisher index approaches to input measurement (as well as to output and productivity measurement). He analyzed the merits of these two indexes from two perspectives. First, he examined the indexes from the perspective of the "test" or "axiomatic" approach: which index methods meet a number of tests, or possess specific mathematical properties, that have been suggested by various writers as desirable for an input quantity index, or indexes of output and productivity? He also considers economic approaches to the construction of index numbers of input, output and productivity. He concludes that there is an equally strong economic

[4] It is often necessary to use value-share weights instead of cost-share weights. In that case, it is necessary to assume competitive output markets as well as input markets and also to assume constant returns to scale.

justification for Tornqvist and Fisher indexes but that the Tornqvist index does not pass all the tests passed by the Fisher. We have concluded from this work that there is no strong reason to prefer one form over the other.

2. OUTPUT INDEXES

It is useful to begin the discussion of output indexes with a brief description of two types of fixed-weight output indexes that BLS used until recently.

Until 1995, BLS prepared its output indexes for its labor productivity series for detailed industries in the following way. Fixed-weight output indexes were computed by, first, dividing time series on nominal output data for detailed types of goods or services by corresponding price indexes. The price indexes reflected price changes relative to a specific year, the base year. This step yielded detailed indexes of real output. These indexes were then weighted, using base-year weights, and added to produce an aggregate index of output for the industry. With each new economic census—generally, every five years—new weights were introduced and the resulting series were linked. (The types of weights used varied; for some series unit value weights—or, roughly, price weights—were used; for other series unit employee hour weights or other weights were used.)

Another example of the BLS use of fixed-weight output indexes relates to the quarterly labor productivity series for two major sectors, the business and nonfarm business sectors; both of these sectors account for about 75 percent of GDP. Until early in 1996, for the output data in these two sectors, BLS used "constant dollar" data from the national accounts, prepared by the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce. (BLS prepares quarterly labor productivity series for six major sectors. The output indexes used for the other four sectors—total manufacturing, durable and nondurable manufacturing, and nonfinancial corporate output—will not be discussed here.) These BEA constant-dollar series were constructed similarly to the BLS industry output series, though there were several important differences. One difference occurred in the step following the deflation of nominal output data by an appropriate price index. The constant-dollar data for particular types of goods or services were directly added to produce constant-dollar output for larger aggregates. Indexes based on these constant-dollar aggregates effectively weighted items based on their prices in the base year. Another difference was that the BEA used the base-year prices of a single year for its entire time series. However, about every five years BEA selected a new, more recent base year. For example, in December 1991, as part of new benchmark calculations for its national accounts data, BEA switched from 1982 price weights for its entire time series to 1987 price weights.

In 1995, BLS changed its index number method for industry output data from the procedure described earlier to a changing-weight method. And early in 1996 BEA began to use annually-weighted indexes as its featured series for real GDP and its major components.[5] Before discussing these recent changes, it is important to discuss the short-comings of fixed-weighted indexes. These problems are analogous to those discussed above in the section on input indexes.

Fixed-weighted indexes are a reasonably good measure of output if the prices of various goods are fairly stable relative to one another.[6] However, when relative prices change, fixed-weighted indexes 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. This is because “constant dollar” series and other fixed-weighted series effectively weight items based on their prices in the

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[5] Both BLS and BEA made some use of annually-weighted output indexes prior to the dates mentioned in this paragraph. BLS first published annually-weighted indexes of output for industry MFP series in 1987. See Sherwood (1987) and Gullickson and Harper (1987). BEA first published annually-weighted data in 1992, as alternative measures of real GDP, while retaining the constant-dollar series as its featured measure. See BEA (July 1995) and BEA (Jan./Feb. 1996).

[6] This discussion will not consider the use of unit employee hour weights or other weights used in some series by BLS in past years; such a discussion is not necessary given the objectives of this paper.

base year. Fixed weights do not take into account the effects of changing relative prices. The growth rate of a fixed-weighted aggregate depends on the specific base year chosen to compute it. As a result, the growth rate is subject to revision when the base year is changed. These revisions can be systematic because consumers and investors tend to buy more of those goods and services that have become relatively cheaper.

Computers were a major source of bias in BEA's fixed-weighted measures. Although the prices of most goods have risen in recent decades, the prices of computers, adjusted for quality change, have fallen dramatically. In 1995, computer prices were much lower than in 1987, and in 1987 they were much lower than in the 1970's. Rapid growth in production of computers during the 1990's was given too much weight in total output growth in aggregates based on constant 1987 dollars. Therefore, before BEA changed its featured method of computing real GDP, growth rates of GDP were overstated for the years since 1987; the same was true for the business sector and nonfarm business sector output that BEA computed for BLS for use in its major sector productivity data. Similarly, growth of these aggregates was understated for time periods before 1987.

The bias that arises in the fixed-weight approach to construction of output indexes is especially obvious when the treatment of computer prices is considered, but the bias is similar for the output of other types of goods and services when their prices are not stable. And the problem is similar to that examined in the discussion, above, of indexes of inputs. The problem is: how to construct an aggregate quantity measure of two or more components when their relative prices are changing? As in the input case, the Tornqvist index is an appropriate answer.

We noted above that the literature on input indexes has often made use of the concept of a production function, relating the production of an output to the use of one or many inputs. The literature on output indexes has made use of similar concepts, including the production possibility frontier and the transformation function; these concepts provide a framework for examining the production of several outputs using several inputs. In particular, production possibility frontiers and transformation functions allow for the examination of situations where more than one output is produced.

In the 1973 paper mentioned above, Christensen, Jorgenson, and Lau explore the characteristics of production possibility frontiers with constant elasticities of substitution and constant elasticities of transformation. They find such frontiers unduly restrictive. One of their conclusions, for one class of such frontiers, is that the frontiers would have proper curvature only with severe restrictions on the numbers of inputs and outputs that could be considered. In contrast, the translog production possibility frontier is less restrictive and more flexible. And Diewert has shown, in the 1976 article mentioned above, that a Tornqvist output index is exact for a translog production technology. Other research has demonstrated additional advantageous characteristics of the Tornqvist output index, analogous to the conclusions regarding input indexes.[7]

[7] See, again, the Caves, Christensen, Diewert (1982) article. As in the input case, the theorem on output indexes set forth in this article requires fewer restrictive assumptions than do some other index formulas. However, some assumptions must be made, as in the input case. In his 1992 article, Diewert finds reason to support the Fisher index.

3. PROBLEMS OF IMPLEMENTING TORNQVIST AND FISHER INDEXES

The literature cited and briefly discussed above simply examines indexes for comparing two economic entities (for example two firms or two countries) at a point in time or for comparing the same entity at two different points in time. Usually, we are interested in a larger number of data points, and in particular in indexes covering entities over a long time span.

This section raises questions that are closer to the practicing statistician's practical concerns. First, how should time series—as distinct from comparisons at two points in time—be constructed? Is a Fisher index preferable to a Tornqvist index for the construction of time series? Do these two index methods yield greatly different results? And should the measurement methods for indexes of inputs, output, and productivity be the same for industries and for larger economic aggregates, including the total economy?

Time series

The recent literature on index methods, and the closely related literature on production functions and transformation functions, do offer a major advantage that some of the earlier literature did not. This recent literature, cited above, is framed in terms of discrete time units. Some of the earlier literature (Solow (1957), Jorgenson and Griliches (1967), and Hulten (1973)) showed the relationship between Divisia indexes and theoretical productivity measures. The Divisia is a continuous index form; the Tornqvist index is the discrete counterpart of the Divisia index. As Diewert (1992; p. 211) has pointed out, "Unfortunately, these Divisia indexes require that price and quantity data . . . be collected on a continuous time basis, which is impossible empirically". Some of the recent discussions are specifically framed in terms of indexes that use discrete data. Among these discussions are several of the contributions discussed above: Diewert (1976), Gollop and Jorgenson (1980), Caves, Christensen and Diewert (1982), Diewert (1992). Hence, this literature provides guidance to a statistician who might seek to use discrete data to compare, for example, the output or productivity of a firm or an industry at two points in time.

Nonetheless, two-period comparisons are cumbersome for someone who wishes to understand long-term trends, or developments over the course of one or several business cycles. It is slightly cumbersome to make a comparison of an industry's productivity in 1994 and 1995, another of its productivity in 1995 and 1996, and a third in 1994 and 1996. It is more cumbersome, though still possible, to add 1997 data to this set of comparisons, thereby adding three more index numbers (one for 1996 and 1997, another for 1995 and 1997, and a third for 1994 and 1997). Hence, to compare data for any pair of years selected from a four-year time span requires six index numbers. (In general, the number of comparisons required is $\frac{1}{2}(n-1)^2 + \frac{1}{2}(n-1) = \frac{1}{2}\left(n^2 - n\right)$.)

It is more convenient to have a single set of consecutive index numbers, using for example 1994 = 100, and a single index number for each year. In fact, it is so much more convenient that we seldom consider any other approach. It is possible to construct such a series by chaining indexes for pairs of consecutive years. (By "chaining" is meant multiplying indexes together, where each of the indexes is derived for a two-period comparison.) This can be done for either Fisher or Tornqvist series. BLS has done this for Tornqvist output indexes and BEA has done it for Fisher indexes of GDP and its components.

These chained indexes generally yield results that differ from the indexes produced by pair-wise comparisons. For example, the index for 1996, on the base

1994 = 100, that is computed by chaining the indexes for 1995 compared to 1994 and 1996 compared to 1995 will generally differ from the index computed directly for comparing 1996 and 1994.

Hulten (1973) has examined this issue rigorously for the Divisia index. Hulten shows that the Divisia index depends, in general, on the specific path followed by the data between the two time periods being compared. That is, the index obtained by chaining two Divisia indexes over the years 1994 to 1996 will in general depend on the observation for 1995. Hulten refers to this as "path dependence." And he examines the specific conditions under which this general conclusion will not hold, that is the conditions under which the Divisia will be path-independent. Under general conditions, path dependence holds also for chained Fisher and chained Tornqvist indexes.

Choice of index method

A number of interesting and important attempts have been made to deal with this problem (for example, Triplett 1988). To examine this body of work here, however, would lead us beyond our present task. We do need to discuss briefly, though, two straight-forward practical issues, the choice between chained and pair-wise comparisons and the choice between the Fisher and Tornqvist indexes.

In large part, because chained indexes are simpler to prepare and to understand, the BLS and BEA have chosen to publish chained indexes. For example, the BLS input indexes, published in 1983 in introducing the BLS measures of MFP, are annually-chained Tornqvist indexes. In 1992, the BEA first introduced two new indexes of real GDP and its major components, both based on the Fisher method, as "alternative" indexes to its constant dollar indexes. One of these two new indexes was presented in annually-chained form—the "chain-type annual-weighted” index. The other alternative was a Fisher index developed by computing pair-wise comparisons over a span of years, customarily five-years apart. For each pair of adjacent benchmark years, two fixed-weighted quantity indexes were prepared, a Laspeyres and a Paasche index; the geometric mean of these two indexes, the Fisher index, was titled the “benchmark years-weighted” index.

Table 1 shows a comparison of these BEA results, published by BEA in 1992. This table indicates that the two indexes, derived from a chained index computed from annual pair-wise Fisher indexes, and a pair-wise Fisher computed over (approximately) five-year spans, yielded very similar results. The differences between these two indexes in average annual growth rates were never greater than 0.1 percentage point. This result seems to provide a hint that for price and quantity data that are not especially volatile, the chain-type annual-weighted index and the pair-wise comparisons over spans of several years may tend to yield similar series. However, the differences between both of these two indexes and the fixed-weight, constant-dollar index were substantial, frequently 0.3 of a percentage point or greater.

Table 1. Fixed-weighted and alternative measures of real GDP: Average annual rate of change over selected periods (percent)

	Fixed-weighted index, 1987 weights	Chain type annual-weighted index	Benchmark years-weighted index	Col. 2-col. 1	Col. 3-col. 1	Col. 3-col. 1
1959-87	3.1	3.4	3.4	0.3	0.3	0.0
1959-63	3.5	3.8	3.8	0.3	0.3	0.0
1963-67	4.9	5.3	5.4	0.4	0.5	0.1
1967-72	3.0	3.3	3.3	0.3	0.3	0.0
1972-77	2.6	2.9	2.9	0.3	0.3	0.0
1977-82	1.3	1.6	1.7	0.3	0.4	0.1
1982-87	3.8	4.0	4.0	0.2	0.2	0.0
1987-90	2.5	2.5	2.4	0.0	-0.1	-0.1

Source: Allan H. Young, "Alternative Measures of Change in Real Output and Prices," Survey of Current Business, April 1992, p. 36.

In January 1996, however, when BEA first published a Fisher-based index as the "featured" real GDP series, the index selected was the chain-type annual-weighted Fisher index.

The choice between the Tornqvist and the Fisher index method may also be made in part on pragmatic grounds. The results obtained by applying the two methods to the same data are often very similar. Table 2 presents a BLS comparison of Tornqvist and Fisher indexes of manufacturing sectoral output for the years 1949-93.[8] The two indexes yield nearly identical results. This result is similar to the results of other, unpublished, calculations made by BLS and to results presented in the literature that has examined superlative index forms (for example, see Diewert 1976, especially p. 135).

[8] This table is very similar to one published in 1995 (Gullickson 1995), though the earlier table compared indexes of manufacturing gross output (rather than sectoral output) and the underlying data have since been revised. The revised sectoral output series is presented in BLS, February 8, 1996, Appendix Table 3.

Table 2. Tornqvist and Fisher Ideal indexes of manufacturing sector output, 1949-93

Year	(1987=100) Tornqvist	Fisher
1949	28.519	28.527
1950	31.322	31.332
1951	33.408	33.412
1952	35.120	35.120
1953	38.065	38.066
1954	35.642	35.643
1955	39.281	39.283
1956	39.624	39.626
1957	39.789	39.790
1958	37.025	37.025
1959	40.254	40.255
1960	40.764	40.764
1961	40.999	40.999
1962	43.802	43.802
1963	46.055	46.056
1964	49.023	49.024
1965	52.957	52.959
1966	57.101	57.102
1967	59.064	59.063
1968	61.949	61.949
1969	63.557	63.557
1970	61.641	61.641
1971	63.213	63.214
1972	68.496	68.500
1973	74.041	74.043
1974	73.289	73.290
1975	67.930	67.930
1976	74.075	74.077
1977	79.923	79.926
1978	84.348	84.351
1979	85.481	85.481
1980	82.121	82.118
1981	82.758	82.754
1982	79.306	79.301
1983	83.205	83.201
1984	91.153	91.149
1985	93.889	93.884
1986	96.667	96.666
1987	100.000	100.000
1988	104.182	104.182
1989	106.403	106.402
1990	105.946	105.946
1991	104.103	104.102
1992	107.211	107.210
1993	110.967	110.966

Source: Bureau of Labor Statistics, Office of Productivity and Technology

The most important aspect of these new indexes, some analysts have argued, is the fact that they use changing weights rather than fixed weights, not so much whether the particular form is Fisher or Tornqvist or whether they are computed as chained or pair-wise indexes. The choice between the Tornqvist and Fisher methods and the choice between pair-wise and chained indexes usually makes little difference, at least for major sectors and large industries in the United States. (This may be because the underlying data for large sectors and industries in the U.S. are not especially volatile; these conditions may not hold for detailed industries.) The important differences, in this view, arise from the choice between a fixed-weighted and a changing-weight approach.

Productivity indexes for industries and sectors

An additional decision must be taken before output and input indexes can be implemented as part of a productivity measurement program. A specific output concept—value added, gross output, or some alternative concept—must be chosen. The issue of the appropriate output concept for computing the change in productivity at the level of industries and large sectors of the economy has been widely examined in the literature. Some analysts have favored a value-added output concept while others have favored gross output or some other concept closely allied to gross output.

It seems clear that the literature on industry productivity measurement unambiguously favors the use of gross output, or a closely related concept, for multifactor productivity measurement. (As will be seen below, the choice is not so clear-cut for labor productivity measurement.) This choice of gross output, or a closely-related concept, is matched on the input side by inclusion of intermediate inputs along with labor and capital inputs. We need to examine the choice of an output concept, however, because some researchers have favored a value-added output concept, accompanied by consideration of labor and capital inputs only.

Consider a general production function for an industry or sector, i, in which the production of gross output is viewed as a function of value added and intermediate inputs, as follows:

$$Z_i = f\left[V\left(K_{i,} L_{i,} t\right) W_i\right]$$

Gross output, Z, is produced by means of a value-added subfunction, V, which includes technology as well as capital (K) and labor (L), and, in addition, by means of intermediate inputs, W. This formulation of the production function posits the separability of value added, the subfunction V, from the overall process of producing gross output. There are several problems with this formulation. One problem is the implicit assumption that developments in intermediate inputs, for example, price change, do not influence the relative use of capital and labor. Another problem is that this formulation assumes that technological improvements can affect gross output only through the value-added subfunction. Intermediate inputs cannot be sources or mediums of productivity growth. In short, intermediate inputs are excluded from consideration in the value-added model on the basis of the assumption that they are insignificant to the analysis of productivity growth.

A number of studies have considered the arguments in favor of computing multifactor productivity using a value-added output series. Gollop (1983) explores appropriate models for industry productivity measurement and finds that the use of value-added output requires quite limiting assumptions. Several studies considering and rejecting the assumption of value-added separability are discussed in Gullickson (1995). In this discussion, Gullickson draws on the research results obtained by Jorgenson, Gollop, and Fraumeni (1987) and Berndt and Wood (1975).

For some time, the BLS has refrained from using value-added output in its publications on multifactor productivity. Instead, BLS has used “sectoral output,” a concept closely related to gross output. Sectoral output is the name given to gross output less intra-sector (or intra-industry) transactions. Sectoral output for an industry represents deliveries to purchasers outside the industry. For example, for total manufacturing, sectoral output represents deliveries to purchasers outside manufacturing.[9]

The use of value-added output for measurement of labor productivity—as distinct from its use in MFP measures—has not been closely examined in the theoretical literature and value-added is in fact frequently used in studies of labor productivity. A persuasive case can be made for the use of gross or sectoral output in labor productivity series also. Some of the considerations that underlie the choice of sectoral or gross output for multifactor productivity measurement carry over to the area of labor productivity. An appealing insight into this choice is conveyed by a question inspired by a comment by Domar (1961): who would be interested in the productivity of producing shoes without leather?

For several decades, the BLS series on labor productivity for selected 3- and 4-digit industries have been based on gross output (for a number of years ending in 1995) or the closely-related sectoral output concept (beginning in 1995). However, until February 1996, the BLS quarterly labor productivity series for total manufacturing, and the series on durable and nondurable manufacturing, were based on value-added output. In that month, BLS began using the sectoral output concept in these series. (For further discussion of these issues, see Dean, Harper, and Otto (1995) and Kunze, Jablonski, and Klarquist (1995).)

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[9] For further discussion of the reasons for the choice of sectoral output, see Gullickson (1995), especially the footnotes on p. 27. The removal of intra-sector transactions from output and intermediate input for industry productivity measurement was first suggested by Domar (1961).)

A brief comment should be made on the output concept to be used for the total economy or for sectors comprising most of the economy. BLS does not publish productivity data for the total economy. However, it does publish data for the business sector and for the nonfarm business sector, both amounting to about three-fourths of GDP. The output data, obtained from BEA, for these two sectors may be viewed as roughly consistent with the value-added concept. And at this level of aggregation, it seems likely that trends in value added and gross output data do not differ greatly.

The choice of an appropriate concept to use for international comparisons of productivity trends is complicated. For MFP comparisons, the sectoral output concept would appear to be preferable (see Gollop 1983), though BLS has not yet prepared MFP comparisons using sectoral output.[10] For international comparisons of productivity trends, however, value added data are typically available. The Bureau of Labor Statistics publishes annual data on international comparisons of labor productivity for total manufacturing, for the U.S. and 11 other countries (BLS, September 8, 1995). Related series on hourly compensation and unit labor costs are also published. At the present time, these series make use of value added output data. Whether value added is the preferred concept for international comparisons of labor productivity is not clear and it may not be possible to address it without considering the purposes of the international comparisons and the particular types of countries to be included in the comparisons. BLS is presently reviewing the question of the preferred output concept for international comparisons of labor productivity.

[10] It is noted elsewhere in this paper that BLS does publish some MFP comparisons for manufacturing, using value-added output; we are considering the feasibility of developing sectoral output data for MFP comparisons.

4. BLS MEASUREMENT PROGRAM: USE OF TORNQVIST AND FISHER INDEXES

Since 1983, BLS has radically revised its productivity measurement program. Prior to 1983, the published BLS productivity data made no use of Fisher or Tornqvist indexes, though the investigation of these methods was actively under way beginning in the late 1970's. By 1996, all of the BLS productivity measures (with the exception of the international comparisons of trends in manufacturing labor productivity) made extensive use of Tornqvist or Fisher indexes.

This section summarizes the Bureau's progress, over the years 1983-96, in developing new measures based on these index methods. The following section examines the impact of these new methods on trends in inputs, output, and productivity.

BLS introduced its first multifactor productivity measures in 1983, as noted above. These measures covered three sectors--private business, private nonfarm business and total manufacturing--for the years 1948 to 1981. The inputs used in this data set were capital services and labor inputs. Tornqvist indexes were used to aggregate capital services series from information available for detailed asset categories. The weights used for the aggregation were developed from BLS estimates of implicit capital rental prices by asset type. This aggregation followed generally the formulas developed by Hall and Jorgenson (1967) and by Jorgenson and other colleagues, though BLS (see Harper 1982) adopted an alternative approach to some components of the rental price formula. Tornqvist indexes were also used to combine capital services and labor inputs. The output series used when this set of measures was introduced in 1983 was the BEA fixed-weight constant-dollar series.

In 1987, BLS expanded its use of the Tornqvist method by computing Tornqvist indexes of outputs as well as improved indexes of inputs. In that year, two separate studies used Tornqvist indexes, annually-chained, to aggregate inputs of capital, labor and purchased intermediate inputs, for use in measures of MFP for industries (Gullickson and Harper 1987; Sherwood 1987). In addition, these two new sets of measures developed Tornqvist indexes of sectoral output. The choice of sectoral output, and the inclusion of purchased intermediates among the inputs was in accord with the conclusions of the literature summarized above. The Gullickson-Harper study covered 20 two-digit manufacturing industries while the Sherwood study covered the steel and motor vehicle industries, at the three-digit level. In the data set covering two-digit manufacturing industries, Tornqvist sub-aggregates are first developed for energy inputs, purchased inputs of materials, and purchased business services. These three series are then Tornqvist-aggregated to the level of total intermediates.

During the late 1980's, several improvements were made in the capital measures. BLS began aggregation of capital services by industry detail as well as by asset detail. Implicit rental prices were estimated at the new, finer, levels of detail. This step was taken in accord with the conclusion in the literature that input aggregation should be from the finest possible level of detail and should use the best possible approximation to marginal revenue product weights. Additional improvements were made in the rental price formula and applied to the data (Harper, Berndt, and Wood 1989). To explore the possibilities of further improvements in capital estimation, studies were made of the possible influence of increased rates of obsolescence induced by energy price increases (Hulten, Robertson, and Wykoff 1986) and of alternative data sources for estimation of capital services (Powers 1988).

Prior to 1993, all of the BLS labor input series were simple summations of hours of labor input, under the assumption that hours of labor were homogeneous. In 1993, however, Tornqvist indexes of labor composition change were introduced for the major sector MFP series (BLS, Labor Composition and U.S. Productivity Growth, 1948-90, 1993; see also Rosenblum et al 1990 and Dean, Kunze and Rosenblum 1988). In this study, detailed information on the composition of labor input was developed, with special attention to level of education, gender, and estimated years of actual work experience (as distinct from the potential work experience concept). Using wage equations, estimated prices of each type of labor input were developed. These prices were then used to aggregate the hours of each type of labor. The approach taken benefited from earlier studies by Jorgenson and his colleagues (Jorgenson, Gollop and Fraumeni 1987 and Jorgenson and Fraumeni 1989). As in the case of the BLS capital services measure, this approach was designed to develop an aggregate from the finest possible level of detail, using as weights the best possible estimates of the marginal revenue product of each input type.

As of 1994, the BLS productivity program was producing three sets of multifactor productivity measures—major sector, two-digit manufacturing, and selected three-and four-digit industries, mainly in manufacturing—and two sets of labor productivity measures—for major sectors and for detailed industries at the 2-, 3-, and 4-digit levels. In addition, international comparisons of labor productivity for total manufacturing were published. In 1994, all three of the MFP data sets used Tornqvist aggregates of inputs, but only the two industry MFP data sets used a current-weighted index of output. Neither of the two labor productivity series used current-weighted output indexes, nor did the international comparisons data set.

During the years 1994 to 1996, current-weighted output indexes were introduced for all of the BLS productivity data sets for the United States that were not using such indexes. In July 1994, BLS released major sector MFP data incorporating annually-chained Fisher indexes of output provided by the BEA, in place of the previously-used BEA constant-dollar series (BLS July 11, 1994). BLS is grateful to BEA for these series for the private business and private nonfarm business sectors; BEA computed the data for these two sectors from elements of their annually-weighted series for GDP.

In July 1995, BLS first published annually-chained Tornqvist indexes of output for its detailed 3- and 4-digit labor productivity data set. At the same time, this data set was converted from a gross output to a sectoral output series, by developing data on intra-industry deliveries and eliminating these deliveries from gross output (Kunze, Jablonski, and Klarquist, 1995).

In February 1996, current-weighted output data were incorporated into the quarterly major sector labor productivity series (BLS February 8, 1996). These output data, also obtained from BEA, are based on data from annually-chained Fisher indexes.[11] This step was taken a few weeks after the BEA adopted a chain-type annual-weighted series as its featured measure for GDP and its major components. These BEA data are now used for business, nonfarm business and nonfinancial corporate output. At the same time, BLS ceased using constant-dollar value-added series for output in manufacturing and durable and nondurable manufacturing. It replaced these series with the Tornqvist indexes of sectoral output developed initially for use in the MFP series for two-digit manufacturing industries.

With this adoption of these output series for the quarterly labor productivity data set, all of the BLS data series for the U.S. make use of changing-weight output series. Regarding inputs, in all of the MFP series the inputs are

[11] The historical quarterly data are estimated using prices from the year of the specific quarter for which a change is being estimated as well as prices for adjacent years.

Tornqvist-aggregated, with the exception of labor input. In all data sets but one, labor input is a direct aggregate of hours (or, for a few detailed industries, employees). Only in the major sector MFP series on private business and private nonfarm business is a Tornqvist index used to estimate the effects on productivity trends of changes in the composition of the workforce.

Prior to 1995, the only published BLS measures on international comparisons of productivity were the comparisons of manufacturing labor productivity for 12 countries. (As noted above, these comparisons continue to make use of fixed-weighted output measures.) However, in July 1995 a new MFP international comparisons data set was introduced (Lysko 1995). These data compare MFP trends in total manufacturing for the U.S., Germany, and France. In this data set, output is fixed weighted; the output concept is value-added; and input is a Tornqvist aggregate of capital services and labor. As in the case of the U.S. capital services data when it was first introduced in 1983, the capital services series for Germany and France are Tornqvist aggregates of detailed asset types; however, only a small number of asset types is considered.

The current status of the BLS productivity measurement program is summarized in table 3. The columns provide summary information on the types of input and output indexes used.

Table 3. Productivity data produced by the Bureau of Labor Statistics

Data Series	Data Availability	Output Index	Input Index
Output per Hour			
Major Sectors:			
Business	Q	F-VA	L
Nonfarm business	Q	F-VA	L
Non-financial corporations	Q	F-VA	L
Manufacturing	Q	T-Sectoral	L
Durable	Q	T-Sectoral	L
Nondurable	Q	T-Sectoral	L
3 and 4-digit Industries:			
176 Industries	A	T-Sectoral	L
Multifactor Productivity			
Major Sectors:			
Private business	A	F-VA	T-KL(L.A.)
Private nonfarm business	A	F-VA	T-KL(L.A.)
Manufacturing	A	T-Sectoral	T-KLEMS
Major Industry Groups in Manufacturing:			
20 2-digit groups	A	T-Sectoral	T-KLEMS
3 and 4-digit Industries:			
9 Industries	A	T-Sectoral	T-KLI
Other Data Series			
Hours at work/hours paid	A		
Labor composition	P		
Research and development	P		
Hourly compensation	Q		
Unit labor costs	Q		
Capital and other non-labor inputs	A		

Notes:
Data availability: A = annual; Q = quarterly; P = periodically
Output index: F = Fisher; T = Tornqvist; VA = value added
Input index: L = hours of labor, a direct aggregate; L.A. = hours are adjusted for labor composition change; T = Tornqvist; K = capital; E = energy; M = purchased materials, S = business services; I = intermediates.

Note: This table does not include the BLS international comparisons of manufacturing productivity.

Source: Bureau of Labor Statistics, Office of Productivity and Technology

5. EFFECTS OF RECENT CHANGES IN INDEX METHODS

The development of the improved indexes discussed in the previous section has made a substantial difference in the measured productivity trends in the United States. Economists and statisticians will no doubt support the idea that it is important to publish improved productivity data that reflect the best of recent research efforts. However, many people would agree that it is even more important to introduce these improvements if they make a difference in the broad productivity trends shown by the data and in analysts' ability to assess and understand the history of economic performance.

This section examines the effects of adopting the improved index number methods discussed above. However, to stay within reasonable space limits the discussion that follows is confined to examination of trends in major sectors, especially the private nonfarm business sector, and to the effects of the improvements in measuring trends in capital, labor and output.

In the United States, much of the popular discussion of productivity is focused on trends in labor productivity rather than in multifactor productivity. This is partly because the Bureau of Labor Statistics does not produce quarterly data on MFP and the annual MFP data are typically available with a lag of a year or more. The two series show rather different trends. Following are selected peak-to-peak compound annual rates of growth in output per hour and in MFP for the private nonfarm business sector.[12]

	Output per hour	MFP
1948-94	2.1	1.1
1948-73	2.9	1.9
1973-79	1.0	0.3
1979-90	1.0	0.0
1990-94	1.2	0.3

The hours data used in the denominator of the output per hour column are direct aggregates of all hours worked, while the MFP data are computed net of any contributions made to output through changes in the composition of the workforce.

It is probably not useful to examine which of these two series is “right”. Certainly both have important uses. Nonetheless, the MFP series comes closer to capturing the effects of improvements in technology and the effects of increases in the efficiency of resource allocation than the output per hour series. From this perspective, it is not encouraging to note that the average annual growth in MFP

[12] These data, on the private nonfarm business sector, are consistent with the BLS news release on MFP, dated January 17, 1996. The output per hour data in this table differ slightly from the output per hour data presented in column e of table 9 below. The data in table 9 are consistent with the BLS data set on quarterly output per hour, which relates to the nonfarm business sector. The difference between the two sectors is government enterprises, which are included in nonfarm business but excluded from private nonfarm business. BLS does not compute MFP data for the whole nonfarm business sector because data on the annual flow of capital services in government enterprises are inadequate. In addition, the BLS MFP news release of January 17, 1996 uses BEA data available prior to the BEA comprehensive revision of January 19, 1996, while table 9, and other tables compiled from the BLS quarterly output per hour data set, use BEA data available after this BEA comprehensive revision.

has been between zero and a half a percent since 1973. Both series show a substantial decline in the growth rate of productivity since 1973.

One major reason that MFP has grown more slowly than labor productivity is of course that MFP is net of the effects of increases in capital available per hour of labor input, while labor productivity is gross of the effects of these increases. Another reason, however, is the adoption of the input measurement methods that are discussed above. Precisely because of the adoption of these measurement techniques, the BLS measure of "capital services input" has grown more rapidly than its capital stock measure. And the composition of the labor force has shifted so that the average hour worked contributes more to production than previously. In addition, the trends in output, the numerator in both the output per hour and the MFP computations, are different in the most recent data sets than they were before the adoption of BEA's chained indexes. This last factor, of course, affects output per hour and MFP similarly.

The remainder of this section examines each of these measurement issues, starting with the capital services input data.

Capital services input

The BLS aggregation method for capital services input applies the Tornqvist index method to detailed information on capital stock by asset type and by industry. Capital stock data are prepared for individual cells defined by the intersection of asset type and industry. For each cell, annual investment information is obtained and the perpetual inventory method is applied to estimate capital stock; estimates of asset-specific capital lives and the adoption of annual decay functions are important components of this estimation. Table 4 shows the resulting "productive capital stock" estimates after individual asset types have been aggregated to five broadly-defined categories. All of the data in table 4 are direct sums of stock over industries and over detailed asset types.

Table 4. Private nonfarm business sector: Productive capital stock, 1948-94

Year	All Assets	Equip-ment	Structures	Rental Residential Capital	Inventories	Land
Indexes (1987 = 100.0)						
1948	29.2	17.5	33.7	38.7	26.8	33.0
1949	29.7	18.8	34.1	39.0	25.7	33.4
1950	30.5	19.8	34.4	39.3	28.3	33.8
1951	31.4	21.1	34.8	39.7	31.6	34.3
1952	32.1	22.3	35.4	39.8	32.5	34.8
1953	32.8	23.5	36.0	40.0	33.1	35.4
1954	33.4	24.6	36.8	40.2	32.4	36.0
1955	34.3	25.8	37.6	40.5	34.4	36.8
1956	35.4	27.1	38.6	40.8	36.2	37.7
1957	36.3	28.4	39.8	41.1	36.1	38.7
1958	37.0	29.2	40.7	41.5	35.5	39.6
1959	37.8	29.8	41.6	42.2	36.6	40.5
1960	38.8	30.6	42.6	42.9	38.4	41.5
1961	39.6	31.4	43.6	43.8	38.3	42.6
1962	40.7	32.1	44.7	45.0	40.0	43.8
1963	42.0	33.2	45.8	46.6	41.6	45.2
1964	43.4	34.5	47.1	48.4	43.6	46.7
1965	45.3	36.4	48.7	50.2	46.3	48.6
1966	47.5	38.9	50.7	51.9	49.8	50.6
1967	49.8	41.5	52.6	53.3	53.8	52.5
1968	51.9	44.0	54.6	54.8	56.7	54.4
1969	54.2	46.8	56.6	56.9	59.5	56.5
1970	56.4	49.5	58.6	59.0	61.3	58.7
1971	58.5	51.7	60.6	61.1	63.1	60.8
1972	60.7	54.1	62.5	63.7	65.1	63.0
1973	63.4	57.3	64.5	66.3	68.7	65.3
1974	66.0	61.1	66.6	68.0	72.7	67.3
1975	67.8	64.0	68.3	68.9	73.1	68.7
1976	69.3	66.1	69.8	69.8	74.7	69.9
1977	71.2	68.8	71.3	71.0	78.2	71.1
1978	73.7	72.3	73.1	72.6	82.4	72.8
1979	77.0	76.5	75.5	76.5	85.7	75.6
1980	80.4	80.2	78.4	82.1	85.7	79.4
1981	83.7	83.4	81.7	87.0	86.5	83.3
1982	86.3	85.7	85.1	89.7	86.3	86.5
1983	88.1	87.4	87.8	91.1	85.0	88.8
1984	90.9	89.8	90.6	93.0	91.1	91.3

Table 4. Private nonfarm business sector: Productive capital stock, 1948-94, continued

Year	All Assets	Equip-ment	Structures	Rental Residential Capital	Inventories	Land
Indexes (1987 = 100.0)						
1985	94.4	93.3	94.1	95.7	95.6	94.6
1986	97.5	96.9	97.4	98.1	98.5	97.7
1987	100.0	100.0	100.0	100.0	100.0	100.0
1988	102.6	103.0	102.4	102.0	103.7	102.1
1989	105.2	106.3	104.8	103.7	107.6	104.2
1990	107.5	109.3	107.3	104.7	109.6	106.0
1991	109.0	111.5	109.4	105.4	108.8	107.4
1992	110.2	113.6	110.6	106.4	108.8	108.1
1993	111.9	117.1	111.5	108.1	110.2	108.8
1994	114.6	123.2	112.4	109.8	113.5	109.5
Annual average growth rates						
1948-1994	3.0	4.3	2.7	2.3	3.2	2.6
1948-1973	3.1	4.9	2.6	2.2	3.8	2.8
1973-1994	2.9	3.7	2.7	2.4	2.4	2.5
1973-1979	3.3	4.9	2.7	2.4	3.8	2.5
1979-1990	3.1	3.3	3.2	2.9	2.3	3.1
1990-1994	1.6	3.0	1.2	1.2	0.9	0.8

Source: Bureau of Labor Statistics, Office of Productivity and Technology

Table 5. Private nonfarm business sector: Real capital input, 1948-94

Year	All Assets	Equip-ment	Structures	Rental Residential Capital	Inventories	Land
Indexes (1987 = 100.0)						
1948	20.1	11.6	25.9	35.5	24.6	25.5
1949	20.5	12.6	26.3	35.8	23.8	26.0
1950	21.5	13.6	26.6	36.3	26.1	26.6
1951	22.8	14.5	27.2	36.7	30.1	27.1
1952	23.8	15.9	28.0	37.0	31.2	27.7
1953	24.6	17.1	28.8	37.3	31.8	28.4
1954	25.2	18.0	29.7	37.6	31.0	29.3
1955	26.2	18.9	30.7	38.0	33.1	30.0
1956	27.3	20.0	32.0	38.5	34.9	30.9
1957	28.2	21.0	33.5	38.9	34.9	32.0
1958	28.8	21.6	34.6	39.4	34.4	33.0
1959	29.5	22.0	35.7	40.2	35.3	33.9
1960	30.5	22.7	36.8	41.0	37.1	34.8
1961	31.2	23.3	38.1	41.9	36.9	35.8
1962	32.3	24.0	39.4	43.1	38.9	36.9
1963	33.5	24.9	40.7	44.7	40.6	38.0
1964	34.8	26.0	42.1	46.5	42.4	39.3
1965	36.7	27.6	43.9	48.3	45.3	41.0
1966	39.0	29.8	46.2	50.0	49.3	42.8
1967	41.4	32.0	48.4	51.4	53.7	44.7
1968	43.4	33.9	50.6	53.0	56.5	46.4
1969	45.6	36.1	52.8	55.1	59.3	48.1
1970	47.7	38.3	55.0	57.2	61.2	49.7
1971	49.6	40.2	57.0	59.5	62.7	51.2
1972	51.7	42.4	58.9	62.3	64.4	52.8
1973	54.5	45.4	60.9	65.1	68.3	55.3
1974	57.5	48.9	63.0	67.1	72.5	57.8
1975	59.7	51.7	64.8	68.2	73.2	60.1
1976	61.6	54.1	66.4	69.2	74.7	62.1
1977	63.8	56.9	68.0	70.5	78.1	64.1
1978	66.8	61.3	70.1	72.4	82.2	66.0
1979	70.3	65.5	72.8	76.3	85.7	68.7
1980	74.2	69.6	76.1	81.6	85.6	73.4
1981	78.2	73.6	80.2	86.1	86.7	78.7
1982	81.6	77.0	84.4	88.8	86.5	82.3
1983	84.1	79.9	87.6	90.2	85.4	85.5
1984	87.7	83.7	90.6	92.2	91.6	89.5

Table 5. Private nonfarm business sector: Real capital input, 1948-94, continued

Year	All Assets	Equip-ment	Structures	Rental Residential Capital	Inventories	Land
Indexes (1987 = 100.0)						
1985	92.0	89.4	94.1	95.0	95.8	93.1
1986	96.7	95.2	97.3	97.7	99.1	96.6
1987	100.0	100.0	100.0	100.0	100.0	100.0
1988	103.2	104.2	102.3	102.4	103.6	101.9
1989	106.2	108.2	104.7	104.5	107.0	103.7
1990	108.8	111.8	107.1	105.9	108.7	105.2
1991	110.6	114.4	109.1	106.8	107.8	105.8
1992	112.4	116.9	110.5	108.0	109.2	107.2
1993	114.7	121.0	111.4	109.7	110.9	108.4
1994	118.0	127.7	112.3	111.5	113.3	109.4
Annual average growth rates						
1948-1994	3.9	5.4	3.2	2.5	3.4	3.2
1948-1973	4.1	5.6	3.5	2.5	4.2	3.2
1973-1994	3.7	5.1	3.0	2.6	2.4	3.3
1973-1979	4.3	6.3	3.0	2.7	3.9	3.7
1979-1990	4.0	5.0	3.6	3.0	2.2	3.9
1990-1994	2.0	3.4	1.2	1.3	1.0	1.0

Source: Bureau of Labor Statistics, Office of Productivity and Technology

Table 6. Private nonfarm business sector: Capital Composition (Ratio of Capital Input to Productive Stock), 1948-94

Year	All Assets	Equip-ment	Structures	Rental Residential Capital	Inventories	Land
Indexes (1987 = 100.0)						
1948	68.8	66.1	76.8	91.6	91.9	77.1
1949	69.2	66.9	77.2	91.9	92.6	77.8
1950	70.6	68.7	77.5	92.2	92.3	78.5
1951	72.6	69.0	78.1	92.6	95.4	79.0
1952	74.0	71.1	79.0	93.0	96.0	79.7
1953	75.1	72.7	79.9	93.3	96.3	80.4
1954	75.3	73.0	80.8	93.6	95.6	81.2
1955	76.3	73.5	81.8	94.0	96.0	81.4
1956	77.2	73.9	82.9	94.3	96.6	81.8
1957	77.7	74.0	84.1	94.7	96.5	82.5
1958	77.9	73.9	85.1	95.0	96.8	83.2
1959	78.2	73.8	85.8	95.3	96.5	83.6
1960	78.7	74.0	86.6	95.5	96.6	83.9
1961	78.9	74.3	87.4	95.7	96.3	84.1
1962	79.4	74.6	88.1	95.8	97.1	84.1
1963	79.8	75.1	88.8	96.0	97.5	84.1
1964	80.2	75.5	89.5	96.1	97.3	84.2
1965	80.9	76.0	90.2	96.2	97.8	84.3
1966	82.0	76.6	91.1	96.3	99.0	84.7
1967	83.1	77.0	92.0	96.5	99.8	85.1
1968	83.5	77.0	92.7	96.6	99.6	85.2
1969	84.1	77.2	93.3	96.9	99.6	85.1
1970	84.5	77.3	93.8	97.1	99.8	84.7
1971	84.7	77.6	94.1	97.3	99.4	84.2
1972	85.1	78.3	94.3	97.7	98.9	83.7
1973	86.1	79.1	94.5	98.1	99.5	84.8
1974	87.1	80.0	94.6	98.6	99.6	85.9
1975	88.1	80.8	94.9	98.9	100.1	87.5
1976	88.9	81.8	95.2	99.1	100.0	88.9
1977	89.6	82.8	95.4	99.4	99.9	90.2
1978	90.7	84.7	95.9	99.6	99.7	90.7
1979	91.4	85.6	96.4	99.7	100.0	90.9
1980	92.3	86.7	97.0	99.4	99.9	92.4
1981	93.5	88.2	98.1	99.0	100.2	94.4
1982	94.5	89.8	99.2	99.0	100.2	95.1
1983	95.5	91.4	99.7	99.0	100.5	96.2
1984	96.4	93.2	100.0	99.1	100.5	98.0

Table 6. Private nonfarm business sector: Capital Composition (Ratio of Capital Input to Productive Stock), 1948-94, continued

Year	All Assets	Equip- ment	Structures	Rental Residential Capital	Inventories	Land
Indexes (1987 = 100.0)						
1985	97.5	95.8	100.0	99.3	100.3	98.4
1986	99.2	98.2	99.9	99.5	100.6	98.9
1987	100.0	100.0	100.0	100.0	100.0	100.0
1988	100.6	101.2	100.0	100.4	99.9	99.8
1989	100.9	101.9	99.9	100.8	99.4	99.5
1990	101.2	102.3	99.8	101.1	99.1	99.2
1991	101.5	102.6	99.8	101.3	99.1	98.6
1992	102.0	102.9	99.9	101.5	100.3	99.2
1993	102.4	103.3	99.9	101.5	100.7	99.7
1994	103.0	103.7	99.9	101.5	99.8	100.0
Annual average growth rates						
1948-1994	0.9	1.0	0.6	0.2	0.2	0.6
1948-1973	0.9	0.7	0.8	0.3	0.3	0.4
1973-1994	0.9	1.3	0.3	0.2	0.0	0.8
1973-1979	1.0	1.3	0.3	0.3	0.1	1.2
1979-1990	0.9	1.6	0.3	0.1	-0.1	0.8
1990-1994	0.4	0.3	0.0	0.1	0.2	0.2

Source: Bureau of Labor Statistics, Office of Productivity and Technology

In addition to the computation of detailed "productive capital stocks," implicit capital rental prices by detailed asset types and by industry are estimated. These estimated rental prices are used to develop cost-share weights for each capital category. A Tornqvist aggregate is then computed: annual changes in logarithms of the capital stock data are weighted by these cost shares. The resulting series is an estimate of annual "real capital input," or the estimated flow of services from the capital stock. These series are shown, again by broad asset category, in table 5. A third table on capital, table 6, is derived from the first two: it is capital composition, or the ratio of capital services input to productive capital stock in the private nonfarm business sector.

Table 6 shows that capital services input generally has risen more rapidly than capital stock. Over the years 1948-94, the average annual rate of increase in the input-to-stock ratio was 0.9 percent. This trend reflects an increased annual rate of services flow from the "average" capital asset and results from a shift in the composition of assets toward assets with higher estimated rental prices. This trend is considerably influenced by a long-term trend toward shorter-lived asset types, which yield their services over a shorter life span and have higher annual rental prices. In the last few decades, it is likely that rapidly rising corporate spending on computers is an important factor in this shift to short-lived asset types.

The flow of capital services rose more rapidly than capital stock not only for all assets over the whole period 1948-94, but also for each broad category of assets over this period (table 6). And the input-to-stock ratio also rose over all the sub-periods shown in the table. Note, however, that this ratio rose less rapidly after 1990 than in earlier time periods.

These trends in capital input in the BLS data have been observable only because BLS has adopted an index method that accords with research on aggregation techniques and on the measurement of capital in the production context. The Tornqvist index method is an important element of implementing this approach. One of the effects of the adoption of this measurement method is that measured capital input has risen more rapidly, and MFP somewhat less rapidly, than if capital stocks alone were taken into account.

Labor input

In 1993, BLS introduced Tornqvist indexes of labor composition change into its major sector MFP series (BLS, Labor Composition and U.S. Productivity Growth, 1948-90, 1993), as noted above. This study makes use of wage equations to estimate the prices of detailed types of labor input; the detailed types result from a cross-classification of hours worked by level of education, gender, and estimated years of actual work experience (as distinct from potential work experience). These estimated prices permit the development of estimates of the annual flow of services, to the production process, from the total of hours worked in each sector. The difference between this estimated annual flow and the direct aggregate of hours worked is the contribution to output, and ultimately to productivity, of changes in the composition of the work force.

Tables 7 and 8 show the most recent BLS estimates of total labor input, computed as just described; the direct aggregate of all hours worked; and the difference between the two, or labor composition change. Tables 7 and 8 show

Table 7. Labor input, hours and labor composition in private business, selected years, 1948-94

Year	Labor Input	Hours of all Persons	Labor Composition
Indexes (1987 = 100.0)			
1948	64.1	71.2	90.0
1950	63.0	69.3	90.8
1955	66.7	71.8	92.9
1960	66.7	70.7	94.4
1965	71.2	74.2	96.0
1970	74.2	76.7	96.7
1973	78.7	81.8	96.2
1975	75.7	78.1	96.9
1979	87.4	90.6	96.5
1980	86.8	89.7	96.8
1981	88.0	90.3	97.5
1982	86.6	87.9	98.5
1983	88.5	89.5	98.9
1984	93.7	94.6	99.0
1985	95.8	96.5	99.3
1986	96.8	97.0	99.7
1987	100.0	100.0	100.0
1988	104.2	103.3	100.8
1989	107.2	105.9	101.2
1990	107.8	105.9	101.8
1991	106.5	103.5	102.9
1992	107.5	103.2	104.2
1993	110.4	105.7	104.4
1994	114.8	109.4	104.9
Average annual growth rates			
1948-1994	1.3	0.9	0.3
1948-1973	0.8	0.6	0.3
1973-1994	1.8	1.4	0.4
1973-1979	1.8	1.7	0.0
1979-1990	1.9	1.4	0.5
1990-1994	1.6	0.8	0.8

Source: Bureau of Labor Statistics, Office of Productivity and Technology

Table 8. Labor input, hours and labor composition in private nonfarm business, selected years, 1948-94

Year	Labor Input	Hours of all persons	Labor Composition
Indexes (1987 = 100.0)			
1948	54.2	59.5	91.0
1950	53.8	58.8	91.5
1955	59.7	63.6	93.8
1960	61.4	64.8	94.7
1965	67.6	70.0	96.6
1970	72.0	74.3	96.8
1973	76.9	79.8	96.4
1975	73.9	76.2	97.0
1979	86.2	89.4	96.5
1980	85.7	88.5	96.8
1981	87.0	89.2	97.5
1982	85.6	86.8	98.6
1983	87.6	88.5	98.9
1984	93.0	93.9	99.0
1985	95.5	96.2	99.2
1986	96.6	96.8	99.8
1987	100.0	100.0	100.0
1988	103.2	103.5	100.8
1989	107.6	106.3	101.2
1990	108.3	106.4	101.8
1991	106.8	103.8	102.9
1992	108.0	103.6	104.2
1993	111.2	106.4	104.5
1994	115.6	110.1	105.0
Average annual growth rates			
1948-1994	1.7	1.3	0.3
1948-1973	1.4	1.2	0.2
1973-1994	2.0	1.5	0.4
1973-1979	1.9	1.9	0.0
1979-1990	2.1	1.6	0.5
1990-1994	1.6	0.9	0.8

Source: Bureau of Labor Statistics, Office of Productivity and Technology

the data for the private business sector and the private nonfarm business sector, respectively. Generally, the flow of labor services increased more rapidly than the direct aggregate of hours. For the whole period, 1948-94, total labor input in the private nonfarm business sector—the flow of services—rose at an average annual rate of 1.7 percent, while the direct aggregate rose at an average annual rate of 1.3. The difference, 0.3 percent (after rounding), represents the contribution of change in labor composition to the flow of labor services. Further, for most of the peak-to-peak cyclical periods shown in tables 7 and 8, the flow of services also increased more rapidly than aggregate hours. (The data in these two tables were developed in the process of preparing the data for BLS, Multifactor Productivity Trends, 1994, January 17, 1996.)

Several results of this analysis are noteworthy. First, the fact that labor input rose more rapidly than the direct aggregate of hours results in a decrease in the growth rate of MFP. The actual increase in MFP was lower than the apparent increase that would have resulted from disregarding the change in labor composition. (However, note that the contribution of labor composition change is smaller, for the whole span of years covered, than the 0.3 figure noted above. The calculation of this contribution must take into account an estimate of the elasticity of output with respect to labor input; the best estimate of this elasticity is provided by labor's share of input, roughly two-thirds at the macro level.) In a sense, growth in output that would have been deemed to be a result of productivity change is, following this labor composition study, deemed to be a result of increasing labor input.

A second noteworthy result is that for the years 1973-79 the growth rate of labor composition declined to zero. This decline contributed to the dramatic slowdown in overall productivity growth after 1973. A third important result is that the growth rate of labor composition change has increased in the 1990s and, for the first time, is about as large as the growth in the direct aggregate of hours worked; both grew at 0.8 percent in the private business sector and at about the same rates in private nonfarm business. A fourth result is presented in the bulletin that introduced these data, but is not evident in tables 7 or 8. To the best of our ability to determine the sources of labor composition change, the long-term increase was due predominantly to rising educational levels. In contrast, the turning points in labor composition trends between sub-periods were apparently due mainly to changes in work experience. However, the qualification, "to the best of our ability" is important: BLS researchers concluded that exact measures of the separate contributions of each component of labor composition change require a set of highly unlikely assumptions (BLS, Labor Composition and U.S. Productivity Growth, 1948-90, 1993, Appendix H; see also Rosenblum et al 1990).

Revised output data

The adoption of current-weighted output indexes has also had an important influence on measured productivity trends. As noted earlier, during the years 1994 to 1996, current-weighted output indexes were introduced for the three BLS productivity data sets for the United States that were not using such indexes as of 1994. In February 1996, current-weighted output data were incorporated into the quarterly major sector labor productivity series. The effects on trends in nonfarm business productivity of introducing the new series are evident through an examination of table 9, which relates to the nonfarm business sector. The discussion of table 9 will focus on columns d, e, and f, because these columns relate solely to the effect of changing the output measure from constant 1987 dollars to annually-weighted output data. (The other columns include the effects of another change in output data, also carried out in February 1996, a change from income side to product side information.[13])

[13] The difference between the income side and the product side data is statistical discrepancy. For further discussion of change from income side to product side data, see Dean, Harper and Otto (1995).

Table 9. A comparison of old and new measures of output and productivity, nonfarm business sector, compound average annual rates of change (percent)

	Output		Productivity				
	(a) **Old** Constant 1987 dollars, income side *	(b) **New** Annual weighted product side **	(c) **Old** Constant 1987 dollars, income side *	(d) **Old** Constant 1987 dollars, product side *	(e) **New** Annual weighted product side **	(f) Difference (e)-(d)	(g) Difference (e)-(c)
			Trends				
60-94	3.1	3.4	1.5	1.5	1.8	0.3	0.3
60-73	4.2	4.7	2.5	2.6	3.0	0.4	0.5
73-79	2.5	3.1	0.6	0.7	1.1	0.4	0.5
79-90	2.4	2.6	0.8	0.8	1.0	0.2	0.2
90-94	2.7	2.0	1.8	1.6	1.1	-0.5	-0.7
			Single Years				
90-91	-1.0	-1.8	1.5	1.3	0.7	-0.6	-0.8
91-92	2.4	3.0	2.7	2.8	3.2	0.4	0.5
92-93	4.1	2.9	1.3	1.2	0.2	-1.0	-1.1
93-94	5.3	4.0	1.9	1.3	0.5	-0.8	-1.4
			Recent Quarters				
94:1	5.2	0.9	1.7	0.2	-2.5	-2.7	-4.2
94:2	3.2	6.8	-1.4	-0.5	1.9	2.4	3.3
94:3	4.3	4.2	2.7	3.0	2.6	-0.4	-0.1
94:4	7.7	4.2	4.3	2.7	0.9	-1.8	-3.4
95:1	4.5	0.8	2.5	1.3	-1.1	-2.4	-3.6
95:2	2.4	0.5	4.9	4.3	3.0	-1.3	-1.9
95:3	4.9	4.4	2.0	2.0	1.4	-0.6	-0.6
			Cyclical Movements				
80:1-80:3	-6.1	-6.6	-1.6	-2.8	-2.3	0.5	-0.7
80:3-81:3	3.8	3.9	2.0	1.9	2.1	0.2	0.1
81:3-82:4	-2.5	-3.1	0.4	-0.3	-0.3	0.0	-0.6
82:4-90:3	3.8	4.1	1.0	1.1	1.3	0.2	0.3
90:3-91:1	-2.7	-4.6	1.4	0.2	-0.6	-0.9	-2.0
91:1-95:3	3.8	3.0	2.2	2.0	1.4	-0.6	-0.8

Sources: Bureau of Economic Analysis and Bureau of Labor Statistics, Office of Productivity and Technology. Prepared by BLS on February 8, 1996.

* Pre-benchmark (before the BEA comprehensive revisions of January 19, 1996)
** Post-benchmark (after the BEA comprehensive revisions of January 19, 1996)

For the nonfarm business sector, the switch to annually-weighted output data resulted in a rise of 0.3 percent in long-term (1960-94) average annual growth in output and productivity. The average annual growth of output per hour increased from 1.5 percent to 1.8 percent (columns d, e and f). As would have been expected, in light of the change from constant 1987 computer prices to contemporaneous computer prices, the upward revision in the growth rate was largest for the earliest years of this period. In particular, the upward revision in labor productivity was 0.4 percent for the years 1960-73. And, as expected, for the years after 1987 the revision was downward. For the years 1990 to 1994, the downward revision is a half percentage point.

For students of recent productivity trends, a critical question is whether the post-1973 productivity slowdown has been reversed. The 1987 constant dollar data show a slowdown from 2.6 percent in the years 1960 to 1973 (see column d) to 0.7 percent for 1973-79, a drop of 1.9 percent. This slowdown was followed by a partial recovery in the growth rate. By the years 1990-94, the growth rate had recovered to 1.6 percent. In contrast, the revised data for nonfarm business indicate that there is little evidence of a recovery since 1973. Over various sub-periods since 1973, the growth rate has been close to one percent. It appears, then, that there is no evidence from these data for nonfarm business of a recovery from the post-1973 productivity slowdown.

About every five years BEA undertakes a comprehensive revision of the national income and product accounts. For many years, an essential aspect of the comprehensive revision was the change in the base year used to compute constant dollar data for GDP and its major components. For example, as part of the comprehensive revision completed in December 1991, BEA began presenting its constant dollar data for GDP, for all years, in prices of 1987, in place of the previous constant dollar series, prepared using prices of 1982 (see BEA 1991). BLS, in its capacity as a user of BEA data for output in its major sector labor productivity series, made a practice of introducing the new constant dollar output series shortly after BEA completed its comprehensive revision.

It is interesting to ask a “what if” question: what revisions to historical productivity growth rates would BLS have made early in 1996 if BEA had continued to use constant dollar data, but would have changed at that time from GDP computed in constant 1987 dollars to 1992 constant dollars? BEA has kindly provided BLS with 1992 constant dollar data for the nonfarm business sector. BLS has computed trends in this series, shown in table 10. Table 10 permits a comparison of the revised output data that BLS actually used in a news release of February 1996 (column c of table 10), using BEA’s chained Fisher index data for nonfarm business, with the revisions that BLS would have made if it had continued using the constant dollar concept, but had switched from 1987 constant dollar data to 1992 constant dollar data (column d of table 10). Columns c and d both reflect BEA’s comprehensive revision of January 1996, including improvements made by BEA in this comprehensive revision that were unrelated to the change in the weighting scheme. Columns a and b present 1987 constant dollar and annually-weighted data as they stood prior to the comprehensive revision. All data in this table are product-side data.

Table 10. A comparison of product side measures of output,
nonfarm business sector compound average annual rates of change (percent)

	(a) Constant 1987 dollars pre-benchmark *	(b) Annual weighted pre-benchmark *	(c) Annual weighted post-benchmark **	(d) Constant 1992 dollars, post-benchmark **	(e) Difference (b)-(a)	(f) Difference (c)-(d)
Trends						
60-94	3.1	3.4	3.4	3.1	0.3	0.3
60-73	4.2	4.7	4.7	4.3	0.5	0.4
73-79	2.6	2.9	3.1	2.8	0.3	0.3
79-90	2.4	2.6	2.6	2.3	0.2	0.3
90-94	2.5	2.1	2.0	2.0	-0.4	0.0
Single Years						
90-91	-1.1	-1.3	-1.8	-1.9	-0.2	0.1
91-92	2.6	2.3	3.0	2.9	-0.3	0.1
92-93	3.9	3.2	2.9	2.9	-0.7	0.0
93-94	4.6	4.1	4.0	4.2	-0.5	-0.2
Recent Quarters						
94:1	3.6	3.5	0.9	1.1	-0.1	-0.2
94:2	4.3	4.5	6.8	6.9	0.2	-0.1
94:3	4.6	4.2	4.2	4.6	-0.4	-0.4
94:4	6.0	4.8	4.2	4.7	-1.2	-0.5
95:1	3.3	2.2	0.8	1.0	-1.1	-0.2
95:2	1.8	0.9	0.5	0.6	-0.9	-0.1
95:3	5.0	3.6	4.4	5.0	-1.4	-0.6
Cyclical Movements						
80:1-80:3	-7.2	-6.2	-6.6	-6.8	1.0	0.3
80:3-81:3	3.7	4.3	3.9	3.1	0.6	0.8
81:3-82:4	-3.1	-3.4	-3.1	-2.5	-0.3	-0.6
82:4-90:3	3.9	4.1	4.1	3.7	0.2	0.4
90:3-91:1	-3.8	-3.9	-4.6	-5.0	-0.1	0.4
91:1-95:3	3.6	3.0	3.0	3.2	-0.6	-0.1

Sources: Bureau of Economic Analysis and Bureau of Labor Statistics, Office of Productivity and Technology. Prepared by BLS on April 16, 1996.

* Before the BEA comprehensive revisions of January 19, 1996
** After the BEA comprehensive revisions of January 19, 1996

The annually-weighted output data and the 1992 constant dollar data both yielded a 2.0 percent growth rate for the most recent period, 1990-94. Obviously, the use of 1992 prices produced similar results as the chained annual Fisher index method, which uses prices for each year over the period 1990 to 1994. This result is not surprising. It can be concluded, then, that for this recent time period the BLS productivity data are showing the same trend that they would have shown if BLS were still using constant dollar data from BEA, but following its former practice of incorporating new benchmark data every five years, using price weights from a more recent year.

A brief comment on long-term trends is appropriate. It is noteworthy that annual weighting results in a higher growth rate of output for earlier time periods than either 1987 or 1992 constant dollars. Columns e and f show that the switch to annual weighting yielded a higher growth rate, for 1960-73, of roughly a half percentage point, regardless of whether the pre-benchmark or the post-benchmark data are used. Apparently, biased results for a past period like 1960 to 1973 are obtained if the price weights used for combining detailed outputs are obtained from a much later year, regardless of whether that later year is 1987 or 1992. And the bias is similar regardless of whether 1987 or 1992 price data are used.

Effects of Aggregation Based on Production Theory

In the BLS multifactor productivity (MFP) work, the economic theory of production is now the basis for aggregating detailed categories of both capital and labor inputs and outputs. In each case the weights now used are based on contemporaneous value shares. Also, indexes now are constructed using changing (annually chained superlative index number) weights. Each of the three kinds of aggregates (output, capital, and labor) was traditionally constructed by economists using simpler methods. Output was measured using constant base year prices; capital was measured as a direct aggregate of real capital stock levels; and labor was a direct aggregate of total hours worked.

To ensure consistency with theory, the BLS aggregates are now constructed so that, at each point in time, the growth rate of each aggregate is a weighted average of the growth rates of its components, where the weights are based on *shares in the total value of output*. For inputs, the value shares are designed to correspond to the *output elasticities* (derived from a production function) of the various inputs. For outputs, the value shares of output are designed to reflect the *marginal rates of transformation* of the various outputs (derived from a model of joint production).

As we have seen, the traditional measures of aggregate U.S. output were based on aggregation using fixed base period prices. Since 1994, the BLS output series used in the MFP data for the private business and private nonfarm business sectors have been based on an annual-weighted Fisher Ideal index. Of course labor traditionally was measured as a direct aggregate of total hours worked. For its private business and nonfarm business MFP measures, BLS followed this convention for labor input until 1994. Beginning in 1994, the BLS labor input measure has used wage equations to estimate the relative marginal products of workers with varying levels of education and experience and has used these to produce annual-weighted Tornqvist indexes of labor input. Finally, economists have traditionally used a direct aggregate of past real investments, termed the "capital stock," to measure aggregate capital inputs. Since it began publishing its MFP measures in 1983, BLS has used estimated "implicit rental prices" to approximate the marginal product weights of various types of capital assets and it has used annual-weighted Tornqvist indexes in aggregation.

Table 11 shows the effects on MFP growth rates of using production-theory-based measures in place of the traditional methods. The table provides, for selected periods, the growth rates of the published BLS measures of MFP for the private nonfarm business sector. It also shows weighted growth rates of labor and capital inputs. The weights

Table 11. Output and Inputs: Measures Based on Production Theory Compared to Traditional Measures

Estimation of Multifactor Productivity Growth in the Private Nonfarm Business Sector

	1948-73	1973-79	1979-90	1990-94
Output				
Production Theory	**4.1**	**2.9**	**2.6**	**2.1**
Traditional (Constant 87$)	3.8	2.4	2.7	2.9
Difference	0.3	0.5	-0.1	-0.8
less Weighted Labor Input[1]				
Production Theory	**1.0**	**1.4**	**1.5**	**1.2**
Traditional	0.8	1.4	1.1	0.6
Difference	0.2	0.0	0.4	0.6
Effects of Education	0.2	0.3	0.3	0.4
Effects of Experience	-0.1	-0.3	0.1	0.2
Other Effects	0.0	0.0	0.0	0.0
less Weighted Capital Input[1]				
Production Theory	**1.2**	**1.2**	**1.2**	**0.6**
Traditional	0.9	0.9	0.9	0.5
Difference	0.3	0.3	0.3	0.1
Multifactor Productivity				
Production Theory	**1.9**	**0.3**	**0.0**	**0.3**
Traditional[2]	2.1	0.1	0.8	1.8
Difference	-0.2	0.2	-0.8	-1.5

[1] For each pair of successive years, the growth rate of each input is multiplied by that input's average share in the value of output for the two years. The data reported are averages of this result over the time period.

[2] The multifactor productivity trend based on production theory minus the "difference" associated with output plus the sum of the two "differences" associated with labor and capital.

Notes: The "private nonfarm business" sector excludes government enterprises, while these enterprises are included in the "nonfarm business" sector. Note also that the sums presented in this table may not equal the totals due to rounding.

applied to labor and capital growth rates are the shares of the input in the nominal value of output. The MFP growth rates at the bottom of the table can be computed by subtracting the weighted capital and labor input growth rates from the growth rate of output at the top of the table. The aggregates computed on the basis of the economic theory of production are labeled “production theory” and are shown in bold print, while the aggregates based on traditional methods are labeled “traditional” and are shown in regular type.

For output and both inputs, Table 11 shows the difference between aggregates based on production theory and traditional aggregates. It is clear that the measures based on production theory exhibit different magnitudes and time patterns than the traditional measures. In the case of labor input, the “difference” corresponds to what BLS calls the “effects of changes in labor composition on output”. The table furtherdisaggregates this labor composition effect into separate effects of education, experience and “other” influences (which are negligible in our measures).

The multifactor productivity growth rate presented in the next-to-last line of the table, and labeled “production theory,” is the published BLS growth rate of MFP; this series clearly shows the post-1973 productivity slowdown. The last line of the table presents ”traditional” MFP growth rates based on traditional output and input data. The traditional measure can be computed as the multifactor productivity trend based on production theory minus the “difference” associated with output plus the sum of the two “differences” associated with labor and capital. Of course, the “traditional” MFP itself (which involves combining capital and labor inputs into an index of total input) was derived from production theory. Nonetheless, Table 11 reflects the measures that would be obtained if production theory were not applied to the problem of aggregating detailed outputs and inputs. The data indicate that BLS would obtain a very different pattern of historical MFP growth rates using traditional output and input measures, particularly in the periods since 1979.

At the beginning of this section of the paper, we stated that it was important to know whether the improved index number methods described earlier make a difference in the broad productivity trends shown by the data. The data in table 11 show that these improved methods make a considerable difference. The patterns of historical MFP growth rates and the magnitude and timing of the contributions of capital and labor inputs to output growth differ substantially under the traditional and the production theory approaches to measurement.

6. CONCLUSION

Among the conclusions reached in this paper, the following deserve the most emphasis.

1. Changing-weight indexes of output and inputs are superior for purposes of productivity measurement. Among the changing-weight indexes, research by index number theorists shows that some have superior qualities, and these are most deserving of consideration by those interested in productivity measurement. The Tornqvist and Fisher indexes are among those with superior qualities.

2. Application of simple logic and micro-economic theory to the choice of index number methods also supports the use of changing-weight indexes for productivity measurement.

3. While the Tornqvist and Fisher indexes both have superior qualities, at present the Tornqvist index is probably more frequently used for measurement of multifactor (often referred to as total factor) productivity. Several studies indicate that trends in Fisher and Tornqvist indexes tend to be quiet similar, but this is not necessarily the case.

4. Chaining of changing-weight indexes for two periods to form longer term time series is common. While direct comparisons between two non-adjacent points of time are preferable to chaining, some examples indicate that chaining and direct comparisons sometimes yield similar results.

5. For measurement of industry multifactor productivity, the relevant literature shows that the sectoral output concept (or the closely-related gross output concept) is preferable to value added. Some of the arguments for use of sectoral output in the MFP context carry over to the labor productivity context.

6. The adoption of changing-weight indexes can produce substantial effects on trends in inputs, output, and productivity. An examination of the U.S. Bureau of Labor Statistics' changing-weight indexes for the U.S. private nonfarm business sector demonstrates that they yield substantially different trends than fixed-weight indexes. Adoption of changing-weight indexes has affected trends for capital inputs, labor inputs and output in this sector. Adoption of changing-weight output indexes for the quarterly labor productivity series for nonfarm business has also led to substantial changes. The effects have been large enough to influence our understanding of the sources of economic growth.

The organizers of this conference have rightly called attention to the effects of new measurement procedures on the international comparability of productivity data. The main implications of this paper for this important subject are the following.

1. The adoption of changing-weight indexes of output and inputs by the U.S. Bureau of Labor Statistics is, for the present, yielding one unfortunate result. The U.S. productivity data are probably less comparable now than they formerly were to data for countries that use fixed-weight indexes.[14]

2. Lack of comparability between national productivity measures can arise from many sources. The Wyckoff (1995) study of national differences in computer price methodologies provides an example of another source of incomparability, especially at the level of detailed industries.[15] Differences in the industrial composition of output and in consumption patterns also complicate international comparisons of productivity. Adoption of similar index number methodologies, by

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[14] However, see the comment below about the comparability of data in the BLS comparisons of manufacturing productivity.

[15] Note, however, that Wyckoff shows that the differences in national computer price methodologies originate in part from use of different index number methods.

all countries, would not necessarily yield highly comparable measures of productivity trends. This conclusion also applies to comparisons of productivity levels.

3. For the U.S. output data in its international comparisons of manufacturing labor productivity, BLS continues to use the BEA constant-dollar series. For a number of the other countries in this set of comparisons, periodic changes in the base year may tend to yield results that lie somewhere between those of a chained Tornqvist and a strictly fixed-weight series. The BLS plans to examine the issue of changing its manufacturing productivity comparisons to a gross output or a sectoral output basis for as many countries as possible.

4. BLS experience indicates that the introduction of such indexes may call for a considerable investment of time and resources.   However, for countries that plan to produce labor productivity data only, and are not presently interested in developing MFP measures, the investment will be smaller.

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