Measurement of productivity growth in U.S. manufacturing

Productivity measurement cannot be restricted to capital and labor factors—intermediate inputs constitute too large a part of the cost structure; revised and extended data show upward trend in multifactor productivity growth

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The indexes of multifactor productivity for two-digit manufacturing sectors prepared by the Bureau of Labor Statistics for sectors in manufacturing have been revised and extended to cover the 1949–92 period. These indexes, also called the "KLEMS" multifactor measures, compare changes in output to changes in a composite of all the inputs used in production—capital, labor, energy inputs, nonenergy material inputs, and business services.[1] Because of this comprehensive input list, these indexes give an indication of advances in technology and production efficiency in these broad sectors, important topics as the economy emerges from the recession of the early 1990's.

This article discusses the measurement of multifactor productivity for manufacturing and analyzes growth trends within the sector. Through the years, a wide variety of productivity statistics have appeared in the literature, distinguished by the concepts underlying the measurement of output, the methods of aggregation, and the inputs included for analysis. Recent additions of "superlative" indexes of gross domestic product (GDP) by industry to the U.S. National Income and Product Accounts, prepared by the Bureau of Economic Analysis, U.S. Department of Commerce, have enhanced available alternatives for measuring manufacturing productivity. Planned changes in the way BLS measures manufacturing productivity are also discussed.[2]

Multifactor productivity growth trends are then examined for the overall manufacturing sector and for 19 two-digit SIC manufacturing subsectors.[3] In particular, early postwar and more recent productivity growth trends are compared. When this comparison was last discussed in 1992, data were available through 1988, covering a period of rapid growth following emergence from the 1982 recession.[4] Because of this growth, multifactor productivity growth seemed to have regained much of its early postwar momentum. It is now possible to examine recent trends more comprehensively because the extended series cover the 1990 business cycle peak, the brief recession that followed in 1991, and a recovery period in 1992. These trends indicate that the productivity growth rates of the early postwar period were not entirely regained during the 1980's.

Issues in measurement

Until recently, the Bureau of Labor Statistics produced two distinct and fairly different measures of multifactor productivity for the manufacturing sector. One measure was a comparison of "net" output to capital and labor inputs.[5] The other was the KLEMS multifactor measure, issued along with multifactor productivity measures for broad (two-digit SIC) manufacturing industries, which compares "sectoral" output to capital, labor, and "intermediate" inputs.

In the future, BLS will use the measure based on sectoral output for both purposes, while continuing to use a somewhat modified net output-type multifactor productivity measure for its international comparisons of multifactor productivity. Some further background on measures

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Alternative output measures

The Tornqvist gross output index. This is obtained by chain-weighting four-digit industry deflated values of shipments to the two-digit level, at which level inventory change is added; then aggregating to total manufacturing. Values of shipments are from the U.S. Bureau of the Census and are maintained, among other four-digit industry data, in BLS; deflated shipments for each industry are equal to the census value of shipments adjusted by a four-digit deflator which in turn is a composite of five-digit deflators from the BLS producer price program, the Bureau of Economic Analysis, and other sources. All data are arranged according to the 1987 Standard Industrial Classification (SIC) system. A Tornqvist aggregate quantity index is a chain of two-period indexes (Q_2/Q_1), each of which is obtained as a weighted average of individual item indexes, with weights based on cost or value shares taken from the two periods. For further discussion of Tornqvist indexes, see *Trends in Multifactor Productivity, 1948–81,* Bulletin 2178 (Bureau of Labor Statistics, 1983).

The Tornqvist sectoral output measure. "Sectoral" output is the name given to gross output less intrasector transactions. This name was introduced by Frank M. Gollop. See "Accounting for Intermediate Input: The Link Between Sectoral and Aggregate Measures of Productivity Growth," *in Measurement and Interpretation of Productivity* (Washington, National Academy of Sciences, 1979), pp. 318–33. Sectoral output thus represents deliveries to consumers outside the industry. The BLS sector output index is a Tornqvist index, obtained by removing estimated intrasector transactions from the Tornqvist gross output measure using current weights for the removal.

Sector output for an industry represents deliveries to consumers outside the industry; for total manufacturing, sector output represents deliveries to consumers outside manufacturing. Intrasector transactions are estimated from input-output tables published by the Bureau of Economic Analysis in benchmark years, and prepared by BLS for other years.

Benchmark-years-weighted gross output. This measure of gross output underlies the estimation of benchmark-years-weighted gross product originating; the latter series is published in the National Income and Product Accounts. Benchmark-years-weighting is designed to achieve moving weights even when all the requisite data are not available annually. See Allan H. Young, "Alternative Measures of Change in Real Output and Prices," *Survey of Current Business,* April 1992; and Jack E. Triplett, "Economic Theory and BEA's Alternative Quantity and Price Indexes," *Survey of Current Business,* April 1992.

Throughout the National Income and Product Accounts, but especially in manufacturing, more detailed data are available in the years of the economic censuses, usually 5 years apart. The benchmark-years-weighted quantity index is the (geometric) mean of two fixed-weighted indexes—a Laspeyres index, based on prices of the first benchmark year and a Paasche index, based on prices of the second. The averaging of Paasche and Laspeyres indexes yields a "Fisher Ideal" index, which has among its benefits the quality of "reversibility": any two of the benchmark-to-benchmark ratios of quantity, price, and value suggest the third. The benchmark-years-weighted gross output series are available for two-digit manufacturing industries from 1977 to 1987, according to the 1972 SIC.

which help explain these changes are provided in the following sections. The main issues have to do with which inputs and outputs should be included in a multifactor productivity ratio and how heterogeneous inputs and outputs should be weighted together.

Basic principles. BLS is engaged in efforts to insure that its measures conform, as nearly as possible, to some basic principles of productivity measurement which have been developed in the economics literature.[6] One of the basic principles is that inputs be as comprehensive as possible, so that productivity growth does not merely reflect changes through time in unmeasured inputs. Thus, the multifactor productivity measures for manufacturing industries presented later in this article take into account all intermediate inputs (energy and other materials and business services). The importance of intermediates first gained prominence in the literature because of the events of the 1970's.[7] In the period following the OPEC oil embargo, fuel prices rose almost 150 percent in a 4-year period (1973–77) and researchers began to suspect that this price increase was contributing to the emerging slowdown in productivity growth. Since then, increases in the use of business services, such as equipment leasing, computer services, and the use of temporary labor—all of which could have an important impact on production and employment—have affected productivity measurement.

A second principle is that inputs and outputs be defined as comprehensively as possible *without double counting.* In sectors as broad as those discussed in this article (two-digit SIC), there are inevitably transactions between establishments in

Alternative output measures

Benchmark-years-weighted gross product originating. This measure was introduced to the National Income and Product Accounts in 1993 and is available for two-digit industries in manufacturing for the period 1977 to 1987.

The real gross product originating index and its fixed-weighted counterpart are obtained by removing an estimate of real intermediate inputs from an estimate of real gross output. The use of weights from benchmark years derives from the fact that data necessary for annual reweighting of intermediate inputs are not available. Although the total costs of materials are available annually for manufacturing industries, materials by type are available only in the benchmark Census of Manufactures, collected every 5 years. Thus, annual estimates of gross product originating based entirely on annual data are not possible.

The index of intermediate inputs for manufacturing industries is obtained through the use of a benchmark-years-weighted price composite using a wide variety of annual commodity and service input prices, including BLS producer prices. Taking advantage of the reversibility of price and quantity growth in this form of index, quantity growth is computed as total cost change less price change.

Lastly, an index of real gross product originating is obtained by removing real intermediate inputs from real gross output. The calculation is done in index form using weights that ensure consistency with the benchmark-years-weighted gross output formula. Thus, between benchmark years, a benchmark-years-weighted index combining real gross product originating and real intermediate inputs equals the index of real gross output. See Robert P. Parker, "Gross Product by Industry, 1977–90," *Survey of Current Business*, May 1993.

Fixed-weighted gross product originating. These are the traditional measures of industry gross product available from the U.S. National Income Product Accounts, first published in the 1960's. Presently, the series are available for two-digit industries as well as for durable, nondurable, and total manufacturing, for the period 1977 to 1992, although, like the benchmark-years-weighted series, estimates for 1977–86 are based on the 1972 SIC.

The Federal Reserve Board's Index of Industrial Production. The Federal Reserve Board prepares monthly indexes of industrial production, which are averaged to reflect annual movements in the index shown. The Board's indexes are based on 225 individual series, which are in turn based either on physical quantities obtained by survey or on measures of labor or energy inputs. In the latter cases, output movements are inferred from labor measures from the BLS establishment survey or estimates of kilowatt hours from a Federal Reserve Board survey, together with historic input-output relationships. Most of the individual series are benchmarked to deflated Census values of production (some of the physical quantity measures are not). Aggregate indexes, such as the total manufacturing one shown in table 1 are "linked Laspeyres" indexes: weights for aggregation are periodically updated and then held constant for a number of years. The weights used by Federal Reserve Board for aggregating are based on value-added measures taken from the Census of Manufactures. For a complete description of the Federal Reserve Board Index of Industrial Production, see *Industrial Production 1986 Edition* (Washington, DC, Board of Governors of the Federal Reserve System, 1986).

the same sector. It is best to include all inputs—including raw and semi-finished material inputs along with primary inputs of labor and capital—in a productivity measure which is supposed to shed light on trends in industrial efficiency and applied technology; but it is also important not to include as inputs both a semi-finished good and the inputs used to produce that semi-finished good. When there are transactions between producers in the same sector, the available data sources will often reflect such duplication and, to prevent double-counting, BLS adjusts them.

A third principle which has emerged from the literature concerns aggregation. Multifactor productivity measures for broad industrial groups, such as the two-digit manufacturing industries discussed in this article and the BLS measure for the private business sector, necessarily involve substantial aggregation. For the two-digit measures, outputs of individual industries are combined into a single measure for the numerator, while highly diverse inputs are combined for the denominator; for the private business indexes, the output measure is a combination of all goods and services purchased by final users from private industry. Because of the extent to which aggregation takes place, the method of aggregation is crucial. It is particularly important that, wherever possible, aggregation be done according to a weighting procedure that allows weights to change over time as the relative importance of various inputs and outputs changes.

Alternative output measures. Because many of the issues concern the measurement of output, we begin the investigation by comparing movements in several of the most prominent alternatives. Table 1 shows movements in six series in two main groups, net and gross. (See box, pages 14–15.)

The net output series are the various measures of real gross product by industry (sometimes called gross product originating, or GPO) in manufacturing from the U.S. National Income and Product Accounts.[8] Measures of net output reflect value-added concepts—they represent the real contribution of capital and labor in converting intermediate inputs into finished products. The gross measures, by contrast, reflect deliveries of the finished products. Both net and gross measures, except for the Federal Reserve Board's Index of Industrial Production, are based on deflation of four-digit values of shipments from the Bureau of the Census, using composite deflators based, in turn, on five-digit prices from the BLS producer price program or other sources.

Several observations can be made from the data in table 1. First, the similarity of Tornqvist and benchmark-years-weighting is apparent from the two gross output indexes. This follows from the fact that both reflect contemporary economic theory (both are associated with production functions which are second order approximations to the "true" underlying functional form). The Tornqvist aggregate (annual) index is constructed by computing weighted average annual rates of change, using value share data (averages for each pair of consecutive years) for weights; and by "chaining" (multiplying consecutive index numbers) into a time series index.

The benchmark-years-weighted index is constructed in two stages. First, Fisher Ideal index numbers are computed between each successive pair of preselected benchmark years. Then, annual index numbers for the intervening years are computed by averaging two indexes, one constructed using weights from the first benchmark year, the other using weights from the second. The benchmark-years-weighted index is designed to reduce systematic drift which can occur with chained time series and at the same time to take advantage of more detailed data available in benchmark years. As will be discussed later, the Fisher Ideal and the Tornqvist procedures are computationally similar and yield very similar results. Thus, estimates of total growth between benchmark years using the two indexing procedures are likely to be similar. Larger differences are more likely in nonbenchmark years, as is seen in the comparison for 1983–86.

The contrast between the fixed-weighted and benchmark-years-weighted gross product originating series demonstrates the usual relationship between fixed and moving-weighted aggregates. The disadvantage of any fixed-weighted quantity index is that relative expenditures for various products, which indicate the importance which should be given to

Table 1. **Alternative output measures for manufacturing, 1958–93**

[Indexes, 1987=100]

Year	Tornqvist gross output	Tornqvist sectoral output	Benchmark years weighted gross output originating	Benchmark years weighted gross product	Fixed-weighted gross product originating	Federal Reserve Board index of industrial production
1958	39.3	37.0	—	—	—	30.61
1959	44.0	40.4	—	—	—	34.5
1960	44.4	40.8	—	—	—	35.2
1961	44.3	41.1	—	—	—	35.3
1962	47.8	43.5	—	—	—	38.4
1963	50.6	46.2	—	—	—	40.7
1964	53.8	49.3	—	—	—	43.5
1965	58.1	53.1	—	—	—	48.2
1966	62.4	57.3	—	—	—	52.6
1967	63.6	59.2	—	—	—	53.6
1968	66.8	62.1	—	—	—	56.6
1969	68.9	63.7	—	—	—	59.1
1970	65.1	61.7	—	—	—	56.4
1971	66.6	63.4	—	—	—	57.3
1972	3.0	68.8	—	—	—	63.3
1973	78.9	74.4	—	—	—	68.9
1974	77.7	73.5	—	—	—	67.9
1975	70.5	68.1	—	—	—	61.1
1976	77.6	74.4	—	—	—	67.4
1977	83.6	80.2	84.0	78.7	84.4	73.3
1978	88.0	84.6	88.0	81.7	88.0	77.8
1979	89.2	85.6	89.5	83.5	88.8	80.9
1980	84.7	82.0	84.7	78.9	82.6	78.8
1981	85.0	82.7	85.1	82.1	85.0	80.3
1982	79.9	79.3	80.8	79.0	81.0	76.6
1983	83.4	82.7	84.7	82.3	83.5	80.9
1984	90.8	90.1	92.4	89.5	90.1	89.3
1985	91.4	92.1	93.4	91.9	92.3	91.6
1986	93.0	94.2	95.2	92.4	93.3	94.3
1987	100.0	100.0	100.0	100.0	100.0	100.0
1988	104.8	104.6	—	—	105.2	104.7
1989	104.9	105.4	—	—	106.2	106.4
1990	103.6	104.3	—	—	105.8	106.1
1991	101.3	102.2	—	—	103.8	103.9
1992	107.4	106.8	—	—	105.3	108.0
1993	—	—	—	—	—	112.9

NOTE: See box, pages 14–15 for definition of the indexes. Dash indicates data not available.

each item in aggregation, change over time. The fixed-weighted aggregate therefore, while roughly appropriate for years close to the base year, may be subject to greater error for years further removed from the base year, the degree, depending on changes in relative expenditures due to relative price change or other reasons.

Because of changes in relative prices in manufacturing attributable largely to the rapidly declining prices of computers and peripheral equipment, differences are substantial between manufacturing aggregate indexes prepared using fixed weights and moving weights. For years before the 1987 National Income and Product Accounts base year, the use of fixed weights based on 1987 prices understates the growth in the aggregate because the rapid growth in the output of the computer industry is weighted, not by the price of computers in those years, but by weights based on the lower 1987 price. Similarly, the fixed-weighted aggregate for years after 1987 overstates aggregate growth because the 1987 weight is based on a price greater than actual prices in the later years.[9]

"Net" output productivity measures. BLS publishes several productivity series based on "net" output. Among these productivity measures are the multifactor (*K-L*) measures for the aggregates—the private business sector and the private nonfarm business sector—and the quarterly labor productivity series for business, nonfarm business, manufacturing, and nonfinancial corporations. All compare real gross product originating in the sector to inputs of labor or capital and labor together.

The real gross product originating measures for the economic aggregates are based on data provided by the Bureau of Economic Analysis, U.S. Department of Commerce, most of which are published with the U.S. National Income and Product Accounts. Gross product originating represents the contribution of each industry or sector to gross domestic product. Equivalent to the more familiar concept of value-added, gross product originating is equal to gross output (sales or receipts and other income, plus inventory change) minus intermediate inputs (goods and service inputs purchased from other domestic industries and foreign sources). Gross product originating represents, therefore, the value that is added, by the application of capital and labor, to intermediate inputs in converting those inputs to finished products; productivity based on a value-added output measure is thus limited to capital and labor as inputs. A productivity measure based on "net" output concepts is thus in distinct contrast to the "gross" and "sectoral" definitions of output underlying both the KLEMS measures reported here and the BLS industry labor productivity measures reported elsewhere, for which output is defined in terms of finished products purchased by consumers.

The use of gross product originating for a system of productivity accounts—both aggregate and industry measures—has certain advantages and disadvantages. An advantage is that the relation between industry and aggregate (total economy) measures is straightforward and simple: In the fixed-weighted, constant-dollar case for example, the sum of real (constant-dollar) gross product originating for all industries is equal to real (constant-dollar) gross domestic product; and the index of aggregate productivity is a weighted average of industry indexes, where the weights are fixed and based on industry gross product originating in the price index base year.

However, the value-added specification also carries with it a distinct drawback which has led to the development of the KLEMS measures for industries reported in this article. The existence of the value-added function requires that the production of gross output is characterized by value-added "separability," as follows:

$$Y = f[V(K,L,t),X].$$

In this specification, gross output is defined in terms of a separable value-added subfunction (V) which includes technology, and intermediate inputs (X). Important implications of this specification are that intermediate inputs cannot be the source of productivity growth; that, if technical change is "augmenting," that is, associated with changed usage of particular inputs, it can augment only capital and labor; and that developments in intermediate inputs, for example, price change, cannot influence the relative use of capital and labor. 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.[10]

The predominance of intermediate inputs in the cost structure of most manufacturing industries suggests that intermediates should not be ignored in the analysis of technical change. For the two-digit industries discussed in this article, costs of material and business service inputs together represent 40 percent to 80 percent of all costs. Developments such as the previously mentioned price increases in energy and other materials in the 1970's and the growth of service inputs such as computer services and temporary labor are clearly sufficient to affect production decisions. In addition, many modern manufacturing productivity enhancement techniques are aimed at improving the efficiency with which both intermediate inputs and primary inputs are used. Just-in-time production, statistical process control, computer-aided design and manufacturing, and many other recent developments in production technique, reduce error rates and thus cut down on substandard, rejected production. In so doing, they reduce the wastage of materials as well as workers' time. The full benefits of such improvements can only be measured with a productivity index which takes into account all inputs.

In summarizing the discussion of value-added, it is important to note that for large segments of the U.S. economy such as private business as a whole, intermediates are a relatively small part of the input structure and can be ignored.[11] But for industries, the value-added specification of output rests on a restrictive version of production theory and for this reason, the gross output specification is generally preferred for industry productivity measurement.

Intrasector transactions. When one establishment provides materials used by other establishments in the same industry, a form of double counting occurs in the data on which KLEMS multifactor measures are based: summing the unadjusted data for all the establishments in the industry gives a total input measure which includes both the intrasector-sector transaction and the inputs required to produce it; the output measure based on unadjusted data includes both the intrasector-sector transaction and the goods made from it and sold to consumers outside the sector.

This double counting carries with it at least two potential hazards for productivity measurement. The first of these is that double counting tends to obscure the evidence of technological change actually occurring in industries. If the intrasector-sector transaction were not removed, it would appear identically in both the numerator and the denominator of the productivity ratio; with identical components included as both input and output, change in productivity is always closer to zero than if that component is removed.

Another consideration is the possibility that the degree of integration in the data on which the measures are based might change over time, which would introduce a bias to productivity growth trends. Over a long period (such as that covered by the data presented in this article), changes in the degree of integration reported to the Census Bureau and therefore expressed in the data are bound to occur. For example, if a plant reporting to the census as one plant in one year is divided into two plants the next year, with all output of one consumed by the other, the result would be increases in both output and material input reported to the Census Bureau. In this case, the addition of equal quantities to both output and input would result in a tendency toward zero in the rate of change in the output/materials ratio and in the growth rate of multifactor productivity, notwithstanding any actual change in production, efficiency, technology, and so forth.

The need to avoid the double counting of internal transactions has long been recognized.[12] This problem is addressed in the BLS productivity measures for major economic aggregates, such as for the business sector as a whole, by the means of their definition: real aggregate output is defined as sales to final consumers (governments, investors, households, and net exports), and input includes only capital and labor. Thus, "intermediate" transactions—sales from one producer to another—are included in neither the output measure nor input and double counting is avoided.

For industries, the same goal is achieved by subtracting from output, and from intermediates, those intermediates purchased from other establishments within the industry being studied, while leaving in purchases from outside the industry or sector. This removal yields what has come to be called "sector" input and output measures, for which output is defined as deliveries to consumers outside the sector (plus inventory change), and material inputs as all consumed items obtained from outside the sector.[13]

It is important to note that the removal of intrasector transactions implies a notion of output which is dependent on the level of industry or sectoral aggregation under consideration. That is, as the sector size becomes larger, the proportion of all transactions which are intrasector tends to rise, and the ratio of intermediate inputs to value-added tends to fall.

The index number issue. In any construction of data for large economic groups, such as the productivity measures for two-digit industries discussed in this article, or the multifactor measures for the total business sector done by BLS and reported elsewhere, the means of aggregation is a fundamental issue.

Aggregation methods for inputs and outputs for productivity measurement were developed by Dale Jorgenson and Zvi Griliches, using the economic theory of the firm.[14] It is easiest to explain their procedure for input aggregation. A production function is assumed:

$$Y = f(x_1, x_2, \ldots x_n, t)$$

where f is the technologically maximum amount of output, Y, which can be made from a set of inputs x_i at time t. Multifactor productivity is identified with a shift in f over time. The multifactor productivity growth rate is defined as the percent increase in Y which can be obtained from a given set of inputs in one year. Because input quantities are changing contemporaneously with output, a practical measurement scheme must allow for changes in the input mix. To allow for input change, the productivity ratio must compare the output growth rate to a *weighted average of the input growth rates.*[15] By assuming firms buy input factors in competitive markets, the appropriate weights are the cost shares[16] of the respective inputs at the point in time at which growth rates are being aggregated.

Once growth rates have been calculated for discrete periods (usually years) the Jorgenson-Griliches procedure "chains" the growth rates into an index number time series. Each period's index number is arrived at by multiplying the previous period's index number by the growth rate between the two periods. The theory associated with this procedure has been sharpened over the years to address such issues as what problems can arise in chaining multifactor productivity growth rates when prices are changing[17] and what conditions must be met to combine subgroups of inputs.[18] However, the key points are to aggregate inputs in terms of growth rates and to weight with contemporaneous cost shares.

BLS makes use of annually chained Tornqvist index numbers in aggregating together major input classes (capital with labor and capital with labor and intermediates) in all of its multifactor productivity measures. In addition, the chained Tornqvist procedure is used for aggregating together subcategories of capital and of intermediates. In 1994, BLS introduced the procedure for aggregating subcategories of labor.[19]

Theory also recommends the use of growth rates and contemporaneous weights for aggregating outputs. W. Erwin Diewert discussed alternative ways to generalize a production function to describe tradeoffs faced by a multiproduct firm.[20] He concluded that growth rates of various outputs should be weighted with their respective shares in the nominal value of output. BLS has used annually chained Tornqvist index numbers to aggregate outputs in its industry multifactor productivity measures since their inception. However, until recently, BLS used constant, dollar output measures (from the Bureau of Economic Analysis) in its major sector multifactor productivity measures.

The Bureau of Economic Analysis subsequently made available annually chained Fisher Ideal index measures of output for private business and private nonfarm business and BLS began using these as its main measures of output for major sector multifactor productivity in 1994.[21]

The issue of aggregation again arises because there are many measures available for manufacturing. As part of the National Income and Product Accounts, the Bureau of Economic Analysis now prepares three types of output aggregates: the traditional, fixed-weighted constant-dollar estimates of both gross output and gross product originating; the chain-weighted Fisher Ideal indexes; and the benchmark-years-weighted indexes. BLS has, for many years, used the Tornqvist method for aggregation in its multifactor productivity program, a practice which continues in the two-digit manufacturing measures reported on in this article.

The Fisher Ideal, the Tornqvist, and the benchmark-years-weighted indexes are all from a class of aggregating procedures in which the weights used in averaging are based on values or costs and are allowed to change through time. In 1976, Diewert showed that only a small class of index numbers, which he named "superlative," were consistent with a flexible functional form.[22] In connection with modern productivity analysis, a flexible form of production function is one which places few restrictions on the elasticities of substitution among the inputs being aggregated. The Tornqvist and Fisher Ideal indexes are two of the superlative indexes; aggregation methods which use fixed weights, for example, the summation of deflated dollar values traditionally used in the National Income and Product Accounts, are consistent with a specific, but rather restrictive production function.

While there has been a certain amount of debate about the relative merits of Tornqvist and Fisher Ideal indexes, Diewert concluded that neither has any compelling theoretical advantage and suggested that users choose on practical grounds. Nor is there much difference practically, as data on manufacturing gross output shows. (See table 2.) The Tornqvist manufacturing index presented in table 2 is the Tornqvist gross output chain index, constructed from annual growth rates, also shown in table 1; these growth rates are calculated using weights which are computed as geometric averages of current-value weights taken from each of the 2 years over which growth is being measured.

Nevertheless, the two measures differ in certain ways which may make either preferable to a given user. The Fisher Ideal has the quality of being based on two computationally simple and familiar indexes—the Paasche and Laspeyres—as well as the quality of "reversibility" (discussed earlier). The National Income and Product Accounts have traditionally been based on these two indexes—outputs have been fixed-weighted (Laspeyres) aggregates and prices current-weighted (Paasche) indexes. The Fisher Ideal quantity index, which is the geometric average of Paasche and Laspeyres quantity indexes, is easily understood by users of the National Income and Product Accounts and for this reason, the Bureau of Economic Analysis has chosen to emphasize the chain index based on the Fisher Ideal procedure as a new alternative gross domestic product measure published as part of the National Income and Product Accounts.

The Tornqvist index, on the other hand, has been widely used in productivity measurement since the 1970's, and is probably more familiar to productivity analysts. For that reason, it is used throughout the manufacturing multifactor productivity measurement program and presented in this article.

It is worthwhile to summarize the discussion of the definition of BLS industry multifactor productivity measures. First, in reference to the two-digit and total manufacturing data underlying this study, we use the term "sectoral output" to refer to output measures because they can be classified neither as gross output nor as value-added. In these, output is measured in terms of gross output—that is, as the real value of production—except that intra-industry sales are removed from the industry's output. Correspondingly, intra-industry purchases of materials are left out of the materials

Table 2. Tornqvist and Fisher Ideal indexes of manufacturing gross output, 1949–92

[1987=100]

Year	Tornqvist	Fisher Ideal
1949	29.435	29.437
1950	33.110	33.114
1951	35.081	35.085
1952	36.795	36.799
1953	40.411	40.417
1954	37.448	37.452
1955	41.814	41.818
1956	42.276	42.280
1957	42.211	42.215
1958	39.315	39.318
1959	44.020	44.023
1960	44.443	44.445
1961	44.273	44.276
1962	47.822	47.825
1963	50.563	50.566
1964	53.798	53.801
1965	58.137	58.141
1966	62.411	62.415
1967	63.622	63.626
1968	66.833	66.837
1969	68.887	68.891
1970	65.112	65.115
1971	66.630	66.634
1972	72.965	72.970
1973	78.923	78.925
1974	77.660	77.667
1975	70.493	70.494
1976	77.587	77.588
1977	83.566	83.567
1978	87.978	87.979
1979	89.156	89.157
1980	84.694	84.693
1981	85.024	85.023
1982	79.883	79.879
1983	83.418	83.413
1984	90.767	90.762
1985	91.364	91.360
1986	93.025	93.025
1987	100.000	100.000
1988	104.816	104.817
1989	104.867	104.867
1990	103.597	103.598
1991	101.282	101.283
1992	107.382	107.393

measure, while interindustry purchases are included. There are several reasons for this. First, removing intra-industry sales eliminates a degree of double counting. Inputs of materials produced and consumed in the same sector are already represented by the inputs used to make them. Counting both the intrasector transaction and the inputs that they embody tends to give an exaggerated importance to these inputs. Also, because these transactions are shown in both the numerator and denominator of a productivity ratio, productivity change is artificially reduced when intra-industry transactions are not removed.

Second, especially in any large aggregate such as the two-digit manufacturing sector measures, it is important to use aggregation methods which employ current, value- or cost-based share weights. The Tornqvist index is used here because of its traditional use in productivity analysis and because of its use of cost or value shares for both periods over which growth is measured. There are no significant differences between Tornqvist and Fisher Ideal indexes in the various productivity data sets we have worked with, however, and we considered them interchangeable.

Last, it is important to consider all inputs actually used in production in constructing data which is supposed to reflect improvements in industrial efficiency. Intermediate inputs—fuels, raw materials and semi-finished component inputs, and business services—represent a large part of the cost structure of manufacturing industries and developments in these inputs (for example business services, including those related to computers, and temporary labor) have clearly been powerful forces in shaping production.

Net output discontinued. In a July 1994 news release, BLS stopped showing a net output multifactor productivity measure for manufacturing in its major sector news release.[23] There were several reasons for discontinuing this practice. One reason was that BLS began using the Fisher output measures developed by the Bureau of Economic Analysis for the private business and private nonfarm business multifactor productivity measures at that time. Although a comparable, moving-weighted measure (the benchmark-years-weighted index) is available for manufacturing in the 1977–86 period, for years after 1987, the only available manufacturing net output index is fixed-weighted. Because alternative output measures were unavailable after 1987, the manufacturing numbers would not have been comparable with the other sectors.

A second reason for discontinuing the manufacturing net output multifactor productivity measures in 1994 was that it was difficult to explain to users of our data why we had two multifactor productivity measures for U.S. manufacturing. The rationale for having the two measures had been that one was more comparable to the net output for business and nonfarm business, while the other was more comparable to the sectoral output measures for two-digit manufacturing industries. Further, we had recently concluded that the role of manufacturing multifactor productivity in nonfarm business multifactor productivity is best assessed by using Domar's approach.[24] This involves using the sectoral output measure for manufacturing.

A final reason for not showing a net output multifactor productivity measure is that BLS introduced measures of labor composition for private business and private nonfarm business into the calculation of multifactor productivity in the July 1994 release. Because similar measures are as yet unavailable for manufacturing, this would have represented another conceptual difference between the multifactor productivity measures for major sectors previously published in a news release.[25]

In light of the foregoing discussion, the main BLS measure of multifactor productivity in manufacturing will use the sectoral measure of output. We plan to resume the presentation of manufacturing data in our news releases on major sector multifactor productivity. However, because of differences in concept and differences in the timing of data availability, BLS will present manufacturing multifactor productivity in a separate section which stresses these differences and which briefly discusses how the manufacturing numbers relate to the more aggregate measures.

BLS will continue to maintain a set of multifactor productivity measures which compare net output to capital and labor inputs for U.S. manufacturing. These will be used for international comparisons, because the information needed to construct sectoral output and intermediate inputs for other countries is generally difficult to obtain. These measures are presented in this issue in the article by Wolodar Lysko.

Long-term trends in productivity

In any discussion of productivity growth trends, the productivity slowdown, which commenced some time in the 1970's, and the degree to which we have emerged from it, are topics that arise. Table 3 shows multifactor productivity growth rates for selected periods and illustrates this general slowing of productivity growth in recent years. Using 1973, a business cycle peak year, to delineate early and late periods and comparing 1949–73 with 1973–92, most industries exhibited some degree of slowdown. In total manufacturing, the growth rate dropped from 1.8 to 0.8 percent per year; among the 19 industries, growth slowed by some degree in all but five—apparel, leather and leather products, industrial and commercial products and computer equipment, electrical and electronic equipment, and instruments. In most other industries, growth slowed substantially, by at least 0.3 percentage points.

Table 3 also illustrates the problems presented by multifactor productivity performance in the 1973–79 period in analyzing the productivity slowdown. The multifactor productivity level declined in manufacturing as a whole by a total of 0.6 percent over this 6-year period—an average annual decline of 0.1 percent. While there are several single-recession years in which multifactor productivity declined, there is no other instance of a multi-year decline in multifactor productivity in manufacturing since the beginning of the series in 1949. Whether the 1973–79 performance was due to energy shocks, the double-digit inflation that followed, or to an actual slowing of innovation, the period seems to be uniquely dismal.

Extension of the data to 1992 allows average growth rates for the period beginning with the 1979 business cycle peak and ending in 1992 to be computed and these averages, also shown in table 3, might be more representative of current conditions and more appropriate for comparison with the early years. These averages suggest that manufacturing productivity growth has regained some, although not all, of the pace of the early postwar period. For manufacturing as a whole, the average annual growth after 1979 in multifactor

Table 3. Multifactor productivity growth in U.S. manufacturing, selected periods, 1949–92

[Compound average annual growth rates]

Industry	1949–92	1949–73	1973–92	1973–79	1979–92
Total manufacturing	1.3	1.8	0.8	–0.1	1.2
Nondurable manufacturing	.9	1.6	.1	-.3	.3
Food and kindred products	.8	1.0	.5	2.1	.6
Textile mill products	1.9	2.1	1.6	2.1	1.3
Apparel and related products	1.1	1.0	1.3	1.9	1.0
Paper and allied products	.9	1.5	.1	–.9	.6
Printing and publishing	.0	.5	–.8	–.3	1.0
Chemicals and allied products	1.4	2.8	–.3	–1.7	.3
Petroleum refining and related industries	.3	.8	–.4	–.4	–.4
Rubber and miscellaneous plastics products	1.2	1.3	1.0	–1.5	2.2
Leather and leather products	.2	.0	.4	–.8	.9
Durable goods	1.5	1.6	1.3	.0	1.9
Lumber and wood products	1.0	1.4	.6	.0	.9
Furniture and fixtures	.5	.7	.3	.2	.3
Stone, clay, glass and concrete products	.6	1.0	.1	–1.1	.6
Primary metal industries	.2	.4	.0	–1.9	.9
Fabricated metal products	.6	.9	.4	–.6	.8
Industrial and commercial products, and computer equipment	1.7	1.0	2.7	1.2	3.3
Electrical and electronic equipment	2.3	2.2	2.6	1.9	2.9
Transportation equipment	1.0	1.6	.2	–.3	.5
Measuring, analyzing, and controlling instruments	1.9	1.8	2.0	2.0	2.0
Miscellaneous manufacturing	.9	1.5	.2	–.8	.7

productivity was 1.2 percent per year, compared with the 1949–73 rate of 1.8 percent.

Multifactor productivity growth varies substantially across industries, both in terms of total postwar growth and in the pattern of growth through subperiods. At the high end of the growth spectrum for the entire 1949–92 period are electrical and electronic equipment (2.3 percent per year), textile mills (1.9 percent), industrial and commercial machinery and computer equipment (1.7 percent), and measuring, analyzing, and controlling instruments (1.9 percent). Primary metals, and leather and leather products, with average growth rates of 0.2 percent, and printing and publishing (no growth) were at the other end.

Since 1979, the leaders have been industrial and commercial machinery and computer equipment (3.3 percent per year), electrical and electronic equipment (2.9), rubber and miscellaneous plastics products (2.2), and measuring, analyzing, and controlling instruments (2.0). The industries in which productivity grew fastest in the early period were not always the same ones in which it has grown fastest more recently. Using 1949–73 to represent the early period and 1979–92 for the late, we find that only textile mill products, electrical and electronic products, and measuring, analyzing, and controlling instruments were in the top third in both periods.

Thus, even though growth rates for manufacturing as a whole were similar in the two periods 1949–73 and 1979–92, the sources of growth were rather different. Table 3 shows that, on average, multifactor productivity grew 1.8 percent per year in 1949–73 and 1.2 percent in 1979–92 in total manufacturing. In the early period, growth rates in durable and nondurable groups had been the same (1.6 percent), thus contributing to the total in roughly equal proportions. In the later period, however, multifactor productivity growth in nondurable manufacturing declined almost to nil; the source of manufacturing multifactor productivity growth in the later period thus was growth in durable industries, especially industrial and commercial products, and computer equipment and electrical and electronic equipment. Table 4, which shows the growth in inputs, in output, and in multifactor productivity for early and late periods, sheds some light on the improvement in productivity growth over the last few years. The growth rate in durable goods output as a whole was more than twice the rate evidenced before 1979; there was a substantial im-

Chart 1. Output, input, and multifactor productivity indexes, 1949–92

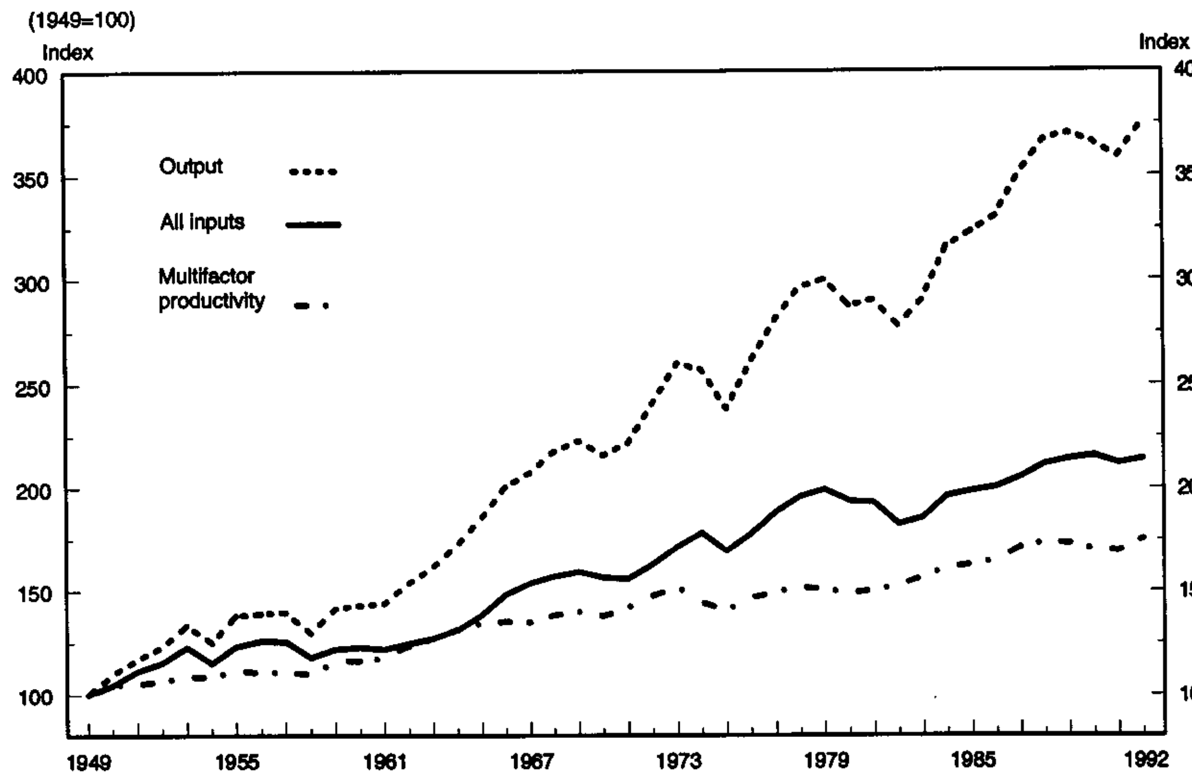

Table 4. **Input, output, and multifactor productivity growth, 1949–92 selected periods**

[Compound average annual growth rates]

Industry	Capital	Labor	Intermediate inputs	All inputs	Multifactor productivity	Output
Total manufacturing						
1949–73	4.1	1.4	2.6	2.3	1.8	4.1
1973–79	4.6	.3	4.1	2.5	–.1	2.4
1979–92	3.6	–.9	.7	.6	1.2	1.7
Nondurable goods						
1949–73	3.3	.7	2.5	2.0	1.5	3.5
1973–79	4.4	–.2	3.9	2.7	–.3	2.4
1979–92	3.8	–.2	1.2	1.3	.3	1.5
Food and kindred products						
1949–73	1.5	–.4	1.9	1.4	1.0	2.4
1973–79	3.5	–.2	3.3	2.7	.2	3.0
1979–92	2.6	–.2	1.5	1.3	.6	2.0
Textile mill products						
1949–73	1.2	–.4	4.2	1.9	2.1	4.0
1973–79	1.2	–2.4	1.3	–.1	2.1	2.0
1979–92	.2	–1.9	.5	-.3	1.3	1.0
Apparel and related products						
1949–73	4.2	.8	2.5	1.9	1.0	2.9
1973–79	2.9	–1.8	–1.4	–1.3	1.9	.6
1979–92	.5	–1.5	.8	.3	1.0	1.3
Paper and allied products						
1949–73	3.8	1.8	4.2	3.3	1.5	4.8
1973–79	5.5	–.4	3.9	2.7	–.9	1.8
1979–92	3.4	.1	.5	1.3	.5	1.9
Printing and publishing						
1949–73	4.3	1.4	4.4	2.9	.5	3.5
1973–79	3.4	1.6	3.4	2.6	–.3	2.3
1979–92	5.5	2.0	4.3	3.5	.0	2.4
Chemicals and allied products						
1949–73	4.1	2.1	4.8	3.8	2.8	6.7
1973–79	6.2	.9	4.3	3.7	–1.7	2.0
1979–92	3.0	.0	1.0	1.2	.3	1.5
Petroleum refining and related industries						
1949–73	3.3	–.3	3.9	3.3	.8	4.1
1973–79	3.3	1.6	2.8	2.7	–.4	2.3
1979–92	8.9	-2.1	-1.0	.6	–.4	.2
Rubber and miscellaneous plastics products						
1949–73	6.3	3.8	5.8	5.1	1.3	6.5
1973–79	5.4	4.6	2.9	2.6	–1.5	1.1
1979–92	2.9	.7	1.0	1.3	2.2	3.5
Leather and leather products						
1949–73	1.0	–1.3	2.3	.5	.0	.5
1973–79	1.2	–2.6	–1.1	–1.6	–.8	–2.4
1979–92	.2	–5.1	–4.3	–3.7	.9	–2.8
Durable goods						
1949–73	4.8	2.0	4.0	3.1	1.6	4.8
1973–79	4.6	.7	3.4	2.2	.0	2.2
1979–92	3.4	–1.4	.0	.0	1.9	1.8
Lumber and wood products						
1949–73	3.3	.0	3.7	2.0	1.4	3.3
1973–79	4.7	.0	.7	1.1	.0	1.0
1979–92	–.7	–.8	1.8	.4	.9	1.3
Furniture and fixtures						
1949–73	3.7	1.9	4.0	3.2	.7	3.9
1973–79	4.0	–.9	1.3	.7	.2	.9
1979–92	3.0	.2	1.6	1.5	.3	1.8

Table 4. **Continued—Input, output, and multifactor productivity growth, 1949–92 selected periods**

[Compound average annual growth rates]

Industry	Capital	Labor	Inter-mediate	All inputs	Multifactor productivity	Output inputs
Stone, clay, glass and concrete products						
1949–73	3.2	1.4	4.3	3.0	1.0	4.0
1973–79	4.6	–.5	2.8	1.7	–1.1	.6
1979–92	2.1	–1.8	–1.2	–1.1	.6	–.4
Primary metal industries						
1949–73	3.9	.9	3.7	2.7	.4	3.1
1973–79	2.5	–.7	1.4	.9	–1.9	–1.0
1979–92	–.5	–4.1	–2.2	–2.6	.9	–1.8
Fabricated metal products						
1949–73	4.7	2.5	4.2	3.6	.9	4.5
1973–79	4.5	.1	1.1	1.0	–.6	.4
1979–92	1.4	–1.7	–.8	–.9	.8	–.1
Industrial and commercial products, and computer equipment						
1949–73	4.3	2.5	4.9	3.8	1.0	4.8
1973–79	6.5	2.2	3.4	3.2	1.2	4.5
1979–92	5.3	–1.8	.3	.0	3.3	3.3
Electrical and electronic equipment						
1949–73	6.4	3.6	4.7	4.4	2.2	6.7
1973–79	6.0	.8	3.4	2.4	1.9	4.3
1979–92	6.4	–1.0	1.9	1.2	–2.9	4.1
Transportation equipment						
1949–73	5.6	2.0	3.8	3.4	1.6	5.0
1973–79	2.9	.7	2.7	1.9	–.3	1.6
1979–92	3.2	–.8	.6	.4	.5	.9
Measuring, analyzing, and controlling instruments						
1949–73	6.8	3.3	6.9	5.1	1.8	7.0
1973–79	6.5	2.4	6.7	4.7	2.0	6.8
1979–92	7.9	–.6	3.3	1.8	2.0	3.9
Miscellaneous manufacturing						
1949–73	4.0	.5	3.7	2.4	1.5	4.0
1973–79	3.7	–.2	1.3	1.0	–.8	.2
1979–92	1.5	–.7	.5	.2	.7	.9

provement in output growth rates in all durable industries (led by industrial and commercial products, and computer equipment). Chart 1 (page 22) shows the acceleration of multifactor productivity growth coinciding with the rapid growth in output which commenced around 1983.

Productivity's effect on prices

Multifactor productivity represents the difference between the growth of output and the growth of a composite of all inputs and therefore represents the extent to which output may grow beyond the increased use of scarce inputs. Multifactor productivity also represents the difference between output price change and the change in a composite price for all inputs. Multifactor productivity is the residual in the relationship between output and inputs and, identically, it is the residual in the relation between output and input prices. It is in this connection that productivity takes on a particular significance in the present, highly competitive manufacturing environment: productivity growth represents the means by which a competitive position may be enhanced in the absence of input price reductions; the means by which the effects of input price increases may be mitigated; or the means by which payments to labor and to the owners of capital may rise without increasing price.[26]

Table 5 shows average movements in input prices, multifactor productivity, and output price in selected postwar periods. The importance of multifactor productivity growth in offsetting the effects of input price increases is suggested in this table. Averages for three periods are shown, and special attention should be given to the contrasts between the early and late periods and the 1973–79 years. It was during the mid-1970's when the economy suffered a simultaneous increase in input price growth rates and a

Table 5. Growth rates of input prices, multifactor productivity, and output price in manufacturing industries, selected periods, 1949–92

[Compound average annual growth rates]

Industry	Capital	Labor	Inter-mediate inputs	All inputs	Multifactor productivity	Output
Total manufacturing (SIC 20-39)						
1949–73	2.0	5.4	3.1	3.9	1.8	2.1
1973–79	4.9	9.9	10.6	9.5	–.1	9.6
1979–92	2.2	5.4	3.2	4.0	1.2	2.8
Nondurable goods (SIC 20-23, 26-31)						
1949–73	2.3	5.1	2.7	3.4	1.6	1.8
1973–79	7.3	9.8	11.3	10.4	–.3	10.7
1979–92	3.1	5.6	2.2	3.3	.3	3.0
Food and kindred products (SIC 20)						
1949–73	2.2	5.4	2.7	3.2	1.0	2.2
1973–79	8.2	9.6	6.8	7.3	.2	7.1
1979–92	7.3	5.1	2.0	3.0	.6	2.4
Textile mill products (SIC 22)						
1949–73	1.6	4.5	1.4	2.7	2.1	.6
1973–79	6.2	8.2	6.5	7.1	.1	4.9
1979–92	5.7	5.3	3.0	4.1	1.3	2.7
Apparel and related products (SIC 23)						
1949–73	.7	4.1	1.0	2.2	1.0	1.2
1973–79	8.8	8.7	6.8	7.7	1.9	5.7
1979–92	5.8	4.7	3.3	4.1	1.0	3.1
Paper and allied products (SIC 26)						
1949–73	2.7	5.4	2.9	3.7	1.5	2.2
1973–79	2.9	10.7	10.5	9.3	-.9	10.3
1979–92	3.4	5.5	4.2	4.4	.6	3.8
Printing and publishing (SIC 27)						
1949–73	2.4	4.6	2.6	3.5	.5	3.01
1973–79	6.9	9.1	8.6	8.6	-.3	8.9
1979–92	3.0	5.2	3.6	4.2	-1.0	5.3
Chemicals and allied products (SIC 28)						
1949–73	2.7	5.7	2.5	3.5	2.8	.7
1973–79	3.1	10.5	12.6	10.1	–1.7	12.0
1979–92	4.7	6.3	3.1	4.3	.3	4.0
Petroleum refining and related industries (SIC 29)						
1949–73	1.3	5.1	2.2	2.5	.8	1.6
1973–79	23.7	12.7	24.7	23.6	–.4	24.1
1979–92	–13.3	4.5	.5	–.3	–.4	.1
Rubber and miscellaneous plastics products (SIC 30)						
1949–73	3.4	4.8	1.9	3.1	1.3	1.7
1973–79	–.7	8.2	10.5	8.7	-1.5	10.4
1979–92	5.8	5.4	5.0	5.2	2.2	3.0
Leather and leather products (SIC 31)						
1949–73	2.1	4.5	.5	2.6	.0	2.5
1973–79	9.7	7.5	9.6	8.8	–.8	9.7
1979–92	6.7	4.6	3.1	4.3	.9	3.3
Durable goods (SIC 24, 25, 32-39)						
1949–73	1.8	5.5	3.1	4.1	1.6	2.5
1973–79	2.8	9.8	9.6	8.8	.0	8.8
1979–92	.9	5.4	4.6	4.6	1.9	2.6
Lumber and wood products (SIC 24)						
1949–73	4.2	5.9	3.1	4.5	1.4	3.1
1973–79	6.0	9.2	9.8	8.9	–.2	9.0
1979–92	2.2	5.0	2.8	3.5	.9	2.6
Furniture and fixtures (SIC 25)						
1949–73	1.2	4.6	2.6	3.2	.7	2.5
1973–79	5.0	7.6	8.9	8.2	.2	8.0
1979–92	3.6	5.6	3.5	4.2	.3	3.9

Table 5. Continued—Growth rates of input prices, multifactor productivity, and output price in manufacturing industries, selected periods, 1949–92

[Compound average annual growth rates]

Industry	Capital	Labor	Inter-mediate inputs	All inputs	Multifactor productivity	Output
Stone, clay, glass and concrete products (SIC 32)						
1949–73	3.0	5.4	2.6	3.8	1.0	2.7
1973–79	3.1	10.0	10.6	9.4	-1.1	10.6
1979–92	-1.1	5.0	3.6	3.7	.6	3.1
Primary metal industries (SIC 33)						
1949–73	1.7	5.8	2.9	3.7	.4	3.3
1973–79	5.3	11.1	11.4	10.5	-1.9	12.6
1979–92	-1.9	4.6	3.4	3.3	.9	2.4
Fabricated metal products (SIC 34)						
1949–73	2.4	4.9	3.2	3.8	.9	2.9
1973–79	7.7	9.6	10.9	10.2	-.6	10.9
1979–92	3.2	4.7	3.6	4.0	.8	3.1
Industrial and commercial products, and computer equipment (SIC 35)						
1949–73	2.8	5.3	3.0	4.0	1.0	2.9
1973–79	4.6	9.8	9.7	9.2	1.2	7.9
1979–92	-5.8	5.3	3.9	3.5	3.3	.1
Electrical and electronic equipment (SIC 36)						
1949–73	1.4	4.7	3.2	3.6	2.2	1.4
1973–79	.8	9.5	8.8	8.3	1.9	6.3
1979–92	.7	6.2	4.0	4.5	2.9	1.5
Transportation equipment (SIC 37)						
1949–73	.3	6.1	3.2	3.9	1.6	2.3
1973–79	-8.0	9.9	10.1	8.8	-.3	9.1
1979–92	4.9	5.6	3.9	4.7	.5	4.1
Measuring, analyzing, and controlling instruments (SIC 38)						
1949–73	4.5	5.9	2.3	4.2	1.8	2.3
1973–79	2.5	9.4	8.3	8.5	2.0	6.4
1979–92	8.9	7.2	3.5	5.7	2.0	3.6
Miscellaneous manufacturing (SIC 39)						
1949–73	1.6	4.9	2.5	3.4	1.5	1.9
1973–79	3.0	8.2	9.4	8.4	.8	9.3
1979–92	8.5	4.6	2.9	4.2	.7	3.5

productivity slowdown which, together, had disastrous consequences for growth in output prices.

In the pre-1973 period, multifactor productivity growth absorbed about 46 percent of the increase in input prices, and in the post-1979 period about 28 percent, judging from the data for total manufacturing. In the 1973–79 period, there was no multifactor productivity growth to dampen the extraordinary input price growth. For 12 of the two-digit industries, output price actually grew faster than the prices of inputs. Declines in productivity occurred in all 12 industries in this period.

PRODUCTIVITY MEASURES FOR industries provide important insights into technological change and price increases.This article has presented evidence on the recovery of productivity growth in manufacturing in recent years, and on the forces underlying price change through the postwar period. The form of productivity measures for industries has also been discussed. In particular, analysis of productivity for industries cannot be restricted to capital and labor as inputs. In manufacturing, intermediate inputs—energy, nonenergy materials, and business services—constitute a large part of the cost structure. Firms' managers make decisions based on prices of all inputs and other market conditions, adjusting input mix, labor force, and investment levels accordingly. A specification of productivity which excludes intermediate inputs from consideration makes mismeasurement of growth trends more likely, while severely limiting the kinds of analyses to which the measures can be put. □

Footnotes

[1] For a description of these BLS measures, see William Gullickson and Michael J. Harper, "Multifactor Productivity in U.S. Manufacturing, 1949–83," *Monthly Labor Review*, October 1987, pp. 18–28. The current data set updates the measures described in this article and incorporates several technical improvements. For a thorough discussion of capital measurement procedures, see *Trends in Multifactor Productivity*, 1948–81, Bulletin 2178 (Bureau of Labor Statistics, 1983). For a discussion of BLS rental prices, see Michael J. Harper, Ernst R. Berndt, and David O. Wood, "Rates of Return and Capital Aggregation Using Alternative Rental Prices," in Dale W. Jorgenson and Ralph Landau, eds., *Technology and Capital Formation* (Cambridge, MA., The MIT Press, 1989), pp. 332–72.

[2] BLS plans to publish these changes in future press releases on multifactor productivity in major sectors of the U.S. economy.

[3] Tobacco manufactures is not reported separately because of the small size of the industry and because of data limitations. The industry is, however, included in the nondurable goods and total manufacturing aggregates.

[4] William Gullickson, "Multifactor Productivity in Manufacturing Industries," *Monthly Labor Review*, October 1992, pp. 20–32. See also "Manufacturing Costs, Productivity, and Competitiveness, 1979–93," by Edwin R. Dean and Mark K. Sherwood, *Monthly Labor Review*, October 1994, pp. 3–16, in which multifactor productivity growth for two-digit manufacturing industries is analyzed in the context of price change and competitiveness.

[5] This measure was issued in press releases on multifactor productivity for major sectors (private business, nonfarm business, and total manufacturing). See *Multifactor Productivity Measures, 1991 and 1992*, USDL 94–327 (U.S. Department of Labor) July 11, 1994.

[6] Another article in this issue describes some of these efforts. See Kent Kunze, Mary Jablonski, and Virginia Klarquist, "BLS modernizes industry labor productivity program."

[7] See especially Charles R. Hulten, James W. Robertson, and Frank C. Wycoff, "Energy, Obsolescence, and the Productivity Slowdown," in Dale W. Jorgenson and Ralph Landau, eds., *Technology and Capital Formation*, (Cambridge, MA, MIT Press, 1989), pp. 225–58; Michael J. Harper and William Gullickson, "Cost Function Models and Accounting for Growth in U.S. Manufacturing, 1949–86," paper presented at the National Bureau of Economic Research Summer Institute, July 1988; and J. R. Norsworthy, Michael J. Harper, and Kent Kunze, "The Slowdown in Productivity Growth: Analysis of Some Contributing Factors," *Brookings Papers on Economic Activity*, No. 2, 1979, pp. 388–421.

[8] In productivity analysis, it is common to use the term output in a generic sense when referring to the activities of industries, sectors, or the economy as a whole, regardless of the concepts being followed in defining productivity and the statistics used to estimate it. This term is not used in the U.S. National Income and Product Accounts, which use special terms to refer to specific national accounts series. For example, in the National Income and Products Accounts, the term "real gross product by industry" is used when referring to real value-added, to avoid confusion with gross output.

[9] The effect of computer prices on manufacturing aggregates is discussed in Robert P. Parker, "Gross Product by Industry, 1977–90," *Survey of Current Business*, May 1993.

[10] There is a substantial technical literature reporting on econometric tests of the existence of a value-added function. Dale W. Jorgenson, Frank M. Gollop, and Barbara M. Fraumeni, *Productivity and U.S. Economic Growth* (Cambridge, MA, Harvard University Press, 1987), pp. 211–60, describe these tests extensively and reject the value-added function for 40 of 45 industries analyzed, including all of the two-digit manufacturing industries, on these and other grounds.

There is also a substantial literature relating elasticities of substitution and the separability of production and cost functions into subfunctions. Since the relationships between inputs (that is, elasticities) can be observed, the separability of the production function (and in this case, the permissibility of ignoring intermediates) can be investigated empirically. See Ernst R. Berndt and Laurits R. Christensen, "The Internal Structure of Functional Relationships: Separability, Substitution, and Aggregation," *Review of Economic Studies*, July 1973, pp. 403–10 for a discussion of the history and alternative definitions of the concept of separability.

The question of the existence of a K-L aggregate, necessary for a measure of K-L productivity, has been explored by several investigators. Ernst Berndt and David O. Wood, "Technology, Prices, and the Derived Demand for Energy," *The Review of Economics and Statistics*, vol. LVII, no. 3, pp. 259–68, rejected the K-L aggregate for total U.S. manufacturing (but could not reject a K-E aggregate). J. R. Norsworthy and D. H. Malmquist, "Input Measurement and Productivity Growth in Japanese and U.S. Manufacturing," *The American Economic Review*, December 1983, pp. 947–67, also reject K-L separability.

[11] For national aggregates such as the U.S. business sector, intermediate inputs, defined according to "sector" concepts used here as including only goods and services produced outside the sector, include only imported intermediates. See Frank Gollop, "Growth Accounting in an Open Economy," *Boston College Working Papers in Economics*, March 1981, on this point. While growing in recent years, imported raw materials and components consumed by U.S. producers are still too small to affect aggregate productivity visibly.

[12] The removal of intrasector transactions from output and material input for industry productivity measurement was first suggested by Evsey D. Domar. See Evsey D. Domar, "On the Measurement of Technical Change," *The Economic Journal*, December 1961, pp. 709–29. For additional discussion on this point, see Richard G. Anderson, "On the Specification of Conditional Factor Demand Functions in Recent Studies of U.S. Manufacturing," in Ernst R. Berndt and Barry C. Field, eds., *Modeling and Measuring Natural Resource Substitution* (Cambridge, MA, The MIT Press, 1981), pp. 119–44; and Frank Gollop, "Growth Accounting in an Open Economy," *Boston College Working Papers in Economics*, March 1981.

In his original discussion of the "Residual," Domar showed that the true rate of growth for a sector *in which there are intrasector transactions* is equal to the measured rate raised by the ratio $1/(1-g_1)$, where g_1 is the share of the sector's internal transaction in the cost of all inputs. Domar demonstrated this with the following industry production functions. The first shows the output of an industry varying with inputs of capital and labor, and an input from another industry (R_2), and multifactor productivity change ($dlnA_1/dt$).

$$dlnY_1/dt = dlnA_1/dt + a_1 dlnL_1/dt + b_1 dlnK_1/dt + g_1 dlnR_2/dt.$$

If the second industry's production function for R_2 is identical to that of the Y_1, integrating them gives:

$$Y_1 = A_1^{1/(1-g_1)} L_1^{a_1/(1-g_1)} K_1^{b_1/(1-g_1)}.$$

The growth of the residual for the integrated industry (sector) becomes

$$dlnA = dlnA_1(1 + g_1 + g_1^2 + g_1^3 ...) = dlnA_1/(1 - g_1).$$

With this, Domar distinguished between a "gross" rate of productivity growth—that measured as the change in gross output less the change in a weighted composite of all inputs—and the underlying residual which more accurately reflects changing production technology. It is worth noting that the gross measure of productivity change, computed from summed data for all establishments in the sector, is always *less* than the productivity gain at the establishment level where a technical improvement takes place.

It should be noted that some researchers have preferred not to adjust outputs and intermediate inputs to remove intrasector transactions. See for example, Ernst R. Berndt and David O. Wood, "Technology, Prices, and the Derived Demand for Energy," *Review of Economics and Statistics*, August 1975, pp. 259–68. The advantages of this treatment are: simplicity (in avoiding the need to estimate these transactions); comparability with other countries' data (for which these transactions are most often not available); and a closer resemblance to industry source data (such as the Census of Manufactures) and to "representative" firm data. BLS maintains all data underlying the multifactor productivity measures, and will make unadjusted series available on request.

[13] The removal of intra-sector transactions is accomplished by the use of input-output tables published for the U.S. economy for various years since 1947 by the Bureau of Economic Analysis, U.S. Department of Commerce. The I-O tables used for the estimation of intra-industry transactions and for other purposes in the multifactor program are substantially modified, both for confor-

mity with each other and to conform to multifactor productivity principles. The intrasector transaction for each industry (and for the aggregated manufacturing sector) is estimated as the proportion of total industry output consumed intra-industry in the I-O tables, applied to total industry (sector) gross output underlying the estimates described in this article. The use of proportions from the I-O tables, rather than absolute amounts, is preferred because of incidental differences in industry concepts used for I-O tables and by the Census Bureau (on whose data the multifactor productivity measures are based).

Intrasector sales are deflated (at the two-digit level) using the producing industry's gross output deflators. It is not possible to distinguish between intra- and interindustry sales with regard to price. Output net of intrasectoral transactions is then obtained by "Tornqvist disaggregation," that is, as the weighted difference between growth rates in gross (duplicated) output and the growth in the intrasector transaction.

[14] Dale W. Jorgenson and Zvi Griliches, "The Explanation of Productivity Change," *Review of Economic Studies* (July 1967), pp. 249–82.

[15] From the production function, we differentiate with respect to time and divide by Y, obtaining:

$$(dY/dt)/Y = (\partial f/\partial x_1)(dx_1/dt)/x_1 + \ldots + (\partial f/\partial x_n)(dx_n/dt)/x_n \ldots + (\partial f/\partial t)/Y.$$

In this representation, the growth rate of output equals a weighted average of the input growth rates plus a residual term, $(\partial f/\partial t)/Y$, representing productivity change.

[16] Under the assumption that factor markets are competitive, each factor is paid its marginal product ($Px_i = dY/dx_i$) and the elasticities of output with respect to each input ($\partial f/\partial x_i$) are equal to the shares of each input in the value of output (v_i). Hence,

$v_i = (dY/dx_i)(x_i/Y) = x_i Px_i/Y$ and we may substitute

$$(dY/dt)/Y = v_1 (dx_1/dt)/x_1 + \ldots + v_n (dx_n/dt)/x_n \ldots + (\partial f/\partial t)/Y.$$

[17] Charles Hulten, "Divisia Index Numbers," *Econometrica*, vol. 41, no. 3, showed that a chain index can give an ambiguous result when comparing two remote points in time if the rate of multifactor productivity growth depends on the path taken by prices during the intervening years. Jack Triplett "Economic Theory and BEA's Alternative Quantity and Price Indexes," *Survey of Current Business*, April 1992 has proposed an approach to estimating annual index numbers which can reduce this problem.

[18] Ernst R. Berndt and Laurits R. Chistensen, "The Internal Structure of Functional Relationships: Separability, Substitution, and Aggregation," *Review of Economic Studies*, July 1973, pp. 403–10.

[19] See *Labor Composition and U.S. Productivity Growth*, 1948–90, Bulletin 2426 (Bureau of Labor Statistics, December 1993).

[20] W. E. Diewert, "Functional Forms for Profit and Transformation Functions," *Journal of Economic Theory*, no. 6, 1973, pp. 284–316.

[21] This change was introduced in *Multifactor Productivity Measures, 1991 and 1992*, USDL 94–327 (U.S. Department of Labor) July 11, 1994. Data were updated in *Multifactor Productivity Trends, 1993*, USDL 95–48 (U.S. Department of Labor) Feb. 14, 1995.

[22] W. Erwin Diewert, "Exact and Superlative Index Numbers," *Journal of Econometrics*, vol 4, no. 4 (1976), pp. 115–45 shows that certain index number formulas, including the Tornqvist and the Fisher Ideal, are consistent with flexible production functions. In another paper, "Superlative Index Numbers and Consistency in Aggregation," *Econometrica*, July 1978, pp. 883–900, Diewert shows empirically that chained time series of superlative index numbers are approximately consistent. The comparison in table 2 in this article is similar to one presented by Diewert in "Superlative Index Numbers and Consistency in Aggregation."

[23] *Multifactor Productivity Measures*, 1991 and 1992 (U.S. Department of Labor), July 11, 1994.

[24] See Gullickson, "Multifactor productivity," *Monthly Labor Review*, pp. 20–32.

[25] For a discussion of the labor measures, see *Labor Composition*, Bulletin 2426, Bureau of Labor Statistics.

[26] See Dean and Sherwood, "Manufacturing costs, productivity, and competitiveness" *Monthly Labor Review*, October 1994, pp. 3–16.