Multifactor productivity in U.S. manufacturing, 1949–83

New, more comprehensive measures of multifactor productivity permit the analysis of numerous issues, including developments at the detailed industry level and the importance of factor substitution in labor productivity growth

WILLIAM GULLICKSON AND MICHAEL J. HARPER

The strong labor productivity advance exhibited by the U.S. economy over the 25 years following World War II gave way to sluggish growth beginning in the early 1970's. The manufacturing sector, which accounts for about 20 percent of gross national product, has experienced a similar pattern. Prior to about 1973, the rapid productivity growth in manufacturing contributed to swift increases in the U.S. standard of living, and also to a favorable international balance of payments. After 1973, and particularly during the late 1970's, manufacturing productivity growth fell short of its earlier performance.

In this article, the Bureau of Labor Statistics introduces a new set of multifactor productivity measures designed to strengthen the statistical basis with which labor productivity, and production technology in general, can be analyzed. These new measures of multifactor productivity, available for 20 manufacturing industries, are defined as output per unit of combined capital, labor, energy, materials, and business service inputs (collectively identified by the acronym KLEMS). They expand the BLS manufacturing multifactor productivity measurement program in two important ways: First, they enhance the level of industry detail so that growth can be localized, rather than seen in the aggregate; and second, they consider intermediates—raw materials and business service inputs—explicitly, so that economies in those inputs can be assessed along with those in labor and capital.

Changes over time in these new multifactor measures reflect many influences, including variations in output (especially in the short term, during which most inputs are partially fixed), the utilization of capacity, changes in the characteristics and efforts of the work force, changes in managerial skill, and technological developments. Measures of multifactor productivity have a specific relationship to measures of labor productivity: Labor productivity growth can be seen as deriving from (1) growth in multifactor productivity and (2) changes in the ratios of labor to other inputs, or labor intensity ratios. These input ratios can change for several reasons, most notably in response to relative price change, even in the absence of multifactor productivity growth. Because changes in multifactor productivity and in the intensity of use of the various factors have occurred at different rates throughout the postwar period, the impact of these forces on labor productivity growth has varied also.

In the first section of this article, the methods and sources underlying the new multifactor measures, and their relation to other BLS productivity indexes, are discussed. The next section deals with input, output, and multifactor productivity growth, in the aggregate and by industry. Last, the effects of multifactor productivity growth and changes in

William Gullickson and Michael J. Harper are economists in the Division of Productivity Research, Bureau of Labor Statistics. Steve Rosenthal and Phyllis Otto of the division developed much of the data for this article.

factor intensity on labor productivity growth are explored, particularly with regard to attributing the productivity slowdown to those sources.

Comparison with other productivity measures

The new multifactor measures differ in one important way from the capital-labor multifactor measures for aggregate sectors (business, nonfarm business, and total manufacturing) which have been published by the BLS for several years.[1] For the capital-labor measures, multifactor productivity is defined as real gross product originating in a sector per unit of combined labor and capital inputs—with no explicit consideration of intermediate inputs.[2] The reason for this approach is that, for the largest aggregates, most intermediate transactions are between establishments within the sector and therefore cancel out in the computation of output leaving the sector; because intermediate purchases from outside the sector are a small proportion of total purchases by the large aggregates, all intermediates can safely be ignored in the calculation of productivity.

For industries, intermediate goods are not alway obtained from suppliers within the industry, and for this reason should not be ignored. For the measures presented in this article, therefore, output is defined as the real value of production (rather than value added) sold to purchasers outside the industry; industry output computed this way is referred to as sectoral output. Inputs are defined to include all intermediate purchases from outside the industry. Thus, the entire production process can be analyzed, including developments in intermediate inputs to the greatest extent possible, without double-counting.[3] The new 2-digit measures closely resemble a set of measures prepared previously by BLS for the steel and auto industries, which also reflect sectoral output per unit of combined capital, labor, energy, and other intermediate inputs.[4]

The BLS now publishes several different multifactor measures in addition to labor productivity and cost measures. No single productivity ratio can be regarded as best for all purposes. Because data users have a variety of analytical interests, it is the policy of BLS to make available a family of measures, together with detailed discussion of the assumptions and component data series used to compute them. For example, BLS now publishes three productivity series for total manufacturing: the quarterly labor productivity series, which uses a gross-product-originating measure; the annual capital-labor multifactor series, also based on gross product originating; and the new sectoral output and multifactor input measures. The three exhibit the following compound annual productivity growth rates over the postwar period:

Period	*Labor productivity*	*Capital-labor multifactor productivity*	*KLEMS multifactor productivity*
1949–83	2.5	1.7	1.1
1949–73	2.8	2.1	1.5
1973–83	1.8	.7	.3

The estimates underlying the three different measures are as follows: (1) labor productivity—gross product originating (numerator) and labor hours (denominator); (2) capital-labor multifactor productivity—gross product originating (numerator) and combined inputs of capital and labor (denominator); and (3) KLEMS sectoral multifactor productivity—sectoral output (numerator) and combined inputs of capital, labor, energy, materials, and purchased business services (denominator).

The difference between labor productivity (gross product originating per hour) and capital-labor multifactor productivity (gross product originating per unit of combined capital and labor inputs) reflects changes in the capital-labor ratio.[5] In effect, therefore, multifactor analysis based on gross product originating and capital and labor inputs allows the resolution of labor productivity change into two components: change in the multifactor measure, which reflects changes in output in excess of changes in capital and labor inputs combined, and a contribution from changes in the capital-labor ratio, which represents change in the relative intensity of use of the two factors, including the effects of substitution of capital for labor.

The difference between the multifactor measures based on gross product originating and the sectoral output measures is due to the inclusion of intermediates in both the numerator and denominator of the new sectoral measure.[6] For manufacturing measures based on gross product originating, output is, in effect, calculated by subtracting real intermediate input (materials used in the production process and purchased services) from the real value of production (output). The denominator for these measures, consisting of capital and labor inputs, also excludes intermediates. Because neither exclusion is made for the new sectoral measures, the difference between the two productivity measures can be said to derive from the fact that, in the gross-product-originating measures, the same quantity—intermediates—is subtracted from both numerator and denominator. Because of this, change over time in sectoral output-based measures is smaller in absolute terms, the relationship depending on the share of intermediates in sectoral output. Which of the multifactor estimates should be used depends on the subject being examined, as each measures something different. For some purposes, it is preferable to study the relationships between output and specific inputs rather than the summary multifactor ratios, and BLS therefore makes available the component series used to construct both the gross-product-originating and the sectoral multifactor measures.

Measurement framework and data

As with the major sector measures that include only labor and capital inputs, productivity growth in this study is defined as the difference between output growth and the growth of a composite of inputs, in this case a weighted combination of capital, labor, energy, materials, and business services. Growth in the input composite is calculated as a weighted average of changes in individual inputs, where the weights are based on current factor shares. The general framework underlying the new measures draws on the microeconomic theory of the firm and the notion of a production function to support the use of output elasticities for input factor weights.[7] The weights used for input aggregation are approximated with factor cost shares which sum to 1 in each period. This multifactor productivity measurement work also draws on recent developments in index number theory,[8] which show that Tornqvist weighting—that is, aggregation using weights based on current costs—minimizes restrictive assumptions about the structure of production.

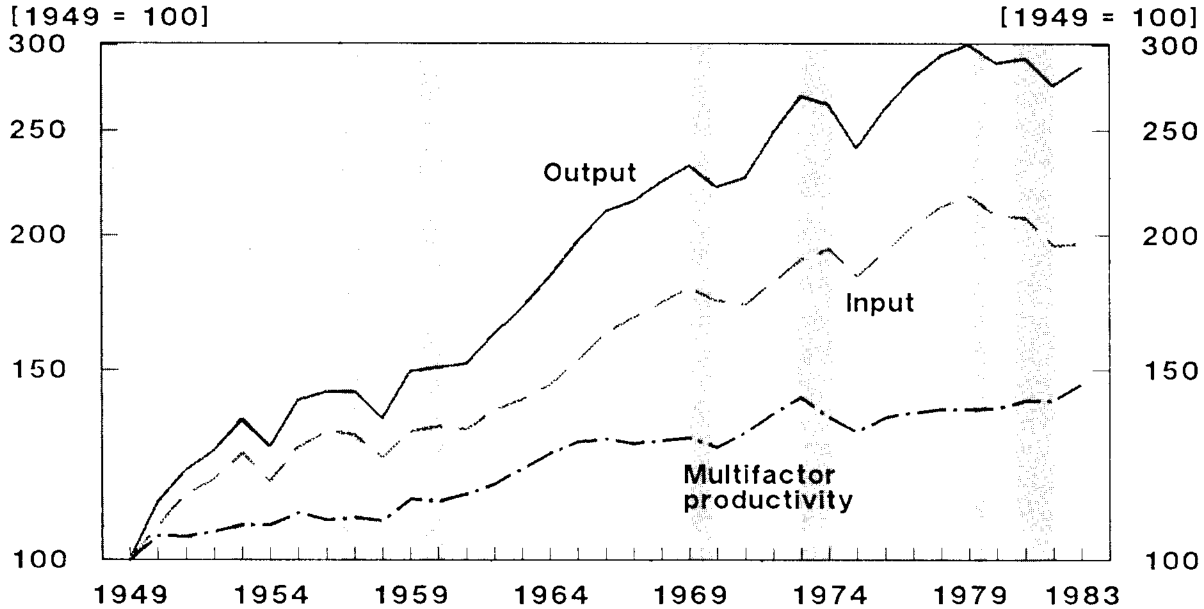
The new sectoral measures are based on indexes of real quantity and cost measures of sectoral output and capital, labor, energy, materials, and service inputs. Measures of capital and labor for the new 2-digit Standard Industrial Classification manufacturing measures employ the same general data sources and procedures used for major sector labor productivity and multifactor productivity measures. As these sources have been discussed previously,[9] they are reviewed only briefly here.

Labor is measured as the paid hours of all persons engaged in a sector. The sources for employment and average weekly hours data are the BLS Current Employment Statistics survey and the Current Population Survey. The BLS currently is developing measures of hours at work for incorporation into future measures.[10]

Capital input is defined as the flow of services from physical assets, which include equipment, structures, inventories, and land. Service flows are assumed proportional to stocks. For depreciable assets (equipment and structures), stocks are measured using the perpetual inventory method. The BLS method relates the services of older assets to those of new ones by assuming that efficiency of assets is a function of age, such that efficiency declines gradually early in an asset's life and more quickly later on.

Stocks of assets for 2-digit industries, as for the aggregate sectors, are combined using weights based on implicit rental price estimates—that is, estimates of the prices that various types of capital would bring on a rental market. The capital rental price formula consists essentially of the rate of return on assets plus the rate of depreciation minus capital gains, all in nominal terms.[11] Capital gains, usually computed as the annual change in the deflator for new investment from the National Accounts, was calculated as a 3-year moving average because of the volatility of that series. Because the rental price formula is derived under an assumption of perfect foresight, the use of a 3-year, moving-average estimate for capital gains is consistent with the view that producers anticipate price movements generally rather than annually.[12]

Chart 1. Indexes of output, input, and multifactor productivity, manufacturing industries, 1949–83



NOTE: Shaded areas indicate recessionary periods, as designated by the National Bureau of Economic Research.

Table 1. Selected measures of output and multifactor productivity change and the post-1973 productivity slowdown in total manufacturing, 1949–83
[Percent change at compound annual rate]

Periods		Output			Multifactor productivity		
		Change		Slowdown (2) – (1)	Change		Slowdown (5) – (4)
Early	Late	Early (1)	Late (2)		Early (4)	Late (5)	
1949–73	1973–83	4.2	0.6	-3.6	1.5	0.3	-1.2
1953–73	1973–83	3.5	0.6	-2.9	1.4	0.3	-1.1
1949–73	1973–79	4.2	1.8	-2.4	1.5	-0.4	-1.9
1953–73	1973–81	3.5	1.0	-2.5	1.4	-0.1	-1.5

"Sectoral" output is based on the deflated value of production, less that portion which is consumed in the same industry.[13] This treatment is consistent with a production function that represents the industry as if it were a single process.[14] Real production equals the deflated value of shipments and miscellaneous receipts plus inventory change.[15] Federal excise taxes are added so that production will be shown at market value.

Intrasector transactions are removed from all output and material input series used in this study, using transactions data contained in the various input-output tables for the economy prepared by the Bureau of Economic Analysis of the U.S. Department of Commerce.[16] It should be noted that the intrasector transaction for total manufacturing is greater than the sum of intrasector transactions for 2-digit industries. For each 2-digit industry, intrasector transactions are those between establishments in the same industry; for total manufacturing, the intrasector transaction consists of all shipments between domestic manufacturers, regardless of industry.

Energy input is contructed using data on price and quantity from the Commerce Department's Census of Manufactures and Annual Survey of Manufactures, together with appropriate BLS Producer Price Indexes used as price deflators. Data on the quantity and cost of fuels purchased for use as heat or power are collected in the Census of Manufactures and the Annual Survey of Manufacturing.[17] Data for the separate energy categories are then Tornqvist-aggregated.[18]

Nonenergy materials input represents all commodity inputs exclusive of fuel (electricity, fuel oil, coal, natural gas, and other miscellaneous fuels) but inclusive of fuel-type inputs used as raw materials in a manufacturing process, such as crude petroleum used by the refining industry. In addition to raw and processed materials, these measures include all incidental commodity inputs such as office supplies, vehicle parts bought for maintenance, and small tools, if these are allowable as current costs for computing business taxes.[19]

Directly collected data on *purchased business services* are relatively scant, and for that reason they have heretofore been ignored in studies of this type.[20] There is ample evidence of an increased use of purchased business services by industries over the postwar period, and there are two important aspects of this development to consider. The first, of course, is that a sizable and growing input should not be ignored in productivity measurement if aggregate inputs are not to be underestimated and productivity mismeasured. The other is the possibility of substitution between capital or labor and services purchased from outside. Examples of the latter are the substitution of leased equipment for owned capital and purchases of accounting, legal, and technical services in place of those services formerly provided by a firm's own employees.[21]

Results

The dramatic slowdown in productivity growth in the early 1970's found in previous studies by the BLS and other researchers[22] is also apparent in the 2-digit manufacturing industry indexes of multifactor productivity. (See chart 1.) Because one purpose of developing these new measures is to provide data on the slowdown for manufacturing industries, the following analysis examines the pre-1973 and post-1973 periods in detail.

Subperiod analysis. The choice of the starting date of the pre-1973 period and the closing date of the post-1973 period has an important effect on an analysis of the slowdown. One alternative is to choose the periods 1949–73 and 1973–83, so as to cover all years in the existing data set. Another is to choose years that are business cycle peaks, such as 1953, 1979, or 1981, for the initial and terminal years of the two

Table 2. Multifactor productivity growth and the post-1973 slowdown in manufacturing industries, selected periods, 1949–83
[Percent change at compound annual rate]

Industry	Change			Slowdown (3) – (2)
	1949–83 (1)	1949–73 (2)	1973–83 (3)	
Total manufacturing	1.1	1.5	0.3	-1.2
Food and kindred products	0.7	0.8	0.5	-0.3
Tobacco manufactures	0.2	1.0	-1.7	-2.7
Textile mill products	1.7	1.7	1.7	0.0
Apparel and related products	1.0	1.0	0.9	-0.1
Lumber and wood products	1.3	2.0	-0.5	-2.5
Furniture and fixtures	0.7	0.8	0.4	-0.4
Paper and allied products	0.9	1.2	0.2	-1.0
Printing and publishing	0.3	0.6	-0.3	-0.9
Chemicals and allied products	1.5	2.3	-0.4	-2.7
Petroleum products	0.4	0.9	-0.9	-1.8
Rubber and miscellaneous plastics	0.7	1.0	0.1	-0.9
Leather and leather products	0.4	0.5	0.2	-0.3
Stone, clay, and glass products	0.5	1.0	-0.7	-1.7
Primary metal industries	-0.5	0.2	-2.1	-2.3
Fabricated metal products	0.4	0.5	0.0	-0.5
Machinery, except electrical	1.2	1.1	1.4	0.3
Electrical and electronic equipment	1.9	1.9	2.0	0.1
Transportation equipment	1.0	1.3	0.3	-1.0
Instruments and related products	1.5	1.9	0.7	-1.2
Miscellaneous manufacturing	0.6	1.3	-1.0	-2.3

Table 3. Changes in output and input quantities and in output/input ratios in total manufacturing, selected periods, 1949–83
[Percent change at compound annual rate]

Period	Output (Q)	Aggregate input	Capital (K)	Labor (L)	Energy (E)	Materials (M)	Services (S)
1949–83	3.1	2.0	3.8	0.8	3.3	2.2	4.6
1949–73	4.2	2.7	3.9	1.5	5.1	3.1	5.4
1973–83	0.6	0.3	3.6	−1.0	−0.8	0.2	2.6
		KLEMS multifactor productivity	Output/input ratios				
			Q/K	Q/L	Q/E	Q/M	Q/S
1949–83		1.1	−0.6	2.4	−0.2	0.9	−1.4
1949–73		1.5	0.3	2.7	−0.8	1.1	−1.2
1973–83		0.3	−2.9	1.6	1.4	0.4	−1.9

periods to minimize the cyclical impact on the productivity movements.[23]

Table 1 shows the effects on the computed slowdown in total manufacturing of adopting different initial and terminal dates for the pre-1973 ("early") and post-1973 ("late") periods. If the terminal years 1949 and 1983 are used—that is, if the entire data set is used—the slowdown in output growth is 3.6 percent annually and in multifactor productivity, about 1.2 percent. If the cyclical peak years of 1953 and 1981 are chosen, the slowdown in output is about 1 percentage point less and the slowdown in multifactor productivity about a third of a percentage point greater. The following analysis is based on data for the whole period 1949–83 for two reasons: First, the choice of initial and terminal dates for the "early" and "late" periods does not change the magnitude of the productivity slowdown greatly; and second, using officially designated peak years is somewhat arbitrary for industry analysis because peak years for many industries do not coincide with the peaks for the whole economy.[24]

The differential growth of inputs. Multifactor productivity growth varies substantially across industries, both in terms of total postwar growth and the degree of slowdown after 1973. (See table 2.) At the high end of the growth spectrum for the period 1949–83 are electrical and electronic equipment (averaging 1.9 percent per year), textile mill products (1.7 percent), chemicals and allied products (1.5 percent), and instruments and related products (1.5 percent). Primary metal industries had an average multifactor productivity decline of half a percent per year and tobacco manufactures, an average annual rise of 0.2 percent.

Although there is substantial variation, most manufacturing industries have exhibited some degree of slowdown in multifactor productivity growth since 1973. Although other BLS productivity series for which more recent data are available show some recovery in the last few years, multifactor productivity growth rates by industry and for total manufacturing demonstrate a pervasive decline after 1973. In total manufacturing, the growth rate dropped from 1.5 to 0.3 percent per year (table 2); among the 20 industries, growth slowed by some degree in all but three—textile mill products, machinery except electrical, and electrical and electronic equipment. In apparel and related products, the decline was insignificant. In all of the other industries, growth slowed substantially, by at least 0.3 percentage points.

Trends in output and inputs have systematic relationships to the differences in multifactor productivity growth rates among industries. For example, industries with the fastest growing productivity also tend to show rapidly rising output levels (an exception is textile mill products); those with slow productivity growth (primary metals, tobacco manufactures, and leather products) also showed the slowest output growth rates. This association is borne out by formal testing. The rank correlation coefficient for the growth rates of mul-

Table 4. Changes in output and input quantities and in multifactor productivity, 20 manufacturing industries, 1949–83
[Percent change at compound annual rate]

Industry	Output	Aggregate input	Capital	Labor	Energy	Materials	Services	KLEMS multifactor productivity
Total manufacturing	3.1	2.0	3.8	0.8	3.3	2.2	4.6	1.1
Food and kindred products	2.4	1.7	1.8	−0.5	2.6	2.1	3.6	0.7
Tobacco manufactures	0.7	0.6	1.5	−1.4	4.0	−0.4	1.9	0.2
Textile mill products	3.0	1.3	0.9	−1.2	1.7	3.5	3.3	1.7
Apparel and related products	2.2	1.2	3.4	0.0	3.6	1.8	2.3	1.0
Lumber and wood products	2.5	1.2	2.9	−0.4	3.0	2.2	2.5	1.3
Furniture and fixtures	3.1	2.3	3.4	1.1	3.6	2.9	4.4	0.7
Paper and allied products	3.8	2.9	3.9	1.1	3.3	3.8	5.3	0.9
Printing and publishing	3.4	3.1	4.0	1.6	5.1	4.4	5.0	0.3
Chemicals and allied products	5.0	3.5	4.1	1.5	3.9	4.5	5.7	1.5
Petroleum products	2.7	2.3	3.4	−0.2	2.3	2.6	3.9	0.4
Rubber and miscellaneous plastics	5.1	4.3	5.3	2.9	5.6	4.9	5.6	0.7
Leather and leather products	−0.2	−0.6	0.9	−1.8	0.6	0.2	1.1	0.4
Stone, clay, and glass	2.4	1.9	3.4	0.4	1.5	2.9	3.8	0.5
Primary metal industries	0.4	0.9	3.2	−0.6	1.0	1.2	2.8	−0.5
Fabricated metal products	2.6	2.2	4.1	1.2	4.0	2.4	4.5	0.4
Machinery, except electrical	4.2	3.0	4.8	1.6	3.3	3.7	5.8	1.2
Electrical and electronic equipment	5.8	3.9	6.6	2.6	5.4	4.1	6.4	1.9
Transportation equipment	3.4	2.4	4.5	1.2	3.4	2.7	5.3	1.0
Instruments and related products	6.2	4.6	5.6	2.8	6.2	6.1	7.4	1.5
Miscellaneous manufacturing	2.4	1.8	3.4	0.0	1.5	2.6	4.8	0.6

tifactor productivity and of output for the period 1949–83 is positive and significant.[25]

The growth rates of the various inputs for total manufacturing provide important insights into several postwar developments. (See table 3.) First, laborsaving changes were made throughout the period; the annual growth rates of labor input in both the early and late periods were 1.2 to 1.4 percentage points lower than the growth rates of all inputs taken together. Second, the use of fuels is sensitive to price changes; in the early period, when fuel prices were rising relatively more slowly than other input prices, their use relative to other inputs rose substantially; later, economies in the use of fuels were instituted in response to dramatic fuel price increases.[26] Third, there was no significant reduction in the use of capital services, which rose 3.9 percent per year in the early period compared with 3.6 percent over the 1973–83 decade. Finally, the growth in the use of business services has been rapid throughout the postwar years; this is an especially significant finding in view of the possibility that purchased services are being substituted for primary inputs, that is, labor and capital employed directly.

Similar patterns emerge among industries, as table 4 indicates. First, the greatest economies have been evident in labor—in every industry, the growth rate of labor input has been slower than that of any other input. Second, for all industries, the growth rate of business services has been faster than that of all inputs together, and in 12 of the 20 industries, services are the fastest growing input. Third, for most industries (19 of 20), production is increasingly capital intensive, by the criterion of growth relative to that of all inputs together. These shifts in resource use, and the possible connection with labor use and productivity, will be discussed further in the next section.

The factor intensity connection

As described previously, the basic multifactor equation relating output and factor inputs can be reorganized to relate labor productivity to multifactor productivity and changes in the ratios of each nonlabor input to labor.[27] Using this decomposition, change in labor productivity is seen to have two fundamental sources: (1) the growth of the multifactor productivity residual, which includes the effects of advances in production technology and efficiency and the growth of worker and managerial skills, among other things, and (2) changing intensity of labor use, which includes the effects of relative input price change.[28] The intensity terms are defined as changes in nonlabor input/labor ratios, multiplied by the shares (in the value of production) paid for each nonlabor factor.

The decomposition of labor productivity change into multifactor productivity growth and changes in labor intensity is shown in table 5 for total manufacturing and for constituent industries. For total manufacturing, labor productivity grew at more than double the rate of multifactor productivity (2.4 percent versus 1.1 percent per year). Thus, over half—about 55 percent—of the growth of labor productivity is attributable to changes in nonlabor/labor ratios which reflect, most notably, substitution of nonlabor factors for labor.[29]

The use of labor has in fact declined relative to each of the other four inputs over the entire study period, as evidenced by the positive contribution estimates for each nonlabor factor. It should be noted especially that the substitution effects for capital and business services are large—over the postwar period, about 0.8 of the 1.3 annual percentage-point difference between labor and multifactor productivity growth can be accounted for by the rapid growth of capital and business service inputs relative to labor. Thus, about 65 percent of the difference between labor and multifactor productivity growth is accounted for by two inputs, which averaged only 27 percent of costs through the postwar period (table 6).

Conversely, relatively little of the difference for manufacturing as a whole is accounted for by materials and fuels inputs: The remaining 35 percent of the difference between multifactor and labor productivity growth is accounted for by these two inputs, which averaged about 28 percent of all costs.

The relative strength of multifactor productivity increases and nonlabor-for-labor substitution as forces underlying labor productivity growth varies somewhat from industry to industry, but for about half of the 2-digit industries, multifactor productivity accounts for 35 to 45 percent of the postwar labor productivity growth rate. For two industries—tobacco manufactures and primary metal industries—labor productivity growth was achieved mainly by intensifying the use of other, nonlabor inputs. At the other extreme, in electrical and electronic equipment, 60 percent of labor productivity growth was accounted for by multifactor productivity change.

The evidence in table 5 concerning the influence of change in factor intensity on labor productivity can be summarized by noting that over the postwar period, in all industries except one—electrical and electronic equipment—shifts between nonlabor and labor inputs are a stronger force in labor productivity growth than is multifactor productivity. In electrical and electronic equipment, a 3.1-percent-per-year increase in labor productivity resulted from 1.9-percent annual growth in multifactor productivity and a contribution from shifts between nonlabor and labor inputs totaling 1.2 percentage points. For all other industries, the summed contribution of substitution effects exceeded that of multifactor productivity growth, in some cases by a wide margin: In six cases, the contribution of shifts out of labor was at least triple the contribution of multifactor productivity growth; in an additional two, the shift contribution was at least double that of multifactor productivity.

Substitution effects and the labor productivity slowdown. For total manufacturing, labor productivity growth

Table 5. Attribution of labor productivity growth to multifactor productivity growth and substitution effects, total manufacturing and 20 manufacturing industries, 1949–83

[Percent changes at compound annual rate]

Period	Output per hour	Contributions of— KLEMS multifactor productivity	Substitution effects: Sum of effects	Capital/labor	Energy/labor	Materials/labor	Services/labor
	Total manufacturing						
1949–83	2.36	1.11	1.25	0.54	0.05	0.36	0.29
1949–73 (a)	2.67	1.46	1.21	0.47	0.07	0.38	0.27
1973–83 (b)	1.62	0.28	1.34	0.69	0.01	0.30	0.33
Change (b-a)	−1.05	−1.18	0.13	0.22	−0.06	−0.08	0.06
	Food and kindred products (SIC 20)						
1949–83	2.86	0.69	2.17	0.27	0.03	1.66	0.18
1949–73 (a)	2.75	0.78	1.97	0.25	0.04	1.51	0.15
1973–83 (b)	3.10	0.47	2.63	0.32	0.01	2.03	0.24
Change (b-a)	0.35	−0.31	0.66	0.07	−0.03	0.52	0.09
	Tobacco manufactures (SIC 21)						
1949–83	2.14	0.18	1.96	1.49	0.02	0.29	0.16
1949–73 (a)	2.60	0.98	1.62	1.14	0.01	0.28	0.18
1973–83 (b)	1.05	−1.73	2.78	2.36	0.03	0.31	0.12
Change (b-a)	−1.55	−2.71	1.16	1.22	0.02	0.03	−0.06
	Textile mill products (SIC 22)						
1949–83	4.23	1.71	2.52	0.24	0.07	1.97	0.19
1949–73 (a)	4.24	1.73	2.51	0.21	0.07	2.01	0.17
1973–83 (b)	4.21	1.67	2.54	0.31	0.06	1.88	0.23
Change (b-a)	−0.03	−0.06	0.03	0.10	−0.01	−0.13	0.00
	Apparel and other textile products (SIC 23)						
1949–83	2.23	1.02	1.21	0.21	0.02	0.85	0.12
1949–73 (a)	1.91	1.05	0.86	0.20	0.02	0.52	0.11
1973–83 (b)	2.99	0.94	2.05	0.24	0.02	1.62	0.15
Change (b-a)	1.08	−0.11	1.19	0.04	0.00	1.10	0.04
	Lumber and wood products (SIC 24)						
1949–83	2.92	1.26	1.66	0.56	0.07	0.87	0.13
1949–73 (a)	3.68	2.00	1.68	0.53	0.11	0.89	0.11
1973–83 (b)	1.11	−0.48	1.59	0.63	−0.04	0.84	0.15
Change (b-a)	−2.57	−2.48	−0.09	0.10	−0.15	−0.05	0.04
	Furniture and fixtures (SIC 25)						
1949–83	1.98	0.72	1.26	0.16	0.02	0.85	0.21
1949–73 (a)	2.10	0.84	1.26	0.14	0.03	0.92	0.17
1973–83 (b)	1.69	0.43	1.26	0.22	0.00	0.69	0.33
Change (b-a)	−0.41	−0.41	0.00	0.08	−0.03	−0.23	0.16
	Paper and allied products (SIC 26)						
1949–83	2.67	0.90	1.77	0.46	0.88	1.02	0.19
1949–73 (a)	2.84	1.20	1.64	0.35	0.10	0.96	0.20
1973–83 (b)	2.26	0.18	2.08	0.71	0.03	1.15	0.18
Change (b-a)	−0.58	−1.02	0.44	0.36	−0.07	0.19	−0.02
	Printing and publishing (SIC 27)						
1949–83	1.80	0.31	1.49	0.30	0.03	0.79	0.37
1949–73 (a)	2.33	0.57	1.76	0.36	0.04	0.92	0.42
1973–83 (b)	0.55	−0.32	0.87	0.17	−0.01	0.46	0.25
Change (b-a)	−1.78	−0.89	−0.89	−0.19	−0.05	−0.46	−0.17
	Chemicals and allied products (SIC 28)						
1949–83	3.45	1.51	1.94	0.55	0.08	0.88	0.39
1949–73 (a)	4.60	2.33	2.27	0.47	0.17	1.11	0.44
1973–83 (b)	0.75	−0.43	1.18	0.74	−0.13	0.32	0.25
Change (b-a)	−3.85	−2.76	−1.09	0.27	−0.30	−0.79	−0.19

Period	Output per hour	Contributions of— KLEMS multifactor productivity	Substitution effects: Sum of effects	Capital/labor	Energy/labor	Materials/labor	Services/labor
	Petroleum and coal products (SIC 29)						
1949–83	2.29	0.39	2.53	0.39	0.04	1.90	0.18
1949–73 (a)	4.74	0.94	3.80	0.46	0.07	3.06	0.16
1973–83 (b)	−1.32	−0.93	−0.39	0.23	−0.02	−0.83	0.23
Change (b-a)	−6.06	−1.87	−4.19	−0.23	−0.09	−3.89	0.07
	Rubber and miscellaneous plastics products (SIC 30)						
1949–83	2.10	0.72	1.38	0.29	0.05	0.90	0.12
1949–73 (a)	2.73	0.99	1.74	0.31	0.04	1.22	0.14
1973–83 (b)	0.59	0.07	0.52	0.24	0.07	0.14	0.07
Change (b-a)	−2.14	−0.92	−1.22	−0.07	0.03	−1.08	−0.07
	Leather and leather products (SIC 31)						
1949–83	1.65	0.40	1.25	0.22	0.02	0.78	0.22
1949–73 (a)	1.79	0.47	1.32	0.17	0.03	0.98	0.14
1973–83 (b)	1.31	0.22	1.09	0.35	0.01	0.32	0.41
Change (b-a)	−0.48	−0.25	−0.23	0.18	−0.02	−0.66	0.27
	Stone, clay, and glass products (SIC 32)						
1949–83	1.99	0.51	1.48	0.43	0.06	0.79	0.20
1949–73 (a)	2.62	1.00	1.62	0.31	0.09	1.01	0.19
1973–83 (b)	0.50	−0.66	1.16	0.70	−0.03	0.29	0.21
Change (b-a)	−2.12	−1.66	−0.46	0.39	−0.12	−0.72	0.02
	Primary metal industries (SIC 33)						
1949–83	1.06	−0.46	1.52	0.57	0.07	0.74	0.15
1949–73 (a)	1.80	0.24	1.56	0.50	0.08	0.81	0.16
1973–83 (b)	−0.69	−2.12	1.43	0.74	0.04	0.56	0.13
Change (b-a)	−2.49	−2.36	−0.13	0.24	−0.04	−0.25	−0.03
	Fabricated metal products (SIC 34)						
1949–83	1.42	0.36	1.06	0.26	0.03	0.60	0.16
1949–73 (a)	1.64	0.52	1.12	0.18	0.04	0.76	0.14
1973–83 (b)	0.88	−0.02	0.90	0.45	0.02	0.22	0.21
Change (b-a)	−0.76	−0.54	−0.22	0.27	−0.02	−0.54	0.07
	Machinery, except electrical (SIC 35)						
1949–83	2.57	1.16	1.41	0.39	0.02	0.77	0.20
1949–73 (a)	2.36	1.07	1.29	0.23	0.02	0.83	0.19
1973–83 (b)	3.07	1.39	1.68	0.79	0.01	0.65	0.20
Change (b-a)	0.71	0.32	0.39	0.56	−0.01	−0.18	0.01
	Electrical and electronic equipment (SIC 36)						
1949–83	3.11	1.90	1.21	0.41	0.02	0.50	0.25
1949–73 (a)	2.92	1.88	1.04	0.34	0.03	0.43	0.22
1973–83 (b)	3.56	1.97	1.59	0.57	0.01	0.66	0.31
Change (b-a)	0.64	0.09	0.55	0.23	−0.02	0.23	0.09
	Transportation equipment (SIC 37)						
1949–83	2.18	1.03	1.15	0.35	0.01	0.62	0.17
1949–73 (a)	2.89	1.33	1.56	0.47	0.02	0.88	0.17
1973–83 (b)	0.50	0.30	0.20	0.07	0.00	−0.01	0.17
Change (b-a)	−2.39	−1.03	−1.36	−0.40	−0.02	−0.89	0.00
	Instruments and related products (SIC 38)						
1949–83	3.32	1.52	1.80	0.39	0.02	1.08	0.28
1949–73 (a)	3.74	1.87	1.87	0.39	0.03	1.13	0.27
1973–83 (b)	2.32	0.68	1.64	0.39	0.00	0.93	0.30
Change (b-a)	−1.42	−1.19	−0.23	0.00	−0.03	−0.20	0.03

Table 5—Continued. Attribution of labor productivity growth to multifactor productivity growth and substitution effects, total manufacturing and 20 manufacturing industries, 1949–83

Period	Output per hour	Contributions of— KLEMS multifactor productivity	Substitution effects: Sum of effects	Capital/ labor	Energy/ labor	Materials/ labor	Services/ labor
	Miscellaneous manufacturing (SIC 39)						
1949–83	2.45	0.59	1.86	0.38	0.04	1.09	0.32
1949–73 (a)	3.40	1.25	2.15	0.37	0.06	1.31	0.37
1973–83 (b)	0.19	−0.98	1.17	0.41	−0.01	0.57	0.20
Change (b-a)	−3.21	−2.23	−0.98	0.04	−0.07	−0.74	−0.17

declined from 2.7 percent per year before 1973 to 1.6 percent after 1973 (a decrease of about 40 percent). The data for total manufacturing show at a glance that multifactor productivity and substitution components bear uneven responsibility for this slowdown. The shift from labor to nonlabor factors has proven to be a powerful source of labor productivity growth, even more powerful than multifactor productivity change, and there has been no cessation of these shifts in recent years. The tendency for production to become increasingly intensive in nonlabor factors, evident in the early postwar period, is still operating. The summed contribution of changes in nonlabor factor/labor ratios in the early years was 1.2 percentage points, and in the later period, 1.3 percentage points. Thus, the slowdown in manufacturing labor productivity must be seen as coming from the factors underlying change in multifactor productivity—that is, factors such as technological advance and changes in the characteristics of the work force, rather than a diminution of the tendency of businesses to make laborsaving changes.

The industry data largely conform to this overall judgment. First, it is notable that there are labor productivity slowdowns of some degree in 15 of the 20 industries, exceptions being food and kindred products, textile mill products, apparel and related products, machinery except electrical, and electrical and electronic equipment. In 10 of the remaining 15 industries, the contribution of substitution effects either increased after 1973 or was of less importance in the slowdown than was multifactor productivity. In only five cases (printing and publishing, petroleum refining, rubber and miscellaneous plastics, leather products, and transportation equipment) was a cessation of shift from labor to nonlabor factors as important as, or more important than, declining growth in multifactor productivity in explaining the slowdown in labor productivity. Hence, in most industries, as in total manufacturing, the post-1973 slowdown was not due mainly to a cessation of the shift from labor to nonlabor inputs.

Table 6. Factor shares[1] for total manufacturing, selected years, 1949–83

Year	Capital	Labor	Energy	Materials	Purchased services
1949–83[2]	19.3	44.8	2.4	25.5	7.8
1949	20.9	41.7	2.0	30.2	5.2
1955	21.3	44.1	1.9	26.5	6.2
1960	19.9	46.2	2.1	25.0	6.7
1965	23.2	45.3	2.0	21.8	7.6
1970	18.6	48.8	2.1	21.5	9.1
1975	17.4	43.1	3.0	27.4	9.1
1980	13.6	42.8	3.7	30.6	9.3
1983	16.2	42.8	4.4	26.2	10.4

[1] Factor cost as a percentage of the value of production.

[2] Mean of shares over all years 1949–83.

Conclusions

Underlying the new measures of multifactor productivity change is an important new set of detailed and conceptually matched time-series data permitting the analysis of numerous issues. This article has begun the task of analyzing these data, and several conclusions have been reached:

- These measures confirm that a slowdown occurred in multifactor productivity growth in total manufacturing after 1973, and show that a slowdown also occurred in most manufacturing industries.
- The slowdown was not due to a reduction in the growth rate of capital services inputs.
- The industries with the fastest growth in multifactor productivity tend to have had rapid output growth.
- The use of purchased business services rose rapidly throughout the postwar period.
- The use of fuels was sensitive to change in the price of fuels. Before 1973, fuel prices rose slowly and fuel use rose rapidly in total manufacturing. After 1973, fuel prices rose rapidly and use declined slightly.

Change in labor productivity can be decomposed into two fundamental sources: the growth in multifactor productivity and the effects of changes in the ratios of nonlabor to labor inputs:

- Over the entire period 1949–83, labor productivity growth was due mainly to changes in the ratios of nonlabor to labor inputs, for total manufacturing and for most industries. For about half of the 2-digit industries, multifactor productivity accounted for 35 to 45 percent of the labor productivity growth rate. In most others, it accounted for less than 35 percent.
- For total manufacturing, the post-1973 slowdown in labor productivity was due entirely to factors resulting in a slowdown in multifactor productivity growth, and not at all to a decrease in the contribution of increasing nonlabor/labor input ratios.
- Similarly, for most industries, the slowdown in labor productivity growth was not due primarily to a decrease in the contribution of nonlabor/labor ratios. □

—— *FOOTNOTES* ——

[1] These measures are described in *Trends in Multifactor Productivity, 1948–81*, Bulletin 2178 (Bureau of Labor Statistics, 1983). For the most recent data, see *Multifactor Productivity Measures, 1985*, USDL 86–402 (Bureau of Labor Statistics, 1986), or table 43 in the Current Labor Statistics section of the *Monthly Labor Review*.

[2] Gross product originating, taken from the National Income and Product Accounts, is the attribution of gross domestic product to industries or sectors of origin. Gross product originating in current dollars is compiled by summing income components—wages and salaries, capital consumption allowance, profits, and so forth—and therefore corresponds in concept to value added. However, it differs somewhat from value added estimates published by the Bureau of the Census, which include business services.

[3] At the industry level, a production function which is descriptive of the entire production process of that industry is generally assumed. This approaches an ideal, described by Paul A. Samuelson, "Parable and Realism in Capital Theory: The Surrogate Production Function," *Review of Economic Studies*, June 1962, pp. 193–206. In this ideal, there is a separate production function describing each process. Studies using these expanded production functions include Ernst R. Berndt and David O. Wood, "Technology, Prices, and the Derived Demand for Energy," *Review of Economics and Statistics*, August 1975, pp. 376–84; and Frank M. Gollop and Dale W. Jorgenson, " U.S. Productivity Growth by Industry 1947–73," in John W. Kendrick and Beatrice N. Vaccara, eds., *New Developments in Productivity Measurement and Analysis* (Chicago, University of Chicago Press, 1980), pp. 17–136.

[4] These measures are presented in Mark K. Sherwood, "Multifactor productivity in the steel and motor vehicles industries," *Monthly Labor Review*, August 1987, pp. 22–31.

[5] The relationship between labor productivity and multifactor productivity is derived by assuming a value added (N) production function:

$$N = f(K,L,t)$$

in which output is determined by capital (K), and labor (L) inputs using the technology available at time t. Assume that the function is differentiable and has constant returns to scale, that inputs are paid the value of their marginal products, and that technical change is "neutral" (that is, the relative marginal products of inputs are unaffected by technical change). The assumption that inputs are paid the value of their marginal products is consistent with an assumption of perfect competition. Using these assumptions, the growth rate of multifactor productivity (A) can be determined from:

$$\frac{\dot{A}}{A} = \frac{\dot{N}}{N} - s_K \frac{\dot{K}}{K} - s_L \frac{\dot{L}}{L}$$

where the notation $\dot{X}/X$ represents the growth rates of the respective variables. The weights, s_K and s_L are output elasticities with respect to inputs. Under constant returns to scale and under the assumption that inputs are paid their marginal products, these elasticities correspond to factor shares in the value of output and $s_K + s_L = 1$. An index, A, is then computed by designating the value of a base year to be 1.00 and by "chaining," that is, determining successive index values by multiplying by the growth rate of $\dot{A}/A$. The relationship between labor productivity and multifactor productivity is then given by:

$$\frac{\dot{N}}{N} - \frac{\dot{L}}{L} = \frac{\dot{A}}{A} + s_K \left(\frac{\dot{K}}{K} - \frac{\dot{L}}{L}\right)$$

That is, they differ by a weighted shift in the capital-labor ratio. This analysis is attributable to Jan Tinbergen and, independently, to Robert M. Solow. See Tinbergen, "Zur theorie der langristigen wirtschaftsentwicklung," *Weltwirtschaftliches Archiv*, Band 55:1, 1942, pp. 511–49 (English translation, "On the Theory of Trend Movements," in L.H. Klassen, L.M. Koyck, and H.J. Witteveen, eds., *Jan Tinbergen, Selected Papers* (Amsterdam, North Holland, 1959)); and Solow, "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics*, vol. 39, no. 3, 1957, pp. 312–20.

[6] The relationship between value added and gross output productivity measures is demonstrated in Martin N. Baily, "Productivity Growth and Materials Use in U.S. Manufacturing," *Quarterly Journal of Economics*, February 1986, pp. 185–95.

[7] The sectoral output (Y) production function is:

$$Y = f(K,L,E,M,S,t)$$

where intermediate inputs of energy (E), materials (M), and purchased business services (S) are included. Using steps paralleling those in the value added model, a sectoral output multifactor productivity index (B) can be determined from:

$$\frac{\dot{B}}{B} = \frac{\dot{Y}}{Y} - s_K \frac{\dot{K}}{K} - s_L \frac{\dot{L}}{L} - s_E \frac{\dot{E}}{E} - s_M \frac{\dot{M}}{M} - s_S \frac{\dot{S}}{S}$$

The shares here are shares in the value of sectoral ouput. The derivation is slightly less restrictive than that of the value added multifactor productivity measure, A, in that functional separability of primary and intermediate inputs is not assumed.

[8] The Tornqvist index is a discrete approximation to a Divisia index in which growth rates are defined as the difference in natural logarithms of successive observations and weights are equal to the mean of the factor shares in the corresponding pair of years. W. Erwin Diewert, "Exact and Superlative Index Numbers," *Journal of Econometrics*, vol. 4, no. 4, 1976, pp. 115–45, shows that the Tornqvist index is consistent with a translog specification of the production function, which in turn is a second-order approximation to any production function, as shown in Laurits R. Christensen, Dale W. Jorgenson, and Lawrence J. Lau, "Transcendental Logarithmic Production Frontiers," *Review of Economics and Statistics*, February 1973, pp. 28–45. However, the maintained assumptions of separability and neutral technical change are implicit in the measure as shown by Charles R. Hulten, "Divisia Index Numbers," *Econometrica*, vol. 41, no. 6, 1973, pp. 1017–25.

[9] These procedures are described in appendices C and D of *Trends in Multifactor Productivity, 1948–81*.

[10] The hours paid data originate in the highly reliable BLS Current Employment Statistics survey. However, they do not reflect hours spent on the job. The difference, leave time paid by employers, is not an input into the production process. The ratio of hours worked to hours paid has gradually fallen over the postwar period (according to special BLS surveys) which implies a slight downward bias in productivity growth estimates. BLS has collected hours worked data since 1981 and is examining these and other available data on hours worked for manufacturing industries.

Labor is the only input category which is not adjusted for composition change. In order to maintain consistency with labor measures published previously by BLS, and because of limitations in the data available for adjustment of labor composition for industries at the 2-digit Standard Industrial Classification level, the labor input series used here are direct aggregates of hours paid, that is, the simple sum of hours, without regard to skill levels. Because of a significant shift toward use of more highly skilled labor throughout the U.S. economy, change in the composition of the labor force has historically been an important source of productivity growth. For the nonfarm business sector as a whole, BLS has estimated that changes in labor composition accounted for about one-tenth of multifactor productivity growth in the postwar period. See William H. Waldorf, Kent Kunze, Larry S. Rosenblum, and Michael B. Tannen, "New Measures of the Contribution of Education and Experience to U.S. Productivity Growth," paper presented at the annual meetings of the American Economic Association, New Orleans, December 1987.

[11] The implicit rental price of capital, c, is derived by assuming that the price of an asset will be recovered by the discounted stream of services (implicit rents) the asset will provide. It corresponds to the one-period user cost of capital:

$$c = T(pr + p\delta - \Delta p)$$

where p is the price of new capital goods, r is the discount rate, δ is the rate of economic depreciation, Δp is the rate of price change for new goods, and T is a factor reflecting tax incentives. Capital measurement methods are reviewed in detail in *Trends in Multifactor Productivity, 1948–81*, appendix C.

[12] The use of a 3-year moving average for the capital gains term is explained in Michael J. Harper, Ernst R. Berndt, and David O. Wood, "Rates of Return and Capital Aggregation Using Alternative Rental Prices," BLS working paper (1987, unpublished).

[13] Expanded discussions of the procedures used to measure sectoral output and intermediate inputs may be found in William Gullickson and Michael J. Harper, "Multifactor Productivity Measurement for Two-Digit Manufacturing Industries," paper presented at the meetings of the Western Economic Association, in San Francisco, CA, July 1986. The multifactor productivity measures presented in that paper were preliminary and are revised in this article.

[14] In this study, the material inputs of an industry consist only of materials purchased from suppliers outside that industry; transactions between establishments in the same industry (intrasector transactions) are excluded from intermediates and from sectoral output. This follows recommendations presented by Frank M. Gollop, "Growth Accounting in an Open Economy," Boston College Working Papers in Economics (Boston, 1981); and "Accounting for Intermediate Input: The Link Between Sectoral and Aggregate Measures of Productivity Growth," in National Research Council, *Measurement and Interpretation of Productivity* (Washington, National Academy of Sciences, 1979), pp. 318–33. Econometric evidence that the exclusion of intraindustry sales is important is presented in 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.

[15] Receipts, value of shipments, inventory change, and cost of materials data (among other data) are published by the U.S. Bureau of the Census for about 400 4-digit establishment groups in manufacturing. These data are tabulated and deflated by the Bureau of Economic Analysis (BEA) of the U.S. Department of Commerce for use in compiling the National Income and Product Accounts. BEA performs this work under the guidance of the Real Product Committee, whose membership includes BLS, BEA, the Federal Reserve Board, the Bureau of the Census, and the Office of Management and Budget. The Census Bureau also publishes annual values of shipments of 5-digit product classes, which allows the BEA to deflate these data at that level before aggregating. The BLS Producer Price Indexes are available at the same level of detail, supplemented in some cases by 5-digit prices estimated by BEA. Four-digit industry real output is aggregated by BEA from 5-digit indexes. The BLS then Tornqvist-aggregates from the 4-digit to the 2-digit level.

One substantial complication to time-series analysis is the periodic revision of the Standard Industrial Classification (SIC). Large revisions took place in 1957 and 1972, both of which caused some establishments to be reclassified to different 2-digit industries. In most cases, the effects of these revisions were trivial, but in a few cases adjustments had to be made to avoid large, spurious jumps in time series.

[16] Input-output tables are presently available for the years 1947, 1958, 1963, and for every year between 1967 and 1980. BLS modifies the published tables for mutual consistency and to reflect establishment output concepts; for years lacking published tables, estimates are obtained by interpolation using annual control totals for gross output, final demand, and value added. Published input-output tables incorporate the 4-digit census materials-consumed data directly and therefore reflect the establishment coding implicit in the census data. The portion of the value of production for each sector which is consumed by the same sector is estimated from the input-output tables. For this purpose, imported goods of all types included in intrasector consumption of a given industry are estimated and removed. The remainder, domestic consumption of materials produced by the same domestic industry, is then divided by total gross output of the industry, as given in the input-output tables. The resulting ratio is multiplied by the census value of production for the industry, as determined in the Census of Manufactures or the Annual Survey of Manufactures, to estimate intrasectoral sales. The result is then deflated at the 2-digit level and output net of intrasectoral transactions computed.

[17] These figures are available for five types of fuels (electricity, coal, fuel oil, natural gas, and miscellaneous fuels) annually for 1973–81, and for several years before 1973: 1947, 1954, 1958, 1962, 1967, and 1971. Quantity is reported in physical units (for example, tons of coal) and cost, in dollars. Quantities were interpolated between census years and extrapolated after 1981 using Producer Price Indexes and annual estimates of the total cost of purchased fuels published in the Annual Survey of Manufactures.

[18] Cost share weighting is particularly important for energy. While it is straightforward to aggregate energy in terms of BTU equivalents, Jack Alterman, *A Historical Perspective on Changes in U.S. Energy-Output Ratios*, Bulletin EA-3997 (Palo Also, CA, Electric Power Research Institute, 1985) has demonstrated a pronounced historical shift toward fuels with a higher price per BTU, such as electricity, and away from less refined fuels, such as coal. Thus, BTU weighting tends to understate substantially the growth rate of the quantity of energy and to overstate the growth rate of its price.

[19] Measures of costs of materials, based on Census of Manufactures and Annual Survey of Manufactures series, are deflated by BEA using materials composite prices. BLS makes substantial adjustments to the BEA data to avoid using fixed weights for aggregation of quantities.

[20] Services consist of the following nine types: communications; finance and insurance; real estate rental; hotel services; repair services; business services, including equipment rental, engineering and technical services, and advertising; vehicle repair; medical and educational services; and puchases from government enterprises. The BLS estimates these services from published input-output tables. The general approach to these estimates is to take service shares in the value of production from annual input-output tables at the greatest possible level of detail; to obtain service costs by multiplying these shares by the value of production as given in the Census of Manufactures or the Annual Survey of Manufactures; and to deflate these current cost estimates. It should be noted that there has been one important survey of service inputs to manufacturing industries, done in conjunction with the 1977 Census of Manufactures. This is incorporated into the input-output table for that year. Prices for many service inputs are available from the BLS price program, from the National Income and Product Accounts, or from private sources. For some services, such as the business service items in Standard Industrial Classification group 73, prices are unavailable. In these cases, prices are estimated as composites of prices of the inputs to those sectors shown in input-output tables.

[21] The measurement of inputs and outputs may not be exact in some cases. While the methods described were chosen deliberately to capture changes in the quality of inputs and outputs, these efforts may not have succeeded completely. Several input and output series are obtained by deflation, and while deflators are commonly prepared specifically to measure price change net of quality change, this effort is sometimes only partially successful. In addition, multifactor productivity measures for broad industries involve considerable aggregation of quantities and, to the extent that shifts at the detailed level are not captured by weighting procedures, a measurement bias can result. To the greatest degree possible, the measures presented here minimize the effects of these problems. For example, the output and input measures used in this article take into account composition change: Current weights are used for aggregating from the 4-digit levels in output products and for aggregating 25 capital asset types, 39 material inputs, 5 fuels, and 9 service inputs. Further, the BLS price program takes explicit account of quality change wherever possible.

[22] See, for example, *Trends in Multifactor Productivity, 1948–81*.

[23] For a discussion of cyclicality in productivity measures, see Lawrence J. Fulco, "U.S. productivity growth since 1982: the post-recession experience," *Monthly Labor Review*, December 1986, pp. 18–22. It should be noted that manufacturing demonstrates a greater reaction to the business cycle than do most other sectors of the economy. The average trough-to-peak growth in output in manufacturing in postwar recessions has been 9.3 percent, compared to 6.5 percent for the business sector as a whole. Total growth over the whole cycle is roughly equal for manufacturing and business as a whole.

The shaded areas in chart 1 represent periods of recession as determined by the National Bureau of Economic Research. These recessions follow peaks that occurred in the following quarters: 1948 IV, 1953 III, 1957 III, 1960 II, 1969 IV, 1973 IV, 1980 I, and 1981 III.

[24] Readers interested in using different initial and terminal years may write the Bureau of Labor Statistics for annual data. Measuring early and late period average growth rates in multifactor productivity for each industry according to its own peak years, then taking the arithmetic average of industry slowdown estimates gives an average industry slowdown of 0.9 percentage points per year. For comparison, the average of industry slow-

down estimates using the years 1949, 1973, and 1983 as terminal years is 1.2 percentage points.

Capital-labor multifactor productivity and output per hour series, for which data are available through 1985 and 1986, respectively, show growth for each year after 1982, the year in which the most recent business-cycle trough occurred. Thus, it is likely that extended versions of the KLEMS multifactor data will show a smaller slowdown. For a discussion of productivity cyclicality, see Fulco, "U.S. productivity growth."

[25] The value of Spearman's rank correlation coefficient is 0.62; this coefficient is significant at the 0.01 probability level.

[26] For total manufacturing, the price of energy rose at an average annual rate of only 1.5 percent during 1949–73 and at a rate of 17.8 percent during 1973–83.

[27] Just as labor productivity, multifactor productivity, and the capital-labor ratio may be related in the two-factor framework, so may labor productivity, multifactor productivity, and all nonlabor factor/labor ratios be related in the KLEMS framework used in this study:

$$\frac{\dot{Y}}{Y} - \frac{\dot{L}}{L} = \frac{\dot{B}}{B} + \Sigma S_i\left(\frac{\dot{I}_i}{I_i} - \frac{\dot{L}}{L}\right)$$

where Y is real gross output, and $i = K, L, E, M, S$.

This equation can be derived from the equation for $\dot{B}/B$ given in note 6 above. First, rearrange the equation in note 6 so that $\dot{Y}/Y$ is on the left-hand side and $\dot{B}/B$ on the right-hand side, along with all the share-weighted input growth rates, now entered with positive rather than negative signs. Then subtract $\dot{L}/L$ from both sides of the equation. Because the share weights sum to 1, apply the term $(s_K + s_L + s_E + s_M + s_S)$ to the $\dot{L}/L$ term inserted on the right-hand side. Gather terms with the same weight and derive the equation above in this note.

Many forces influence the mix of inputs in production. Factor substitution, although one of the most interesting, is only one of these. Others are (1) unmeasured composition change, such as a shift from low-skilled labor to high-skilled labor, which might reduce hours of labor input and thus change the measured nonlabor/labor input ratios without substitution; and (2) "nonneutrality" of technical change, in which technical advances are associated with the use of more or less of some input(s) regardless of relative prices. Where more than two factors are considered, ratio changes must be interpreted especially carefully, because change in individual nonlabor factor/labor ratios may result from substitution of nonlabor factors for each other.

[28] In addition to direct substitution of factors due to differences in relative price growth, price change can also operate through complementarities to affect factor proportions. The best-known example of this is the hypothesized effect of increasing energy prices in the early 1970's on capital formation. The authors have examined these effects based on econometric estimates of substitution elasticities, using a preliminary version of the data set described here. See Michael J. Harper and William Gullickson, "Cost Function Models and Accounting for Growth in U.S. Manufacturing, 1949–83," paper presented at the annual meetings of the Amerian Economic Association, New Orleans, December 1986.

[29] It is plausible to suggest that the increases in nonlabor-to-labor ratios resulted from increases in the price of labor relative to the prices of other factor inputs. Over the whole period 1949–83, the average annual rate of increase (compound rate) in the price of undifferentiated labor was 6.3 percent, while for capital, energy, materials, and purchased services, the rates of increase were 2.4, 6.0, 4.3, and 4.5 percent, respectively. See, however, the cautionary comment in note 27.

A note on communications

The *Monthly Labor Review* welcomes communications that supplement, challenge, or expand on research published in its pages. To be considered for publication, communications should be factual and analytical, not polemical in tone. Communications should be addressed to the Editor-in-Chief, *Monthly Labor Review*, Bureau of Labor Statistics, U.S. Department of Labor, Washington, DC 20212.