Problems encountered in measuring single- and multifactor productivity

Development of new data sources, better utilization of existing sources, and broader coverage are some of the ways in which BLS has improved its productivity measures; progress has been made, but inadequacies remain

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The slowdown in productivity growth since the early 1970's in many countries has stimulated and renewed interest in the causes of productivity change. The observation that there has been a slowdown has generally centered on the traditional indicator of productivity—output per unit of labor input, or labor productivity.

Labor productivity—the relationship between output and labor input—has been the most prevalent measure of productivity for a variety of reasons. First, labor is involved in all aspects of production and generally has been the most important factor in the production process. Second, labor input is the most readily measurable of the various production factors.

Labor productivity measures are useful in that they provide quantitative indicators of the amount of change in labor expended to produce real goods and services of an enterprise, industry, or economy. Changes in output per hour, however, do not measure the specific contribution of labor or any other factor of production. Instead, they reflect the joint effects of many influences which affect the use of labor, including changes in technology, capital investment, utilization of capacity, economies of scale, energy substitution, organization of production, and managerial skills, as well as changes in the characteristics and efforts of the work force.

To provide insights into some of the factors influencing labor productivity changes, other measures of productivity have been developed which include additional inputs, such as capital services and intermediate items (purchased materials, fuels, and business services). The difference in the movements of these multifactor productivity measures and the output per hour measures provides a look at the effect of the substitution of other factors on labor productivity movements. The multifactor measures themselves reflect changes in the use of many factors of production per unit of output over time.

The problems in developing multifactor productivity measures are much more severe than those present in deriving the traditional single-factor productivity measures. All the difficulties of defining and measuring output and labor input in the labor productivity measures are present in the development of the multifactor measures. But the additional problems of defining and quantifying the other inputs, such as capital, energy, and other intermediate inputs, are vastly more complex. This article discusses some of the problems the Bureau of Labor Statistics has encountered in developing productivity measures and explains the approaches taken to solve them.

Derivation of output

The output indexes for the measures of labor and multifactor productivity for the private business economy and its major sectors are derived from data on real gross product published in the National Income and Product Accounts (hereafter, national accounts) by the Bureau of Economic

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Analysis, U. S. Department of Commerce. Output measures for the detailed industries at the SIC (Standard Industrial Classification) two-, three-, and four-digit levels are prepared from basic data developed by various public and private agencies, using the greatest level of detail available.

Several major issues must be examined in the derivation of the output measures. These involve (1) selecting the appropriate output concept to be measured, (2) adjusting output so that it is consistent with available input measures, (3) obtaining quantity data on production, (4) developing appropriate weights for aggregating heterogeneous items into a single output measure, and (5) separating value change into price change and real output change.

The output concept used for the business and major sector measures is a net output or a value-added type of measure. The concept used for industries is a gross output measure that includes the value of purchased goods and services.

In using the national accounts data to derive the output measure for the business economy, several important exclusions from the gross national product (GNP) measures are made. These exclusions are necessary because (1) no adequate corresponding labor or capital input measure can be developed for some components of the national accounts, and (2) the gross product measures for some components are based on labor inputs implying constant output per unit of labor input.

Private business, which accounts for about 80 percent of GNP, includes the output of all activities measured in the national accounts, except for general government, paid employees of private households, nonprofit institutions, the "rest of world" sector, owner-occupied dwellings, government enterprises, and the statistical discrepancy.

General government is excluded because of the manner in which it is measured in the national accounts: The constant-dollar output of general government is derived by adjusting base-year hourly compensation for changes in the total hours of government employees. This assumes that productivity of this component remains constant. Private household employees and nonprofit institutions are also excluded for this reason.

The "rest of world" sector is excluded primarily for reasons of consistency between output and input data. The current value of output of this sector is equal to the payments to factors (labor and capital) abroad owned by U.S. residents, less payments to factors in the United States owned by foreigners. The payments to factors abroad owned by U.S. residents cannot be related to corresponding labor and capital inputs. The returns to income sent abroad to foreign owners of U.S. enterprises should be included but are not, to provide consistency between the output and input data.

Owner-occupied dwellings are also excluded for consistency purposes. In the national accounts, an estimate is made for the rental value of owner-occupied housing for inclusion in the GNP measures. The output of this service, the net rental value of owner-occupied homes, is estimated as the amount for which owner-occupied homes could be rented, less maintenance, insurance, and like expenses. However, there is no measure available for the hours worked by homeowners.

Statistical discrepancy is the difference between GNP estimates constructed from the product (the sum of all production for consumption, investment, government, and net foreign trade) and the income (the sum of all income resulting from compensation, profits, interest, and so forth) sides of the national accounts. Given that the input data are more closely related to the income side of the accounts, measures net of statistical discrepancy are developed to provide greater consistency between the output and input data.

Government enterprises—the U.S. Postal Service, the Tennessee Valley Authority, State and local enterprises, and the like—are excluded from the multifactor productivity measures because only limited data are available on their capital input. In the national accounts, structures and durable equipment used by these enterprises are treated as final sales to general government rather than as investments of the enterprises. Government enterprises thus show no capital cost associated with plant and equipment in the national accounts. Data on labor input of these enterprises, however, are available and the output of these enterprises is included in the labor productivity measures.

The aggregate measure resulting from these adjustments covers the product of the private business sector. Included in the output measure for this sector, however, are national accounts data for some miscellaneous items still based on measures of their inputs. This results from use of hourly compensation indexes or cost indexes as a deflator in the national accounts. Use of these measures implies no productivity change for the associated components. These remaining items, however, do not constitute a serious problem because they amount to only 6 percent of the total. (See table 1.)

Specific problems. Although GNP data are adjusted to make them appropriate for the multifactor productivity series, there are still problems with the measures. Perhaps the most important is the adequacy of the price measures used to derive the constant-dollar measures. The price measures used in the national accounts to deflate the value of output and intermediate inputs are predominantly from components of the consumer and producer price indexes prepared by BLS.

In obtaining the data for these series, respondents are asked to quote prices for clearly specified items. When producers significantly alter a product, they are asked to report the changes so BLS can adjust the reported price to reflect the change in quality based on the additional cost (or saving) due to the change. However, a quality change in a product can be achieved in ways which are not captured by measuring the cost of the change, either because there is no way to identify the direct cost associated with a specific

Table 1. Relationship between gross national product and the BLS measure of private business sector gross product, 1985

Item	Amount (billions of 1982 dollars)	Percent
Gross national product (GNP)	$3,585.2	100
Output items excluded from GNP to obtain BLS private business gross product:		
General government	355.5	10
Owner-occupied housing	209.4	6
Rest-of-the-world	37.0	1
Households and institutions	140.0	4
Government enterprises	43.9	(1)
Statistical discrepancy	-5.0	(1)
BLS private business gross product	2,804.4	78
Value of output deflated by hourly compensation or cost indexes	238.5	6
Nonresidential structures	152.2	4
Other	86.3	2
Value of output deflated by output price indexes	2,565.9	72

[1] Less than 0.5 percent.

SOURCE: *Survey of Current Business*, July 1986, supplemented by unpublished adjustments by Bureau of Economic Analysis, U.S. Department of Commerce, and Bureau of Labor Statistics.

change, or because there is no additional cost involved.

Two items have been particularly weak in the price area: the treatment of computers and the derivation of construction industry measures.

Because of the rapid changes that have been taking place and the inability to obtain reliable data in price surveys, the national accounts, for many years, assumed no change in the price of computers. It was generally believed that rapid changes in quality of the computers resulted in an upward bias in the prices and a downward bias in the resulting output and productivity measures.

To improve these measures, the Bureau of Economic Analysis, in conjunction with IBM, conducted a study in which new price measures for computers were developed.[1] This study compared two approaches: (1) a matched model index in which prices of models on the market in 2 adjacent years were used to compute a chain index over a period of years, and (2) hedonic indexes, computed using regressions showing the effects of specific computer characteristics on computer prices. A composite index was developed combining results from the two approaches. This composite index showed a substantial drop in the prices for computers and a corresponding increase in real output from that previously reported. While this measure is a considerable improvement, further development of the measurement technique for computer prices is being pursued.

In the construction area, developments have not been as fruitful. With the exception of single-family housing and highway construction, the price indexes available for construction activities are generally input price or cost indexes. (This problem is reflected in the entry for nonresidential structures in table 1.) The resultant productivity index for this industry has a bias toward no change and, to a lesser extent, this extends to the overall measure.

A hedonic price measure has been developed for single-family housing and a bid price index is used for highway construction. These price measures do reflect changes in the utilization of materials and labor per unit of output. They do not, however, represent a large proportion of total construction activities.

The output measures for the industry productivity indicators are derived independently of the national accounts. For each industry, the quantities of the various products that are produced by the industry are directly aggregated with the appropriate weights for the various products which make up the output of the industry. The appropriate weight for the direct aggregation of the products is the base-year factor input. Thus, for a labor productivity measure, the weight is the base-year hours of employees in the industry engaged in the production of each output. For a multifactor industry productivity measure, the appropriate weights for the output are the costs of the factor inputs. The resultant productivity measure is an internal mean of the productivity movements of the component elements of the industry. Thus, the labor productivity measure reflects the change in the labor expended in the production of a constant bundle of goods or services, and the multifactor measure reflects the change in all factors expended in the production of the bundle.

In some industries, however, unit employee hour information is not available for individual products. In such cases, substitute weights are used when it is believed that they are proportional to unit employee weights. These are either labor costs per unit of product, unit value added, or prices. The resultant productivity measure from any of these derivations reflects the effects of shifts in the labor cost, value added, or value per hour among the various products within the industry, as well as the change in productivity among the various products.

For some industries, data collected in the U.S. economic censuses have enabled the BLS to develop labor input weights for product classes, if not at the product level. Thus, a hybrid measure is developed which includes substitute (usually price) weights for combining specified products into product classes and labor weights beyond the product class level.

For those industries lacking quantity data, constant-dollar value of shipments data, adjusted for inventory change, are used to develop the output measure. Deflation of the value of the production of the industry by the price change of the various products is a variant of weighting the physical quantity data with unit values. The adequacy of these measures depends to a great extent on the adequacy of the price measures used to deflate the current-dollar value of output.

The problem of inadequate price deflators is more pronounced with the industry output measures. In many cases, its resolution largely determines whether a productivity measure can or cannot be derived. This has been one of the important factors determining the number of productivity measures that are available in the service sector. In recent years, the number of producer and consumer price indexes has been increasing substantially in the service area, as has the number of productivity measures developed.

In developing the deflated value of gross output indexes for SIC two-digit industries, it is useful to remove intraindustry transactions from the output series. Data for the transactions between establishments in the same two-digit industry are difficult to obtain. However, approximations can be obtained from input-output data.[2] For this purpose, the amount of imported goods included in intraindustry consumption is estimated and removed. Domestic consumption of materials produced by the same domestic industry is then divided by the total domestic commodity output and multiplied by gross output to estimate intraindustry sales. These are then subtracted from the two-digit industry deflated shipment data, adjusted for inventory change, to obtain the output measure.

Determining labor input

The labor input measures for both the sector and industry productivity series are based largely on a monthly survey of establishment payroll records. This survey, the BLS Current Employment Statistics program (establishment survey), provides data on total employment (for all employees) and average weekly hours (for production and nonsupervisory workers only) in nonagricultural establishments. Because the output of the goods and services reflects the activities of all persons engaged in economic activity, it is important to develop labor input measures that include the self-employed, unpaid family workers, and, for the total business sector, labor input on farms. These data are derived, for the most part, from a household survey of the noninstitutional population, the Current Population Survey, which is conducted by the Bureau of the Census for the BLS.

Reliance on establishment survey data provides major benefits, but also presents two problems. The major benefits derive mainly from the size and coverage of the survey: Payroll data are provided each month from a nationwide sample of more than 200,000 establishments. The problems are that the establishment hours are based on an hours paid, rather than an hours worked, concept, and the data exclude average weekly hours of nonproduction and supervisory workers.

A desirable measure of productivity is one that reflects the change in labor input actually involved in the productive process. The hours paid data include paid vacations, holidays, sick leave, and other paid time off, in addition to the actual hours worked. To the extent that leave practices change, the resultant productivity measures overstate or understate the actual change in output per hour or output per unit of labor and capital combined.

To develop a better series of hours at work, the BLS has been conducting an annual survey (now in its fifth year) of some 4,000 establishments to collect data on hours at work and hours paid for all production and nonsupervisory workers in the private nonagricultural business sector. From this survey, ratios are developed to adjust the hours paid measures from the establishment survey to an hours at work basis. The definition of hours at work was established, after careful study, as time on the job or at the place of work. Besides actual time at work, it includes coffee breaks, short rest periods, paid cleanup time, and other paid time at the workplace. This definition was considered to be conceptually the most acceptable one for which statistics could be extracted from establishment records. A narrower definition of hours actually worked was considered questionable and, in any case, too difficult to collect.

Although the problem of developing the appropriate hours concept for the productivity measures is being resolved at the level of the business economy and the major sectors, the current survey does not provide data in sufficient detail to enable the BLS to develop corresponding measures at the industry level.

In the absence of information from the establishment survey on the average weekly hours for nonproduction and supervisory workers, two solutions, neither entirely satisfactory, have been adopted. For average weekly hours of nonproduction workers in manufacturing, ratios of the average weekly hours of manufacturing office workers to those of nonoffice workers have been developed from surveys in the 1960's and 1970's. Estimates of average weekly hours of nonproduction workers in manufacturing are obtained by multiplying production worker hours by these ratios. In industries other than manufacturing, supervisory employees' average weekly hours are assumed to be equal to those of nonsupervisory workers.

The BLS measures of productivity based on the hours of all persons assume that workers are homogeneous with respect to skill. However, a highly skilled worker can be viewed as providing more labor services per hour than a lesser skilled worker. When skill differences are ignored, increases in skill levels are measured as increases in productivity. As a result, shifts from less skilled to more skilled labor because of increased education or on-the-job training are not reflected as an increase in the measure of labor input. For some purposes, it is useful to have a productivity measure that includes any changes in the potential productivity or quality of an input in the input measure. The problem is to construct a measure of labor input which accurately reflects changes in the skill level of the work force.

Worker characteristics weights

Previous studies have generally taken the position that relative wage or income level differentials associated with specific worker characteristics—years of schooling, age, sex, and possible industry and occupation—reflect marginal productivity of these attributes. Weighting the quality of labor (hours or employment), classified by these characteristics of the work force, by the relative wage or income differentials results in an aggregate measure of labor input intended to reflect the composition of the work force.

While this procedure certainly is not without merit, it presents some difficulties. In particular, it is not always clear whether certain characteristics are indeed productive. For example, workers with similar characteristics have widely different earnings in different occupations. However, this correlation between occupation and earnings may be due to influences other than the productivity of the occupation *per se*. Furthermore, wages or earnings may also be an imperfect indicator of marginal product because they may vary for reasons unrelated to productivity, including regional differences in the cost of living and various institutional factors.

To address these problems, the BLS is developing new measures of labor input based solely on changes in the amount of work experience and schooling workers acquire. This methodology, which follows directly from the economic theory of human capital as developed by Jacob Mincer and Gary Becker,[3] assumes that increased schooling and on-the-job training increases one's stock of skills, and thus one's productivity. Furthermore, the economic returns to higher education and additional work experience reflect the marginal productivity of these characteristics. The BLS has developed a multidimensional data base which cross-classifies the annual hours of workers grouped by schooling and experience. Simultaneously, the implicit prices of these characteristics have been calculated.

The determination of work experience requires substantial effort. There are no large-scale surveys which directly collect data on work experience. Instead, an econometric model has been developed that estimates an individual's quarters of work experience, based on available survey data regarding other personal characteristics. This model requires that for each year, the work force be cross-classified by age, sex, education, race, marital status, and number of children. For the decennial census years, and for years after 1968 when observation data from the household survey could be used, the cross-classification of the work force is straightforward. For the remaining years (1948, 1949, 1951–59, 1961–67), a multiproportional interpolation procedure is employed.

The experience model makes use of a matched sample developed from both the household survey and Social Security records. The results have proven to be significantly better than previous estimates: They show that there is a positive correlation between education and experience which some measures of experience do not take into account and which can produce biased estimates. This positive correlation is shown by a comparison of the derived returns to education and experience using the traditional estimates of experience and the new estimates.

As mentioned earlier, it is recognized that hourly wages differ not only because of skill differences, but also because of factors unrelated to productivity. Accordingly, simple averages of hourly wage rates for each education and experience group are not necessarily appropriate measures of marginal productivity. To remove these imperfections, another econometric model has been developed which provides measures of wages dependent upon changes in education and experience, but which simultaneously controls for other types of variation.

This model measures the returns to seven different schooling levels and to quarters of work experience. It controls for differentials by full- or part-time status, regional location, and urban or rural residence of a worker. The latter two variables adjust for possible regional price variations. Proprietors and unpaid family workers are excluded from the estimating sample because their income may reflect not only labor returns, but also returns to capital. The model is designed to yield returns to education and experience adjusted for the possible effects of race and sex discrimination on wages. Initially, annual measures of these returns will be constructed for the 1948–85 period.

The construction of aggregate measures of labor input requires that all hours be cross-classified by the level of education and the amount of experience for men and women separately. The hours of each type of cross-classified labor are weighted by the corresponding hourly rental price determined from the model above to obtain a Törnqvist weighted index of labor input. Skill-adjusted labor input measures are presently being developed for the business and nonfarm business sectors.

In sum, the measurement of labor input is limited in several problem areas. One is achieving more accurate coverage of hours of all persons; another is developing hours at work measures; and another is developing weights which reflect differentials in marginal productivity. Some success in each of these areas has been achieved at the macro level with measures for the business economy and major sectors. However, problems remain with the measures for individual industries. It is difficult to see possibilities for substantial improvement in industry measures without substantial expansions in the surveys providing the basic data.

Capital input measures

Capital inputs should be measures of the flow of services from capital stocks rather than of capital stocks themselves. This is consistent with the measurement of labor and output as flows of goods and services. It is also consistent with the general observation that it is the services of a physical asset, rather than the asset itself, that enter into the production process. Further, it permits the capital input measure to differentiate between the annual contributions of a short-lived asset and a long-lived asset that yields its services at a slower annual rate relative to its value as a stock.

The BLS measures adopt the service-flow concept. The assets included are fixed business equipment and structures, inventories, and land. Structures include nonresidential structures and residential capital which is rented out by profitmaking firms or persons. Financial assets are excluded, largely on pragmatic grounds, as are owner-occupied residential structures.

The capital input measures are constructed in two stages. First, stocks are estimated for various types of assets. The stock estimates are developed after assuming that an asset's services diminish in a fixed pattern as it ages. Second, assets are aggregated by weighting with capital income shares based on rental prices. This step requires the development of rental prices for each type of capital stock.

Exhibit 1 summarizes the methods and data sources used to construct the measures of capital input. Steps 1 through 5 correspond to the first stage and steps 6 and 7, the second.

The framework used for deriving the capital input measures is based on the concept that the stock of capital represents the amount of new investment that would be required to produce the same capital services actually produced by existing assets of all vintages. Thus, the stock measure requires historical data on real investment and assumes an age-efficiency function that describes the pattern of services that capital goods supply as they age.

The measures of investment form the initial point for deriving the capital stock measures. These are constant-dollar measures and are derived from price indexes which have limitations similar to those of indexes used in deriving the constant-dollar GNP output measures. For example, equipment is deflated principally by using the Producer Price Indexes. One part of investment equipment includes computers and, for many years, this presented a problem in measurement of this component of investment. The recently developed price measure for computers (discussed earlier) has improved the estimates for this component. Structures are deflated by indexes of residential prices, highway construction prices, and the construction cost indexes. The highway component and the tenant-occupied, single-family housing construction components are deflated by adequate price measures, but the other structures must be deflated by inadequate cost measures.

In general, the relationship between the economic efficiency of an asset and its age is very complex and depends on the particular type of asset as well as a host of other factors, such as the level of economic activity, relative input prices, interest rates, and technological developments.

Use of an efficiency function involves a strong assumption. The quantity of capital services from a particular asset is assumed to be a function of its age alone. Thus, because the pattern of diminishing services remains fixed over time, the resulting capital measure cannot respond to variations in factor demand. In view of this restrictive assumption, the validity of weighting with a function representative of age alone remains a major issue.

Several general forms have been employed, none of which is completely satisfactory. Use of the gross stock assumes that the asset exhibits no loss of services until it suddenly is discarded. Other forms are net of some loss of services during their lives. A straight-line form shows the same loss of services each year. A concave form shows gradual losses early in the life of an asset, and more rapid losses as it ages. A convex form shows rapid early losses followed by more gradual losses of the remaining efficiency.

Several attempts have been made to address the efficiency function issue by observing used asset prices. A relationship is postulated between the efficiency of a used asset and its market price relative to that of a new asset. The most extensive empirical study of used asset prices in the United States was done by Charles Hulten and Frank Wykoff in 1981.[4] BLS concluded that the concave deterioration pattern appeared to be consistent with the empirical data in the Hulten-Wykoff study, as well as with the reports of businesses concerning experiences with their own capital assets.[5]

Many private researchers have used alternative forms such as a gross measure with no deterioration, a geometric decay function with early rapid decline and a slackening of the rate of decline as the asset ages, other concave forms, and straight-line deterioration.[6] To test the impact of the choice of a particular function on the final measure of multifactor productivity, BLS conducted sensitivity tests of the growth rates of multifactor productivity and of the contribution of the capital-labor ratio to the growth in labor productivity using the different age-efficiency relationships. What emerged was that the choice of function had very little effect on either the multifactor productivity growth rates or the contribution of capital services per hour to the growth rates of output per hour. The largest difference in long-term productivity growth produced by the alternative functions was 0.1 percent. (See table 2.)

Depreciable assets have finite lives; eventually they are discarded from stock. Average lives of the different asset groups are based on recently revised estimates from the Department of Commerce. Asset lives are assumed to be normally distributed with a fairly wide dispersion to take account of the range of service lives observed within each investment cohort.

The second stage in constructing measures of capital services is the aggregation of capital stocks by weighting the stocks with income shares based on rental prices. The various types of capital assets are appropriately aggregated using implicit rental prices (sometimes called user costs) for each type of asset. The rental price represents the annual costs which would be incurred by an organizaiton that purchases an asset with the intention of renting it out.[7] Thus, the rental prices are implicit because the owners and users of capital assets are frequently the same.

Rental prices are calculated for each type of asset. Assets with shorter lives tend to have higher depreciation rates, and therefore, higher rental prices, and are given a larger weight in capital input. This implies that assets with higher rental prices contribute more to the annual flow of output than assets with lower rental prices.

The Törnqvist method is used to combine the capital series by asset type. The change in capital input is, in effect,

Table 2. Sensitivity of private business sector multifactor productivity measure to various age-efficiency assumptions, 1949–81

[Percent change]

Period	BLS (Hyperbolic)	Hulten-Wykoff (best geometric approximation)	Gross (one-hoss shay)	Straight line
1949	-1.1	-1.0	-1.0	-1.2
1950	7.2	7.4	7.2	7.1
1951	2.4	2.5	2.5	2.2
1952	1.8	2.0	1.8	1.8
1953	2.6	2.8	2.5	2.6
1954	-.4	-.3	-.5	-.4
1955	4.4	4.4	4.3	4.3
1956	.3	.4	.4	.2
1957	.9	1.0	.9	.8
1958	.7	.8	.5	.7
1959	4.0	4.1	3.9	4.1
1960	.6	.5	.6	.6
1961	2.0	1.9	1.9	1.9
1962	3.6	3.6	3.6	3.6
1963	2.9	2.8	2.9	2.8
1964	3.6	3.6	3.7	3.5
1965	3.1	3.1	3.3	3.0
1966	1.9	2.0	2.2	1.8
1967	.3	.4	.5	.2
1968	2.4	2.5	2.5	2.3
1969	-.5	-.4	-.4	-.5
1970	-1.2	-1.0	-1.1	-1.2
1971	2.2	2.3	2.1	2.2
1972	3.3	3.4	3.2	3.3
1973	2.4	2.4	2.4	2.3
1974	-3.8	-3.7	-3.8	-3.8
1975	-.2	-.1	-.3	-.2
1976	3.8	3.8	3.6	3.9
1977	3.0	3.0	2.9	3.1
1978	1.0	1.0	1.0	1.0
1979	-1.1	-1.1	-1.2	-1.2
1980	-2.2	-2.2	-2.3	-2.2
1981	1.1	1.1	1.0	1.1
1948–65	2.2	2.3	2.3	2.2
1965–73	1.3	1.4	1.4	1.3
1948–73	2.0	2.0	2.0	1.9
1973–81	.1	.2	.1	.2
1948–81	1.5	1.6	1.5	1.5

a weighted sum of the percentage changes in the capital inputs by asset type. The weights are developed as averages, for the current and preceding year, of the asset's capital compensation, which is the product of the asset's rental price and the quantity of its stock.

Stocks for inventories are based on average end-of-quarter real inventories as reported in the national accounts. The land stock estimate for the farm portion of private business, where land represents a large share of capital, is developed by aggregating regional acreage figures using weights reflecting regional rental values. In the nonfarm sector, the measure for land is derived by multiplying structures by a land-structures ratio.[8]

The capital input measures for the SIC two-digit industries are developed in the same manner as those for the major sectors. However, one problem is encountered at the two-digit level in implementation of the usual capital input measurement procedures. The capital rental price formulation includes the rate of return plus the rate of depreciation minus the rate of capital gains—inflation in the value of an asset—all in nominal terms. Rental prices are used to construct weights for asset types as discussed above. Capital gains are usually computed as the year-to-year change in the deflator for new investment.

At the two-digit level, some industries have very low rates of return in some years. After capital gains are subtracted, some rental prices are volatile over time and even negative. The resulting asset weights thus lead to implausible capital aggregates. Furthermore, this volatility clearly comes from asset-specific year-to-year movements in the deflators customarily used to determine capital gains. Because the derivation of the rental price assumes perfect foresight, the usual procedure of estimating capital gains implies, incorrectly, that investors fully anticipate even erratic price movements. After careful study, BLS concluded that the usual procedure of using an annual deflator is not required by theory.[9] A 3-year moving average of the deflator was judged superior on empirical grounds.

Intermediate inputs

Intermediate purchases include materials, fuels, and business services. Material inputs represent all commodity inputs exclusive of fuels (electricity, fuel oil, coal, natural gas, and miscellaneous fuels). Data on the total cost of materials are available from Department of Commerce annual surveys and are deflated by appropriate price indexes to obtain measures of real material inputs. Because the data are obtained on an establishment basis, products transferred between establishments in the same industry are included in the aggregate materials cost. A two-step procedure is used to determine the rate of growth in real expenditures for materials which are purchased from outside the particular industry. First, from the annual current-dollar cost of materials, an estimate of the cost of intraindustry sales and transfers is removed. Second, a materials deflator is constructed with the detailed materials price data and information on weights from input-output tables.

Data on the price and quantity of energy inputs are constructed from annual surveys. These include only the quantity and cost of fuels purchased for heat and power. However, quantity information is not available for all years, and the measures are extrapolated and interpolated using annual estimates of total cost deflated by appropriate Producer Price Indexes.

Directly collected data on purchased business services are relatively scant in the United States. Nevertheless, the inclusion of purchased services in the input measure is important because there is ample evidence of increased use by industries of such services. Also, there is evidence of increased substitution of leased capital for owned capital, and of purchased services such as accounting, legal, and technical services for services performed inhouse.

The BLS estimates these services from published input-output tables. The general approach is to take service shares in the value of production from the input-output tables at the greatest level of detail; to obtain service costs by multiplying the shares by the value of production; and to deflate these current cost estimates by appropriate deflators. Prices for service inputs are obtained from the consumer and producer price indexes or imputed from various data sources. This is a major problem which will be alleviated by developing more extensive price measures for the service activities.

Multifactor productivity

The calculation of multifactor productivity proceeds from dividing the index of output by the derived index of combined inputs. In the net, or value-added, output framework used in developing the measures for the private business economy and the major sectors, the combined inputs are labor (hours) and capital services. The aggregate input index

Exhibit 1. Summary of methods and data sources used to measure capital and multifactor productivity

Step	Data item obtained or constructed	Method used and detail in which step is performed	Data source
1. Obtain real investment data for data for depreciable assets	Investment in:		
	Equipment	20 asset types	National accounts[1]
	Structures	14 asset types	National accounts[1]
	Rental residential capital	9 asset types	National accounts[1]
2. Allocate investment data to major sectors	Investment by asset type by sector (farm manufacturing, nonfarm manufacturing)	Asset detail allocated using methods in step 1	See step 1
		Sectoral investment total proportional to national accounts	National accounts[1]
		Historical data cross-classified by asset detail and sector	National accounts[1]
3. Determine age/efficiency functions for each type of asset	Weights reflecting the declining services of an asset type cohort as it ages	A hyperbolic form using:	
		An average service life estimate	National accounts[1]
		Normal distribution of discards	National accounts[1]
		A shape determined using empirical evidence	Hulten and Wykoff[2]
4. Perform vintage aggregation	Real stocks of depreciable assets by type and sector	Perpetual inventory method: Real historical investments weighted by age/efficiency functions	See steps 2 and 3
5. Measure nondepreciable assets	Stock of inventories	By stage of processing in manufacturing	National accounts[1]
	Stock of farm land	Regional services weighted using rental prices	U.S. Department of Agriculture
	Stock of land in manufacturing and nonfarm manufacturing	Proportional to structures using benchmark land estimate	Allan[3]
6. Obtain constant rental prices	Implicit rental value of the services of a unit of each type of asset in each sector	Rental price formula estimated using data on capital stocks and data on payments to capital	Christensen and Jorgenson;[4] steps 4 and 5; and national accounts[1]
7. Obtain aggregate assets	Measure of real capital input in each sector	Törnqvist index to asset capital stocks using rental prices to determine weights	Steps 4, 5, and 6

[1] National Income and Product Accounts, Bureau of Economic Analysis, U.S. Department of Commerce.

[2] Shares were reconciled to functions reported in C. R. Hulten and F. C. Wykoff, "The Measurement of Economic Depreciation," in C. R. Hulten, ed., *Depreciation, Inflation and Taxation of Income from Capital* (Washington, The Urban Institute Press, 1981), pp. 81–125; and C. R. Hulten and F. C. Wykoff, "The Estimation of Economic Depreciation Using Vintage Asset Prices," *Journal of Econometrics*, 1981, pp. 367–96.

[3] Benchmarks based on estimates from Manvel D. Allan, "Trends in the Value of Real Estate and Land, 1956–1966," *Three Land Research Studies* (Washington, National Commission on Urban Problems, 1966).

[4] Formula used to measure rental prices derived by Laurits R. Christensen and Dale W. Jorgenson, "The Measurement of U.S. Real Capital Input, 1929–1967," *Review of Income and Wealth*, December 1969, pp. 292–320.

is derived by weighting the annual growth rates of the individual components, where the weights are the income shares of each component averaged over the current and preceding year, a Törnqvist index. Within each sector, total income is equal to the sum of labor compensation of all employees (labor income), corporate property income (capital income), and proprietors' income.

The labor compensation data for employees are readily available from the national accounts. However, proprietors' income is the total return to the proprietors' own labor *and* capital. Because this income reflects returns to both factors of production, it is necessary to develop a method to allocate the income between the two factors.

Various assumptions can be made to do this. For example, production worker earnings can be imputed to the self-employed, but this frequently results in negative nonlabor proprietor income (which is obtained as a residual). Conversely, the rate of return on capital in the corporate sector can be applied to the proprietors' capital, but this frequently yields negative proprietors' labor income.

In the BLS measures, proprietor hours are given the same average wages received by paid employees, and capital income is measured by assigning noncorporate capital the same rate of return as corporate capital. The sum of these computed values is compared with reported noncorporate income in the national accounts, and both the derived labor and capital income are scaled to agree with the reported levels.

The combined input index, then, is derived by weighting the labor input index by the derived compensation share of total income, and the capital input index by the income share of capital.

In the derivation of the two-digit industry and the specific industry multifactor measures, the output measure is a gross output index including the value of purchased materials and services. The corresponding factor input measure reflects intermediate materials and purchased services as well as the labor and capital inputs. These are combined with share weights also; in this case, the sum of the labor, capital, and intermediate shares will equal one.

Inadequacies remain, despite progress

Measurement of productivity change is not a simple task. Despite recent progress, it is clear that inadequacies remain in the data available for measurement of both labor and multifactor productivity. In addition, multifactor productivity measurement presents challenging problems of shaping sometimes imperfect data into empirical measures that take advantage of recent theoretical advances. While multifactor productivity measures are useful for understanding factors affecting the traditional productivity movements, and many such measures have been developed, it is important to recognize that they do not have the same degree of precision that the labor productivity measures have. In estimating them, many more assumptions have to be made, particularly with regard to measuring capital input.

Despite problems, improvements in the measures have been made and, undoubtedly, more will follow. For example, better price data for developing constant-dollar output and capital and intermediate material input measures are now available. Better estimates of rental prices for aggregating the heterogeneous capital stocks have been developed. Even the output per hour measures are being improved using more appropriate hours information and developing adjustments for changes in the composition of the work force.

Improvements in the procedures for measuring productivity must and will continue to be made. Productivity measures of high quality can shed light on policy issues of great importance, including questions on the best means of increasing the efficiency of economic resources, the ability of the economy to expand without adding to inflationary pressures, and the determinants of a country's competitive position in international markets. □

———*FOOTNOTES*———

[1] See David W. Cartwright, "Improved Deflation of Purchases of Computers," *Survey of Current Business*, March 1986, pp. 7–10.

[2] Input-output data are available for 1947, 1958, 1963, 1972, and 1977, and estimated data have been developed for the 1967–80 period.

[3] See Jacob Mincer, *Schooling Experience, and Earnings* (New York and London, Columbia University Press, 1974); and Gary Becker, *Human Capital* (Chicago and London, University of Chicago, 1975).

[4] C. R. Hulten and F. C. Wykoff, "The Estimation of Economic Depreciation Using Vintage Asset Prices," *Journal of Econometrics*, 1981, pp. 367–96.

[5] See *Trends in Multifactor Productivity, 1948–81*, Bulletin 2178 (Bureau of Labor Statistics, 1983).

[6] See John W. Kendrick, "Productivity Trends in the United States," in Shlomo Maital and Noah M. Meltz, eds., *Lagging Productivity Growth* (Cambridge, MA, Ballinger Publishing Co., 1980); Edward F. Denison, *Accounting for Slower Economic Growth* (Washington, The Brookings Institution, 1979); and Frank M. Gollop and Dale W. Jorgenson, "U.S. Productivity Growth by Industry, 1947–1973," in John W. Kendrick and Beatrice N. Vaccara, eds., *New Developments in Productivity Measurement and Analysis* (Chicago, The University of Chicago Press, 1980), pp. 17–124.

[7] The foundations for the use of rental prices in asset aggregation were set forth in Laurits R. Christensen and Dale W. Jorgenson, "The Measurement of U.S. Real Capital Input, 1929–1967," *Review of Income and Wealth*, December 1969, pp. 292–320. Their analysis proceeds from the assumption of equilibrium of supply and demand in the rental market and develops a rental price equation. Rental prices derived from this equation are assumed to reflect the stock's marginal products. The equation reflects, among the determinants of rental prices, depreciation costs, and the rate of return in the form of interest and profits. These costs are reduced by inflation in the value of the asset and adjusted for tax considerations.

[8] Manvel D. Allan, "Trends in the Value of Real Estate and Land 1956–1966," *Three Land Research Studies* (Washington, National Commission on Urban Problems, 1966).

[9] Michael J. Harper, Ernst R. Berndt, and David O. Wood, "Rates of Return and Capital Aggregation Using Alternative Rental Prices" (Bureau of Labor Statistics, unpublished working paper, 1986).