The BLS Productivity Measurement Program

Edwin R. Dean
Michael J. Harper

Bureau of Labor Statistics

February 25, 1998

Edwin R. Dean and Michael J. Harper are with the Office of Productivity and Technology of the U.S. Bureau of Labor Statistics. This paper is for presentation at the Conference on Research in Income and Wealth conference on New Directions in Productivity Analysis, March 20-21, 1998.

The BLS Productivity Measurement Program

by Edwin R. Dean and Michael J. Harper

Outline

The BLS Productivity Measurement Program

Edwin R. Dean and Michael J. Harper

I. Introduction

The publication of productivity measures has long been an important activity of the U.S. Bureau of Labor Statistics (BLS). This measurement program has evolved over the years, stimulated by changes in data availability, by new developments in the economics literature, and also by the needs of data users. The program's first major activity was the publication of industry measures. Following the development of the National Income and Product Accounts (NIPA) at the U.S. Department of Commerce, the BLS introduced productivity measures for the aggregate U.S. economy. More recently, the agency has developed measures of multifactor productivity (MFP).

This paper discusses the current status of the BLS program, with emphasis on the data development work done in recent years. By way of background, we first review the status of the BLS program as of the mid-1970s (section II), and also some important advances in the economics literature which had occurred by that time (section III). The paper then describes the development of MFP measures for the private business and private nonfarm business sectors--these were first published in 1983--as well as recent work to expand and improve these measures (section IV). It also describes recent extensions and improvements to measures for the manufacturing sector and for more detailed industries both within and outside of manufacturing (section V). Finally, it provides comments on some of the conceptual and empirical obstacles to further improvements in the measures (section VI). It is hoped that this conference will help to clarify the most desirable future directions for the program.

II. Background on the Industry and Aggregate Labor Productivity and Cost Measures

The early BLS productivity program

The BLS was calculating productivity data for some industries by the 1920s. These measures compared the number of goods produced to the number of people needed to produce them. These measures were used to assess how technological advances affected employment. The immediate consequence of a productivity improvement can be the displacement of workers. Growing companies often can redeploy displaced workers to new jobs. However, this was not happening during the 1930s. The problem of technological displacement was the stimulus for the BLS productivity measurement program. According to Goldberg and Moye [1984, p. 168], “In 1935, the Bureau applied to the WPA for funds to conduct studies of productivity in 50 industries.” In 1941, after initial studies were published, Congress appropriated funds for a program of continuing studies of productivity and technology.

BLS [1942] focused initially on measures of productivity and unit labor costs for manufacturing industries. The concern about worker displacement affected the methodology selected. It was believed that the preferred weights for aggregating outputs for “the computation of an ideal productivity index” were labor requirements (p. viii). Essentially, productivity gains were weighted by the associated job losses.

In addition to publishing measures of productivity, the BLS productivity and technology program prepared qualitative information on technological developments in various industries. According to Goldberg and Moye [1984, p. 169], these were “for the use of U.S. agencies and those of allied governments.”

The development of aggregate measures of labor productivity and costs

The Great Depression and World War II played a role in shaping the NIPAs, upon which BLS [1959] would base its aggregate productivity measures. Keynes’ description of aggregate demand and Leontief’s input-output models became central elements in the NIPAs. As Berndt and Triplett [1990] reminded us, the Conference on Research in Income and Wealth (CRIW) was also an influential part of this process. Using the Accounts, the BLS [1959] introduced annual indexes of real product per man-hour for the total private economy and for the private nonagricultural economy. (Measures for total manufacturing had been introduced in 1955.) The aggregate measures were developed under the supervision of Jerome A. Mark. By this time it was widely recognized that aggregate productivity advances were a necessary condition for rising living standards. The aggregate productivity measures would become a new tool for monitoring the health of the economy. Before long the Bureau was publishing these measures quarterly, shortly after the release by BEA of the quarterly figures on gross national product. These were of interest to the Joint Economic Committee and also to researchers, such as Kendrick, who considered productivity a leading indicator of the business cycle.

One key element of the BLS aggregate output per hour series involved the matching of employment and hours collected in BLS surveys to output measures for selected NIPA sectors. Any difference in coverage can introduce a bias into the productivity trend. In limiting the measures to the total private sector, BLS [1959, p. 1] recognized that “there is no satisfactory method of measuring the goods and services provided by the government.” In part, government output in the NIPAs was measured using data on labor inputs, which implies no productivity change.

The major sector productivity and cost news releases

The aggregate labor productivity measures remain the most frequently cited product of the BLS productivity program. Since 1976 BLS has published quarterly indexes of labor productivity, compensation per hour and unit labor costs for the following sectors: business, nonfarm business, manufacturing (and its durable and nondurable goods producing subsectors) and nonfinancial corporations. In addition to general government, the business sector excludes the following items from gross domestic product: private households and nonprofit institutions and the NIPA imputation of the rental value of owner occupied dwellings. Like government, households and institutions are excluded because they are measured with labor inputs. Owner occupied housing is excluded because no corresponding labor hours data are available.

Table 1 is designed to highlight these data series, which the BLS presently publishes 8 times per year. Trends in output per hour, unit labor costs, hourly compensation, and real hourly compensation are presented for each of the six sectors.

Several major patterns are evident from the data in this table. The data indicate that there was a slowdown in productivity after 1973 in all six sectors. Since 1979, output per hour trends have recovered in manufacturing, due mainly to exceptional strength in durable manufacturing. Output per hour growth has remained slow in nonfarm

Table 1. Measures of labor productivity, unit labor costs, hourly compensation, and real hourly compensation for major sectors

Sector and measure	Annual percent change					
	1947* to 1997*	1947* to 1973	1973 to 1979	1979 to 1990	1990 to 1997*	1996 to 1997
Business sector:						
Output per hour of all persons	2.3	3.3	1.3	1.2	1.2	1.9
Unit labor costs	3.5	2.4	7.8	4.5	2.3	2.0
Hourly compensation	5.8	5.7	9.2	5.7	3.5	3.9
Real hourly compensation	1.7	3.0	0.6	0.2	0.5	1.6
Nonfarm business sector:						
Output per hour of all persons	2.0	2.8	1.1	1.0	1.2	1.7
Unit labor costs	3.6	2.6	8.0	4.6	2.3	2.1
Hourly compensation	5.7	5.5	9.2	5.7	3.5	3.8
Real hourly compensation	1.6	2.7	0.6	0.2	0.5	1.5
Manufacturing sector:						
Output per hour of all persons	2.6	2.6	2.0	2.7	3.1	4.4
Unit labor costs	2.9	2.6	7.5	2.9	0.4	-0.9
Hourly compensation	5.7	5.3	9.7	5.6	3.5	3.5
Real hourly compensation	1.5	2.6	1.0	0.1	0.5	1.2
Durable manufacturing sector:						
Output per hour of all persons	2.9	2.7	1.6	3.1	4.3	5.7
Unit labor costs	2.7	2.6	7.9	2.3	-0.8	-2.5
Hourly compensation	5.7	5.4	9.7	5.6	3.4	3.1
Real hourly compensation	1.5	2.7	1.0	0.1	0.4	0.8
Nondurable manufacturing sector:						
Output per hour of all persons	2.5	2.9	2.5	1.9	2.0	3.2
Unit labor costs	3.0	2.1	6.9	3.9	1.7	0.7
Hourly compensation	5.6	5.1	9.6	5.8	3.7	3.9
Real hourly compensation	1.5	2.4	1.0	0.3	0.6	1.6
Nonfinancial corporate sector:						
Output per employee-hour	2.0	2.6	1.1	1.8	1.9	n.a.
Unit labor costs	3.4	2.5	7.8	3.6	1.3	n.a.
Hourly compensation	5.5	5.2	8.9	5.4	3.1	n.a.
Real hourly compensation	0.9	2.2	0.4	-0.1	0.0	n.a.

* Measures for manufacturing, durable manufacturing, and nondurable manufacturing begin in 1949. Measures for nonfinancial corporations begin in 1958 and end in 1996.

business, but has partially recovered for nonfinancial corporations. Unit labor costs rose sharply after 1973, but since 1990 they have returned to their pre-1973 trends. Finally, real hourly compensation (compensation per hour deflated by the consumer price index) has risen more slowly than output per hour since 1973.

The government productivity program

In 1973 BLS took the leading role in a project, initiated by the Joint Economic Committee, to develop productivity statistics for the Federal government. Working with government agencies, the BLS developed quantifiable output definitions which agencies then used as the basis for regular reports. BLS compiled these, along with information on agency employment. BLS aggregated these results and reported them annually.

III. Advances in Production Theory and Their Implications for Productivity Measurement

Developments in the economic literature on productivity

By the mid-1970s there was a significant accumulation of research relevant to productivity measurement that had not yet been reflected in government measures. The idea of using production functions as a means of analyzing aggregate economic activity was pioneered by Paul Samuelson [1947]. In the following statement, the function, f, reflects the maximum amount of output that can be produced by various combinations of inputs of labor, L, and capital, K, given the technology available at time t:

$$Y = f(K, L, t).$$

A production function is typically the constraint on a model of optimizing behavior by the firm: given a set of prices, the firm determines the proportions of inputs which minimize cost, constrained by technology. Production functions also led to the formulation of macroeconomic growth models. During the 1950s and 1960s, growth models became increasingly sophisticated and detailed.

Robert Solow [1958] used a production function to show the role of capital in labor productivity trends. By assuming a production function and perfect competition in input factor markets, we can calculate the rate at which the production function is shifting:

$$dlnf/dt = dlnY/dt - s_L dlnL/dt - s_K dlnK/dt,$$

where s_L and s_K are the shares of labor and capital, respectively, in total cost. We call the rate at which the function is shifting the growth rate of multifactor productivity (MFP). MFP is also referred to as total factor productivity or the "residual". Solow showed that it follows that the rate of growth of labor productivity depends on the growth rate in the capital-labor ratio, weighted by capital's share, and the growth rate of MFP:

$$dln(Y/L)/dt = s_K dln(K/L)/dt + dlnf/dt.$$

Solow argued that MFP is a better measure of technological change than labor productivity, but he also acknowledged that MFP reflects many other influences, because it is calculated as a residual.

The usefulness of aggregate production models and of aggregate capital stock measures had been debated in the literature during the 1950s. At issue was the validity of assuming that microeconomic relationships applied to aggregate data, as well as the validity of aggregating capital. The literature of the 1960s reflected an effort to build aggregate measures from increasingly detailed data using less restrictive assumptions about aggregation. Evsey Domar [1961] demonstrated how a system of industry and aggregate production functions could be used to compare industry productivity measures to the aggregate measures. A paper by Dale Jorgenson and Zvi Griliches [1967] showed how detailed data could be used to construct a capital aggregate without making strong assumptions about the relative marginal products of dissimilar assets. Also, it was recognized that commonly used index number formulas could introduce bias into the aggregation process. Diewert [1976] showed how production functions could be used to provide a basis for determining which index number formulas were least restrictive.

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

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

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

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

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

The literature on the theory of index numbers has shown that the Tornqvist index of inputs has a number of desirable properties. In particular, Diewert [1976] demonstrated that the Tornqvist index is consistent with one very flexible type of production function, the “translog”.

The panel to review productivity statistics

Earlier in this section we reviewed the development of the BLS productivity work up until the mid-1970s. By that time it was recognized that productivity growth trends had slowed dramatically. There was a flurry of research studies aimed at explaining the slowdown. Much of the analysis relied on concepts which went beyond labor productivity. The researchers often had to compile their own datasets to address the specific issues that interested them. A number of data sets were privately generated and they were often put together hastily.

In this situation, thoughtful analysts recognized that it would be desirable for the BLS to extend its labor productivity measures to encompass additional inputs and other innovations in data construction coming from recent developments in production theory. The Committee on National Statistics of the National Academy of Sciences (NAS) appointed a Panel to Review Productivity Statistics. The panel, chaired by Albert Reese, wrote a report (NAS [1979]) making 23 recommendations to government statistical agencies, many of which were directed to the BLS productivity measurement program. Among these were that the BLS should develop a “survey of hours at the workplace” (recommendation 8), that BLS should study “the use of weighted labor input measures” (recommendation 9) and that the BLS should “experiment with combining labor and other inputs into alternative measures of multi-factor productivity” (MFP). The report made specific mention of capital, weighted labor, and intermediate purchases inputs for inclusion in the MFP work. Many of the other recommendations were aimed at improving the scope and accuracy of productivity statistics by expanding source data on outputs, prices, and labor.

IV. The Development of Major Sector Multifactor Productivity Measures

Following the NAS recommendations, the BLS launched an intensive effort to develop additional input measures suitable for publication with its productivity measures. This effort was facilitated by additional funding for MFP measurement, provided by the Congress beginning in 1982.

The development of aggregate measures of capital service inputs

The first project was to construct capital measures that would be comparable to the output per hour measures for aggregate sectors. Decisions had to be made on a number of issues. Among these issues were what to include in capital, and how best to aggregate detailed data on investment by vintage and by asset type. We will review each of these issues briefly, and then discuss how a series of events led to the present BLS methods.

An excellent review of "the domain of definition of capital" issue in the context of productivity measurement was provided to the CRIW by Diewert [1980, pp. 480-485]. After reviewing precedents, including Christensen and Jorgenson [1970], Denison [1974], and Kendrick [1976], Diewert recommended that capital measures include "structures, land, natural resources, machinery and other durable equipment, and inventory stocks used in the private business sector." This list might be characterized as tangible items which contribute to production for more than one time period. Diewert emphasized that the omission of either land or inventories would tend to bias estimates of the contribution of capital to production and also to bias estimates of multifactor productivity. Financial assets and other intangible assets were excluded due mainly to unresolved measurement issues.

An important result of production theory is that it is desirable to aggregate capital goods in terms of their marginal products in current production as opposed to the marginal costs of producing the capital goods. Hall [1968] derived prices which represent the relevant margins on which to aggregate capital goods. These prices, which are sometimes called "implicit rental prices" and which we will denote as c, reflect the price of new capital goods, p, the nominal discount rate, r, the rate of economic depreciation, δ, and the rate at which goods prices appreciate due to inflation, Δp:

$$c = pr + p\delta + \Delta p \quad .$$

Jorgenson and Griliches [1967] used implicit rental price estimates to aggregate the *services* of assets of different types. Another innovation in aggregation procedures attributable to Jorgenson and Griliches was the use of chained Tornqvist indexes to aggregate capital assets of different types. The growth rate of total capital input, $\Delta \ln K_T$, between successive periods (t-1 and t), was computed as a weighted sum over asset types, a, of the growth rates of asset stocks, $\Delta d\ln k_a$. The weights were the arithmetic means of the shares, in the two periods, of the implicit "rents" generated by the respective assets in total rents. This procedure led to the following:

$$\Delta \ln K_T = \Sigma_a \, \Delta d\ln k_a \, [1/2 \, (k_{a,t}c_{a,t}/\Sigma_j k_{i,t}c_{i,t} + k_{a,t}c_{a,t-1}/\Sigma_j \, k_{i,t-1}c_{i,t-1} \,)].$$

Most of the data needed to estimate rental prices are readily available if capital stocks have been estimated with the perpetual inventory method (PIM). The PIM is applied to a time series of real investment, created by dividing a nominal investment series by a price index, $p_{a,t}$. The PIM also imposes some assumption about depreciation rates, δ_a. Jorgenson and Griliches estimated the discount rate as an "internal rate of return". This involved assuming that implicit rents in each time period account for the total of "property income", Ψ_t, in each period. Property income was assumed to be the residual derived by subtracting labor costs from nominal value added in the sector under study. Thus they solved for a single r_t such that:

$$\Psi_t = \Sigma_a \, k_{a,t}c_{a,t} = \Sigma_a \, k_{a,t} \, (p_{a,t}r_t + p_{a,t}\,\delta_a + p_{a,t} - p_{a,t-1})$$

Empirically, the main effect of using these techniques is to place relatively larger weights on assets which are depreciating quickly, compared to the weights that would result from a direct aggregation of stocks. The rationale for placing more weight on short-lived assets is the following: investors must collect more rents on a dollar’s worth of short lived assets to compensate for their higher depreciation costs. Hall and Jorgenson [1967] formulated the rental prices to reflect the effects of tax laws. In the U.S., tax laws have tended to favor shorter-lived assets, and account should be taken of this effect in a model that implicitly allocates property income to asset rents.

These and related advances in the literature strongly influenced the BLS approach to capital measurement. From the earliest BLS research, described below, until the most recent publications, the BLS has used Tornqvist aggregation with rental prices formulated with Hall-Jorgenson type tax parameters and a Jorgenson-Griliches type of internal rate of return computed using property income data from the NIPA.

As BLS developed its capital measures, a series of papers were prepared for discussion with other productivity researchers. The first set of capital measures completed was presented by Norsworthy and Harper [1981][1] (NH). Their approach to coverage, detail, and methods of aggregation were fairly similar to the study by Christensen and Jorgenson [1970]. The NH study worked with BEA net capital stock measures for three major subsectors of the private business sector: manufacturing, farm, and nonfarm-nonmanufacturing. For each sector, NH obtained BEA stocks of nonresidential structures and equipment and also of residential capital owned and rented out by private businesses. (Rented residential capital was included to ensure that the domain of the capital measures matched the data on labor hours and outputs used in the study.)

The BEA had started measuring capital stocks in the 1960s in an effort to improve the National Income and Product Account (NIPA) estimates of capital consumption allowances (CCA). BEA used capital stocks, which were based on historical investment data, to *adjust* its CCA estimates, which were based on tabulations of business tax returns. The capital stock approach to CCA estimation was deemed preferable because, unlike the tax returns, it used consistent accounting conventions. The BEA capital stock work was reported to the CRIW by Young and Musgrave [1980].

The NH study also made estimates of inventories and land. The five asset categories included in the estimates (structures, equipment, rented residential capital, inventories and land) were fairly close to the domain of capital measures recommended by Diewert for productivity work. The present BLS measures still cover this same domain. The NH study contained tables showing the effects on the growth rate of nonfarm business capital stocks of adjusting the domain of the measures. Capital stocks reflecting the five categories grew more slowly than stocks of private equipment and structures.

The NH study went on to address the issue of *aggregation of stocks of assets of different types*. In this area, the study closely followed the procedures of Jorgenson and Griliches [1967] described earlier. Implicit rental prices were estimated for each of the five asset types and these were used to construct chained Tornqvist indexes of capital inputs. The resulting capital input measures grew about 0.2 percent per year faster than comparable “directly aggregated” capital stocks.

The same capital measures were used in a broader study of factors affecting productivity by Norsworthy, Harper and

---

[1] This work was first reported in a January, 1979 BLS working paper.

Kunze [1979] (NHK). This paper contained a discussion of the issue of *vintage aggregation.* The available options were to use either the BEA gross or net stocks of capital. The BEA gross stocks assumed there were discards, but no depreciation. The BEA net stocks assumed there was straight line depreciation. Denison [1980] had used a 3:1 weighted average of gross and net stocks in his growth accounting work. The NH and NHK studies elected to use the BEA net stocks, although it was noted that "there is evidence that the net capital stock understates and the gross stock overstates real capital input" (NHK, p. 399). Gross and net stocks were compared, and the alternatives made little difference to the long term growth rates of capital. However, it was noted that it did make a 0.5 percent difference in the capital trend during the 1973-1978 period. The investment mix was changing rapidly during this period. We shall return to this vintage aggregation issue.

NHK extended the scope of the MFP analysis beyond capital to look at other quantifiable influences on productivity. These included the effects of changing labor composition (discussed further below), the effects of expenditures on pollution abatement equipment and the effects of cyclical factors. NHK presented the MFP measures in terms of an equation similar to the one used by Solow [1958]. This equation, which was derived from a production function, helps explain the differences between labor productivity and MFP. If y, l, k, and a are the growth rates of output, labor, capital and MFP respectively, then:

$$(y - l) = a + s_k (k - l) ,$$

where s_k is the share of capital income in the nominal value of output. Thus, labor productivity grows because of "shifts in the production function", a, and also because of increases in capital intensity. The NHK paper presented tables which implemented this equation. As Table 4 illustrates, the BLS [1996] has continued to discuss its long term MFP trends using tables like these. These trends are examined later in this paper, following a discussion of the BLS labor composition measures.

The first measures of capital formally published by BLS: new asset type detail and new assumptions about vintage aggregation

Soon after the MFP work was funded, the BLS [1983] issued a formal publication presenting new BLS data series on MFP. This publication presented series on output per unit of combined labor and capital inputs for private business, private nonfarm business and manufacturing. It included descriptions of the methodology underlying this new series and the data sources used. This work was summarized by Jerome Mark and William Waldorf [1983], who directed the project. While similar in coverage and technique to the NHK study, this first formal publication of MFP numbers reflected much more detailed data work than had been done for the earlier research.

Rather than simply use the BEA net stocks of equipment and structures, the BLS [1983] applied the rental price and Tornqvist aggregation techniques to more detailed categories of asset types. The BEA derived its net stock of equipment by adding together stock estimates for about 20 detailed types of assets. Similarly, the BEA made separate stock estimates for 14 types of nonresidential structures and 10 categories of residential assets, each with its own service life. In its estimation of capital consumption allowances, BEA had recognized that it is important to take account of changes in the mix of assets, since there is wide variation in the useful lives of assets. The BLS recognized that the rental prices implied by different service lives would be quite different, and so the use of rental prices in aggregation from this amount of detail had the potential to reveal an important new dimension of capital composition change. It did indeed, as the new capital services input measure grew 0.8 percent per year faster than a corresponding directly aggregated capital stock! The comparable figure in the NH study, when only the five broad classes were used, was 0.2 percent. Thus, by applying the rental price and Tornqvist index techniques to the greater asset detail, changing capital composition contributed four times as much as it had when only the five broad asset classes had been considered. Apparently, the shifts toward shorter lived assets within the five broader asset classes were quite significant, at least for productivity measurement purposes.

The published BLS [1983] work, unlike the earlier work by BLS researchers, did not make use of the BEA net stocks. With the cooperation of BEA, BLS obtained the asset type detail underlying the BEA investment totals. Rather than use net stocks, BLS ran its own perpetual inventory method (PIM) calculations of stocks for detailed asset types. Harper [1983] had examined the issue of what to assume about how the weights for investments decline as assets age. It was clear from the literature that the appropriate weights for this “vintage aggregation” should reflect the relative marginal products of the capital goods, of different vintages, actually used in current production. In theory these marginal products would be reflected in the relative rental prices of the goods in the current period rather than the relative sales prices of the goods.

This posed a dilemma because, while there was some evidence on economic depreciation of sales prices, the BLS researchers were not aware of any empirical evidence on rental prices as a function of age. However, BLS did find one source of quantitative evidence on output deterioration.[2] The mileage that trucks were driven declined only gradually during the first few years of their service lives, and then more rapidly later. BLS adopted "age/efficiency" functions which declined gradually during the first few years of an asset's life, and then more rapidly as the asset aged. BLS used a "hyperbolic" formula to represent the services, s_τ, of a τ year old asset:

$$s_\tau = (L - \tau) / (L - \beta\tau) \quad \text{for } \tau < L$$

$$s_\tau = 0 \quad \text{for } \tau > L ,$$

where L is asset's service life, and β is a "shape" parameter. For $\beta = 1$, this formula yields a gross stock. For $\beta = 0$, it yields a straight line deterioration pattern. For $0 < \beta < 1$, the function declines slowly at first, and then more quickly later. BLS assumed $\beta = 0.5$ for equipment and $\beta = 0.75$ for structures. The formula was implemented assuming BEA's service life estimates and also assuming a discard process similar to the one used by BEA. With these assumptions, the BLS stocks were bounded by BEA's gross and net stocks. The BLS approach was effectively quite similar to that of Denison [1974].

Reformulation of capital measures at the two-digit industry level

Since their introduction, BLS capital measures have undergone several improvements, including reformulation at about the 2-digit industry level. The BEA completed a major data development project, reported by Gorman, Musgrave, Silverstein and Comins [1985], to make investment data

[2] In addition, Ball and Harper [1990] studied cows as a capital asset in conjunction with measures of MFP being developed by the U.S. Department of Agriculture. They found that the output of a cow actually increases between the first and second years of her "service life".

available for two-digit NIPA industries. This study made use of capital flow tables, developed as part of the BEA input-output work, to allocate industry investment control totals to approximately the same asset-type detail which had been available earlier at the sectoral level. The control totals were based on the BEA plant and equipment survey and quinquennial economic censuses with adjustments for NIPA conventions.

The BLS began work to apply the rental price and Tornqvist aggregation techniques to detailed asset-type data at the two-digit industry level. This work made it possible to develop two-digit level measures of capital and MFP. It was also believed that these data improvements would lead to superior results at the major sector level. The first stage in this work was the reprogramming of the PIM and rental price calculations at the two-digit levels.

After completing an initial set of calculations, it was discovered that rental prices for some asset types in some two-digit industries were quite volatile from one year to the next. The problems appeared to be linked to large variations in the "revaluation terms", $\Delta p_a = p_{a,t} - p_{a,t-1}$, of the rental price equations. The problems were most serious from the middle 1970s to the early 1980s, a period when inflation rates accelerated. Some rental prices were even negative. As an example, rental prices were experimentally calculated by BLS in 1986 for metalworking machinery in miscellaneous manufacturing industries. These prices, based on the new data and the earlier methodology, are presented in Table 2.

Table 2: Early Experimental Rental Prices for Miscellaneous Manufacturing Industries

1971	.2997
1972	.3518
1973	.5535
1974	-.4473
1975	.1898
1976	.3425
1977	.4006
1978	.6294
1979	2.0676
1980	1.2731
1981	.4075

The volatility of individual asset rental prices led to instability of the shares in the Tornqvist aggregation of capital assets within some industries. This, in turn, led to some erratic movements in the aggregate index of capital inputs for these industries.

A research project was initiated to determine why the model did not work properly under these circumstances. Harper, Berndt and Wood [1989, p. 336] (HBW) pointed out that the implicit rental price formula is “based on the assumed correspondence between the purchase price of an asset and the discounted value of all future capital services derived from that asset”. Since the asset price is dependent on the future, it is a function of investors’ expectations. Changing expectations could account for the observed variations in the revaluation terms, $p_{a,t}-p_{a,t-1}$. HBW noted that theory does not provide guidance as to how best to measure either expected revaluation, $\exp(\Delta p_a)$, or the discount rate, r. HBW then described various alternative means which had been used in the literature to estimate the rates of return and revaluation.

Following recommendations resulting from this study, the BLS decided to use a three year moving average of prices, $(p_{a,t}-p_{a,t-3})/3$, to estimate expected revaluation. BLS also decided to continue to calculate internal rates of return, except for a few instances where the problem of volatile rental prices remained. In these cases, property income estimates in the NIPA were so low in some years that rates of return were negative. For these cases, BLS decided to assume a 3.5 percent rate of return on all assets, while deducting nothing for expected revaluation. The result is that BLS effectively assumes a 3.5 percent “real” rate of return for industries where the three-year moving average fails.

Empirical evidence on deterioration and depreciation

While the BLS [1983] had adopted a hyperbolic formula to represent the capital decay process, the BLS had used the service life estimates developed by the BEA. However, there was very little evidence in the literature on service lives, rates of decay, or economic depreciation rates. There was some evidence on the economic depreciation of structures, developed by Hulten and Wykoff [1981], but relatively little on equipment. BLS began an effort to find additional evidence. As part of that effort, Berndt [1984] examined data on automobile depreciation and Hulten, Wykoff and Robertson [1989] examined machine tools prices.

Evidence has continued to accumulate.[3] At a CRIW workshop on capital stock measurement, Triplett [199x] recommended that the U.S. government agencies use the evidence already available while putting priority on gathering additional evidence. BEA developed a plan for

---

[3] For example, Ellen Dulberger [1989] and Stephen Oliner [1993] have studied depreciation of computers and their components.

revising its service life estimates and depreciation measures. The available evidence was evaluated by Barbara Fraumeni [1997] and used by Arnold Katz and Shelby Herman [1997] to recalculate the BEA capital stocks. Rather than assume straight-line depreciation, BEA now assumes geometric depreciation of most asset types in computing its net stocks.

Detailed data associated with this new BEA work became available by September 1997. BLS is presently working on re-estimating the two-digit capital input measures, by type of asset, which it uses in the aggregate MFP measures. Since the productivity measures require a model of the deterioration of efficiency with age rather than one of economic depreciation, BLS plans to continue to use its hyperbolic age/efficiency formula. However, BLS will adopt new service lives, based on the new information on depreciation published by BEA. The BLS decisions will rely, as before, on the relationship between “age/efficiency” and “age/price” profiles (depreciation schedules) discussed by Hall [1968]. This relationship permits the calculation of a depreciation rate from any assumed mean service life estimate. BLS will select service lives for consistency with the BEA depreciation rates, while maintaining the assumption of gradual deterioration for new assets. BLS will continue to estimate rental prices and use these in Tornqvist aggregation.

Changes in the composition of the labor force and its effects on productivity

The labor input data used in many studies of productivity are direct aggregates of hours worked or hours paid in a sector or industry. That is, hours are assumed to be homogeneous. It would be more accurate, however, to assume that hours worked are heterogeneous and that some hours contribute more input to economic production than do others. Hence, changes in the composition of the labor force should be taken into account in productivity measurement. For many years, Dale Jorgenson and his colleagues and, using a different approach, Edward Denison prepared estimates of the impact on productivity of changes in the composition of the labor force. Among the many studies of this impact by these two sets of researchers were Jorgenson, Gollop and Fraumeni [1987] and Denison [1985]. After considerable study, BLS researchers developed their own approach to this problem, culminating in a bulletin, BLS [1983]. This introduced a methodology for measuring labor composition change. Since 1993, the BLS major sector MFP data have been measured net of the effects of changes in labor force composition.

The BLS approach can be described, very broadly, along the following lines. The approach builds on the insight that each worker possesses a unique set of skills that are matched in varying degrees to a firm’s needs. Labor hours are differentiated to take account of some of the primary differences in skills among workers, in particular, those skill differences that can be captured by differences in years of schooling and work experience. The methods developed to measure these skill differentials make use of the assumption, fundamental for productivity analysis, that factor inputs are paid the values of their marginal products. Within this framework, labor input is defined as a weighted average of the growth rates of groups of hours. And the groups of hours are defined by reference to specific levels of education and experience. Because labor input is inclusive of labor composition changes, the BLS measures of labor and multifactor productivity can be directly related to these compositional changes.

One major task faced by the BLS researchers was to determine which worker characteristics reflect underlying skill differences. In developing the theory of human capital, Becker and Mincer (for example, Becker [1975]) examined the role of education and on-the-job training in the acquisition of skills and earnings, skills being the ultimate source of worker productivity. Education and training are the means of acquiring additional skills beyond innate abilities, and the economic incentives to invest in skills yield a direct relationship between earnings and education and training. However, data on training are rarely available in the form required by a macro-economic productivity measurement effort, and so on-the-job training is not a practical basis for differentiating workers. Mincer [1974] attacked this problem by developing a wage model which related training investments to the length of work experience.

The BLS methodology took advantage of Mincer’s model by developing time series on work experience and relating these data to other human capital variables. The BLS study cross-classifies hours of work by education and work experience for each sex. The choice of work experience, instead of commonly used variables such as age or the number of years since leaving school, is dictated by the close relationship between work experience and the amount of time that a worker can learn through working.

The Bureau’s approach to these issues was developed not only by the examination of human capital theory and its implications for productivity measurement, but also by a close study of previous productivity research related to the measurement of labor input. Dale Jorgenson, Frank Gollop and Barbara Fraumeni [1987] (JGF) disaggregated the labor input of all employed persons into cells, cross-classified by several characteristics of labor and by several dimensions of the structure of the economy. Further, Edward Denison [1985] provided data on the contribution to changes in output of each of several pertinent characteristics of labor. In both cases, information on the earnings of labor—fundamentally, information on the prices of the different types of labor—was used to provide weights for combining heterogeneous labor inputs. This use of earnings data reflects the common assumption that earnings of different types of labor reflect their respective marginal value products. One unique aspect of the BLS study was to develop labor market prices for each characteristic rather than to use average earnings data for bundles of traits.[4]

The BLS methodology includes the aggregation of different types of labor using Tornqvist indexes, consistent with the procedure introduced by Jorgenson and his colleagues. This aggregation approach is consistent with production theory and permits the incorporation of worker heterogeneity by modelling differences in workers' marginal products.

The labor composition series was introduced in a BLS [1993] bulletin, prepared mainly by Larry Rosenblum. This followed earlier work by Kent Kunze [1979]; William Waldorf, Kunze, Rosenblum, and Michael Tannen [1986]; Edwin Dean, Kunze and Rosenblum [1988]; and Rosenblum, Dean, Mary Jablonski, and Kunze [1990].

The construction of the BLS labor composition series

To implement the methodology just described, estimates of the prices of each relevant type of labor are obtained

[4] For a discussion of similarities and differences between the BLS approach and the approaches of JGF and Denison, see Appendices F and A of BLS [1993].

from annually-fitted hourly earnings functions. The BLS then accepts the coefficients for schooling and experience as good approximate measures of the contribution of the skills associated with schooling and experience to both earnings and worker productivity.

The wage model is specified as:

$$\ln(W_{ijk}) = a + bS_i + cX_j - dX_j^2 + fZ_k$$

The log of the wage, W_{ijk}, is a function of i years of schooling, S; j years of experience, X; and the k^{th} bundle of other traits, Z. In line with the JGF approach and much of the human capital literature, separate equations are estimated for men and women. In this equation, the parameters b, c and d measure the roles of education and experience in determining wages for men and women. First and second order experience terms are included to capture the observed parabolic pattern of earnings with experience. While the full equation is estimated, only the differences in earnings by education and experience are directly used to estimate changes in labor composition. However, the average effect over all other characteristics, $\bar{Z}$, is added to the intercept.[5]

To estimate the wage equations, hourly earnings are constructed from data available in the March Supplement to the Current Population Survey (along with information from the decennial censuses for years before 1967). The education variable is defined for seven schooling groups, with zero through four years of schooling as the lowest schooling group and 17 years or more as the highest.

[5] For a full discussion of the estimating equation used, see Appendices A and E of BLS [1993].

Labor force experience in this equation is not the commonly-used "potential experience," i.e., age minus years of schooling minus 6. Instead, actual quarters of work experience are estimated. The estimating equations make use of actual quarters of work experience reported to the Social Security Administration. Estimated work experience is developed as a function of potential experience, a set of schooling dummy variables, the interaction of potential experience and schooling variables, other work experience variables and selected demographic variables. For women, the estimating equations make use of number of children and marital status. The experience equation was estimated using detailed information for 1973 from an exact-match file linking Social Security data with Current Population Survey and Internal Revenue Service records. For each type of worker, the coefficients from the 1973 equation are used to estimate work experience. While the amount of work experience assigned to each type of worker does not change over time, shifts in the distribution of workers among categories does change annually allowing for changes in the average amount of work experience.

To implement the equation, it was necessary to construct annual matrices of hours worked by each age-experience-sex group. These matrices have 504 cells for men and 4,032 cells for women.

Table 3 shows estimated average annual growth rates of labor input, hours and labor composition change for the private non-farm business sector. Growth rates for total labor input are produced by combining the effects of changes in hours and labor composition.

Table 3. Labor input, hours, and labor composition change in private non-farm business, average annual growth rates for selected time periods, 1948-94

Year	Labor input	Hours of all persons	Labor composition
1948-94	1.7	1.3	0.3
1948-73	1.4	1.2	0.2
1973-94	2.0	1.5	0.4
1973-79	1.9	1.9	0.0
1979-90	2.1	1.6	0.5
1990-94	1.6	0.9	0.8

Note: Hours of all persons plus labor composition may not sum to labor input due to rounding.

Several results of this computation of labor input are noteworthy. First, because labor input rose more rapidly than the direct aggregate of hours, there is a decrease in the estimated growth rate of MFP. Increases in skills, as measured by the labor composition shifts, led to faster labor input growth and slower MFP growth.[6]

A second noteworthy result is that between 1964 and 1979, the growth rate of labor composition declined to zero. This period coincided with the entrance of the baby boom generation into the labor market as well as rapidly rising labor participation rates for women. This decline

[6] Note, however, that the contributions of labor composition change are smaller than the figures presented in the table above. The calculation of this contribution must take into account an estimate of the elasticity of output with respect to labor input; the best estimate of this elasticity is provided by labor’s share of input, roughly two-thirds at the macro level. For further information on the contribution of labor composition change, see tables 4 and 5 and the accompanying text.

contributed to the post-1973 slowdown in overall productivity growth.

A third important result is that the growth rate of labor composition change has increased in the 1990s and, for the first time, is about as large as the growth in the direct aggregate of hours worked; both grew at around 0.8 percent in the private non-farm business sector.

A fourth result is not shown in the above table, but is presented in the bulletin that introduced these data. The researchers who undertook the labor composition study attempted to find a method for determining the contribution of the separate workforce traits—education, experience, and gender—to the overall trend in labor composition. The research concluded that exact measures of the separate traits would require a set of highly unlikely assumptions. Among other problems, an hour of work must be divisible into separate service flows for each trait. Consequently, no study of labor composition change is likely to produce an exact decomposition.[7]

Nonetheless, Rosenblum and his colleagues attempted to provide plausible estimates of the separate contributions of the various traits, by making heroic assumptions within the framework of the BLS labor composition model (BLS [1993], Appendix H). Two of the results of this exercise can be described as follows. First, it appeared that the long-term increasing trend in labor composition was due predominantly to rising educational levels. Second, the turning points in labor composition trends between sub-periods (such as the increased growth after 1979) were apparently due mainly to changes in work experience.

[7] See BLS [1993], Appendix H and also Rosenblum, Dean, Jablonski, and Kunze [1990].

Presently, work is under way within the BLS Office of Productivity and Technology to improve and update the experience equation used to estimate hours of experience.

Hours at work

The actual input of labor into the production process is more closely approximated by hours at work than by hours paid. Yet the Current Employment Survey, the main source of the hours data used in the BLS productivity program, is collected as hours paid. The NAS Panel [1979, p.125] recognized that this situation was unsatisfactory.

The Bureau's Hours at Work Survey has been used to convert the hours paid of nonagricultural production and nonsupervisory employees to an hours-at-work basis. This work is described by Jablonski, Kunze, and Otto [1990] and also in BLS [1997]. Hours at work exclude all forms of paid leave, but include paid time for travel between job sites, coffee breaks and machine downtime. This survey of about 5,500 establishments has collected annual ratios of hours at work to hours paid since 1981. Ratios are developed for each 2-digit SIC industry within manufacturing and for each 1-digit industry outside of manufacturing. Unpublished data and other survey information have been used to extend the annual ratios back to 1947 as well as develop ratios for nonproduction and supervisory workers. Hence, labor productivity in the BLS major sector work is essentially measured as the ratio of output to hours at work. Labor input in the MFP major sector series and the KLEMS manufacturing series is also measured as hours at work.

Fisher indexes for output in major sectors

Earlier sections of this paper have examined the short-comings, for purposes of productivity measurement, of fixed-weighted indexes of outputs and inputs and the advantages of changing-weight, and especially superlative, indexes for productivity measurement. The paper has also examined the BLS introduction of superlative indexes in its measurement program, beginning in 1983. However, up until February 1996, BLS was using fixed-weighted output indexes for its major sector productivity series. For these series, it was continuing to make use of the BEA constant-dollar data from the national accounts.

In 1992, the BEA first introduced two new indices of real GDP and its major components, both based on the Fisher index method, as “alternative” indices to its constant-dollar indices. One of these two new indices was presented in annually-chained form—the “chain-type annual-weighted” index. In January 1996 (check date), the BEA adopted the chain-type annual-weighted series as its featured measure for GDP and its major components. In February 1996, the BLS incorporated this output index into its quarterly major sector labor productivity series.[8]

Trends in major sector multifactor productivity

BLS updates the MFP study about once a year. Table 4 shows the results available at the time of the deadline for this paper. We expect to have new data for 1995 and 1996 available shortly. The trend in output per hour is attributable to growth in capital intensity (as in Solow’s equation, which we discussed earlier), labor composition, and MFP. In addition, effects of expenditures on research

[8] This means that all input indexes and most output indexes used in the BLS productivity measurement program are Tornqvist indexes, while some output indexes are Fisher indexes. This difference is not regarded as significant. For further discussion, see Dean, Harper and Sherwood [1996]; Dean, Harper, and Otto, [1995]; and Gullickson [1995].

and development are estimated using methods published by BLS [1989] based on work by Leo Sveikauskas [1986].

The post-1973 productivity slowdown is clearly evident in Table 4. A slowdown in capital intensity made a modest contribution to the labor productivity slowdown. While labor composition effects contributed 0.2 to the slowdown during the 1973-1979 period, these effects have actually boosted labor productivity since 1979. But the dominant source of the slowdown is MFP. Since MFP is calculated as a residual and reflects many factors, the major factors underlying the slowdown are not evident in the BLS measurement model. The causes of the slowdown have been the subject of intensive investigation, particularly during the 1980s.

Table 4. Compound average annual rates of growth in output per hour of all persons, the contributions of capital intensity, labor composition, and multifactor productivity, by major sector; 1948 to 1994 and sub-periods

Item	1948-1994	1948-1973	1973-1979	1979-1990	1990-1994 1/
Private business 2/					
Output per hour of all persons	2.4	3.4	1.2	1.2	1.3
Contribution of capital intensity 3/	0.9	1.0	0.7	0.7	0.3
Contribution of labor composition 4/	0.2	0.2	0.0	0.3	0.5
Multifactor productivity 5/	1.3	2.2	0.5	0.2	0.4
Private nonfarm business 2/					
Output per hour of all persons	2.1	2.9	1.0	1.0	1.2
Contribution of capital intensity 3/	0.8	0.9	0.7	0.7	0.4
Contribution of labor composition 4/	0.2	0.2	0.0	0.3	0.5
Multifactor productivity 5/	1.1	1.9	0.3	0.0	0.3
Contribution of R&D to multifactor productivity	0.2	0.1	0.1	0.2	0.2

1/ Because 1990-94 is not a completed business cycle, comparison of trends with earlier periods may be misleading.
2/ Excludes government enterprises.
3/ Growth rate in capital services per hour times capital's share of current dollar costs.
4/ Growth rate of labor composition (the growth rate of labor input less the growth rate of hours of all persons) times labor's share of current dollar costs.
5/ Output per unit of combined labor and capital inputs.

Note: The sum of multifactor productivity and the contributions may not equal labor productivity due to independent rounding.

As we have seen, the BLS procedures involve a number of elements designed to ensure consistency of the measures with production theory. These involve aggregating labor, capital and output from detailed data using value-share weights and superlative index numbers. In Table 5 we compare the BLS “production theory” measures (**bold** print) to alternatives based on more traditional measurement techniques. Since 1979, production theory based MFP has grown very little. While MFP itself is not a “traditional measure”, if it were put together from output, labor and capital that were measured using traditional techniques, we would find MFP growing 0.8 percent per year from 1979 through 1990 and 1.8 percent during the period 1990-1994.

Table 5. Output and Inputs: Measures Based on Production Theory Compared to Traditional Measures

Estimation of Multifactor Productivity Growth in the Private Nonfarm Business Sector

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

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

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

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

V. Industry Productivity Work

BLS found guidance for its work on aggregate capital measurement and labor composition measurement in the economics literature. The literature provides additional guidance on industry productivity measurement and on the issue of comparing industry and aggregate productivity measures. This literature stresses the importance of taking account of the goods and services sold by one industry to another. These transactions are included in “gross” output measures. And in computing MFP, these “intermediate transactions” should be reflected in input measures. Estimates of “real value added” output measures treat the issue of intermediates in a restrictive way. The literature also stresses the importance of using nonrestrictive index number formulas at the industry level.

In this section we discuss the development of measures of MFP for the manufacturing sector and its two-digit level subsectors. We then proceed to describe recent and planned improvements in our program to measure labor productivity and MFP for more detailed industries.

Expansion of multifactor productivity measures for manufacturing to include intermediate inputs

The NAS [1979] report recommended that BLS produce measures of intermediate inputs, as well as capital and labor inputs. Frank Gollop, in one section of the NAS report [Gollop 1979], and in a subsequent revised treatment of the same issues [Gollop 1981], discussed the role of intermediate inputs in the measurement of MFP. The correct treatment of MFP varies depending on whether the MFP measurement task is at a highly aggregate level or at the level of detailed industries. At a highly aggregate level, the analyst’s interest may appropriately be focused on final product. Thus gross domestic product excludes intermediate inputs in order to avoid “double counting”. Aggregate production functions, including the work of Solow [1957] on productivity, described the entire economy and so included measures of final product.

For industry level work, however, Gollop and others explained that it was a mistake to ignore intermediate inputs--those purchased from other industries. A different concept of output is also appropriate. Gross outputs, defined as total shipments adjusted for inventory change, should be compared to measures of labor, capital and intermediate input. This approach was implemented by Berndt and Wood [1976] when they used Census of Manufactures data to estimate MFP for two-digit manufacturing industries.

As with capital measurement, the BLS work on manufacturing proceeded in several stages. In BLS [1983], measures of manufacturing MFP compared net outputs to labor and capital inputs. Data from the NIPA on real “gross product originating” (GPO) in manufacturing were used to measure net output. GPO data are net in the sense that intermediate inputs are subtracted from gross output. In concept, they are closely akin to “value added”.

At the same time BLS was experimenting with a dataset for total manufacturing which compared gross output to capital, labor, energy, and materials. Such data were used in research by Norsworthy and Harper [1981] and by Norsworthy and Malmquist [1983].

When capital measurement at the two-digit industry level became feasible, BLS began work on an MFP series for two-digit manufacturing industries, which would include intermediate inputs. In building these measures, BLS made use of definitions proposed by Domar [1961]. Domar had used production functions to develop a structure for relating industry and aggregate MFP measures. The key was to define the output of any industry or sector to include intermediate products it ships *to other sectors* while defining inputs to include intermediates purchased *from other sectors*. At the same time, intermediate transactions occurring between establishments within the industry or sector were to be excluded from both outputs and inputs. Gollop [1979] referred to measures conforming to these definitions as “sectoral” outputs and inputs and recommended that BLS use them. This approach had been used in many studies by Jorgenson and his associates. The most complete of these was a study of U.S. economic growth using the production theory approach by Jorgenson, Gollop and Fraumeni [1987].

A new BLS dataset on MFP for manufacturing and two-digit manufacturing industries compared sectoral outputs to inputs of capital and labor, and also to three categories of intermediate inputs: energy, nonenergy materials, and purchased business services. Borrowing letters from each input, BLS refers to these as “KLEMS” measures. Sectoral output was based on four-digit level shipments data from the Census of Manufactures. Shipments were adjusted for inventory changes and for the exclusion of “intrasectoral” flows of intermediates, and then deflated with price indexes. A Tornqvist index of five types of fuels was derived from data from the Department of Energy. The annual series on nonenergy materials and services were derived from data from the BLS Office of Employment Projections. These, in turn, were based on BEA’s benchmark input-output tables. Deflation is accomplished with NIPA price indexes.

Harper and Gullickson [1986] discussed the interpretation of trends in these input series for manufacturing and manufacturing industies, cautioning that changes in factor proportions were linked, in theory, to changes in relative factor prices. MFP measures from this dataset were formally presented as new BLS measures by Gullickson and Harper [1987]. More recently, BLS [1996] began publishing the new KLEMS MFP measures for total manufacturing in place of the initial comparisons of GPO to capital and labor inputs. In addition, the annual “sectoral output” series has replaced BEA’s “gross product originating” as the basis for annual movements in the output per hour measures which BLS publishes each quarter for manufacturing. The Industrial Production Indexes of the Federal Reserve Board are still used to estimate quarterly movements in this series. These changes in the quarterly series were described by Dean, Harper, and Otto [1995].

Improvements in the productivity measurement program for detailed industries

For many years, the BLS has developed, maintained, and published industry productivity measures at the 3- and 4-digit industry level. The literature cited above, in the discussion of improvements in the data series for major sector and 2-digit manufacturing industry measures, has also been examined for its implications for these detailed industry data. In particular, the work of Solow, Domar, Jorgenson and Diewert, discussed above, suggests that particular methods are appropriate to the development of such measures. This work suggests (1) the use of the sectoral output concept in developing multifactor productivity series; (2) aggregation from detailed product information using superlative indexes, such as the Tornqvist index; and (3) development of major sector productivity measures by aggregation of industry input and output data.

Implementation of the improvements

As of the mid-1970s, the BLS industry measurement program could be described along the following lines. Output indexes were calculated by a fixed-weight formula, with the weights changed (in most cases) every five years. Production indexes for detailed types of output were produced by one of two methods. The indexes in most industries were computed from information on physical quantities produced. In other industries, time series on nominal output data for detailed types of goods or services were divided by corresponding price indexes. The price indexes reflected price changes relative to a specific year, the base year. The detailed output indexes computed by one of these two procedures were then weighted, using base-year weights, and added to produce an aggregate index of output of the industry. With each new economic census—generally, every five years—new weights were introduced and the resulting series were linked. The types of weights used varied: for some series unit value weights—or, roughly, price weights—were used; for other series employment weights or other weights were used. The resulting output indexes were then divided by indexes of hours, generally developed from establishment surveys. For details on this measurement methodology, see Dean and Kunze [1992].

As of 1975, only 53 measures were prepared and published annually. And the program was producing only labor productivity, or output per hour, measures. No multifactor productivity series were produced.

The improvements in the BLS productivity measurement program for detailed industries can best be explained by describing four separate activities that were undertaken between the mid-1970s and the late 1990s.

First, a rapid expansion of the Bureau’s original industry productivity measures was undertaken. While the number of annually-published industry productivity measures was 53 in 1975, by 1985, the BLS published 140 measures. (By 1997, the program published measures for 180 industries.) In addition, the number of measures based on deflated nominal data was expanded greatly and the measures based on physical quantity data became a small proportion of the total. Each new measure was published only after Bureau staff undertook a special study of the industry and selected the best available series. Senior economists reviewed these series carefully for each measure prior to publication. By 1997, about 40 percent of employment in goods-producing industries was covered by these measures, and also about 40 percent of employment in service-producing industries was covered. (The denominators used to compute these percentages are derived from the goods and services portions of employment in the non-farm business sector.) Further discussion of the BLS measurement methodology for labor productivity, as it was being implemented in the early 1970’s, can be found in Dean and Kunze[1992].

Second, development by BLS of multifactor productivity measures at the three-digit industry level began with measures for steel (SIC 331) and automobiles (SIC 371) constructed by Sherwood [1987]. By 1997, data for 10 industries were being regularly published. Examples of the additional industries are railroad transportation (SIC 40) and cotton and synthetic broadwoven fabrics (SIC 221 and 222). As noted earlier, industry measures of MFP were prepared for total manufacturing and for 20 two-digit manufacturing industries. The three-digit as well as the two-digit manufacturing series were prepared using sectoral output and inputs of capital, labor and intermediate purchased inputs. Tornqvist indexes were used to aggregate inputs as well as outputs.

Third, in 1995, most of the output measures for the labor productivity series were converted from fixed-weighted indexes, with the weights periodically updated, to Tornqvist indexes. Relative revenue weights were used to aggregate detailed product indexes in place of employment weights. And at the same time, most of the output indexes were converted from gross output to sectoral output measures. This work was described by Kunze, Jablonski, and Klarqvist [1995].

The fourth stage of improvement of the industry productivity measures is well under way, but not yet completed. This effort is expected to yield a very substantial increase in the number of labor productivity measures for detailed industries in manufacturing as well as in service-producing and other non-manufacturing industries. The objective is to develop output, hours, and output per hour series for all 4-digit industries in manufacturing and in retail trade, and to expand coverage substantially, mostly at the four-digit level, in transportation, communications, utilities, and mining industries. About 600 industry measures will be prepared and made available annually. It is likely that the data for some substantial proportion of these industries will not meet Bureau publication standards and considerably fewer than 600 industries will be published.

This new expanded industry dataset should prove useful in developing new insights into productivity trends in service-producing and other industries and to the on-going effort to improve output and productivity series for service-producing industries.

Following the completion of this expanded industry dataset, two additional steps will be taken. First, the

Bureau plans to use the new four-digit output series for manufacturing industries to improve its data for output and for labor and multifactor productivity in total manufacturing. Presently, these series are Tornqvist aggregates developed from Census Bureau data on nominal shipments by four-digit manufacturing industries, after adjusting for inventory change and estimating and eliminating intra-manufacturing shipments; deflation is accomplished using four-digit BEA price indexes. In the future, the output series for total manufacturing (as well as durable and non-durable manufacturing) will be Tornqvist-aggregated using the output series from the new expanded industry dataset.

The second additional step will relate to MFP data development. The Bureau expects to expand this new industry dataset to include information on capital and intermediate purchases, so that MFP series can be developed. The MFP data, we expect, will be available only at the three-digit level.

Elimination of the government productivity and technology programs

The productivity of the overall economy does not depend solely on activities within the private sector. It depends also on the productivity of resources used in government programs. The BLS major sector labor productivity series for the business sector includes the activities of government enterprises and of private enterprises selling goods and services to government agencies, but the business sector excludes all other government activities. The excluded portion, known as “general government,” amounted to about 11 percent of GDP in 1997.

For more than two decades, the BLS prepared and published data on trends in labor productivity in selected functional categories of the Federal Government (see Dean [1996]). As of 1996, this series covered fiscal years 1967 through 1994. In fiscal year 1994, the program covered organizations with 2.0 million full-time equivalent employees, representing 69 percent of Federal Government employment. This series indicated that during the period 1967-94, productivity in the measured portion of the Federal Government rose at an average annual rate of 1.1 percent. In addition, for a shorter period of time, BLS prepared series on labor productivity in selected state and local government activities. Both series were prepared using indicators of the outputs of specific products and services of government agencies.

In 1994, the state and local government productivity measurement program was terminated and in 1996 the Federal Government program was also terminated. Both actions were taken during times of constraints on the BLS budget.

For about 40 years, the BLS also had a program of studies of the technological changes taking place in specific industries. In the 1980s and early 1990s, publications were produced for two to four industries per year. These studies were a valuable complement to the BLS productivity measurement program, because improvements in technology have been a major force underlying productivity growth. The studies assessed, insofar as practicable, the economic advantages of new types of equipment, processes and products. They also examined changes in occupational structure, usually on the basis of data produced by BLS surveys and employment projections, and examined issues of adjustment of workers to technological change. Examples of the industries studied were bituminous coal, steel, life and health insurance, retail trade, and railroad transportation. This program was terminated in the mid-1994 for budgetary reasons.

VI. Summary and Conclusions

Summary of productivity measures presently published by BLS

This paper has discussed the development, over recent years, of the BLS productivity measures produced for the U. S. economy. It has touched on advances in the literature on productivity measurement and described how these advances have led the BLS to improve the methods it uses and to develop new data series consistent with these advances. Table 6 sets forth the current status of the BLS productivity measurement program. The columns provide summary information on the types of output and input indexes used. The table does not cover the BLS program of international comparisons of trends in productivity.

Table 6. Productivity data produced by the Bureau of Labor Statistics

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

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

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

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

Conceptual and empirical hurdles in planning for further data improvements

The BLS productivity program has addressed many of the concerns expressed by the National Academy of Sciences study [1979]. The BLS work has focused on development of time series of outputs, factor inputs, and other variables considered important for the measurement and analysis of productivity trends. These variables have been developed at the aggregate level and also for numerous individual industries. With the exception of the Hours at Work Survey, these time series have been developed from data published by other programs of the BLS and by other government statistical agencies.

Some further progress is possible by exploiting existing bodies of data to expand and improve the BLS productivity data series. However, at some point we expect to experience diminishing returns to this type of work. Furthermore, assumptions are made at many stages in the development of the BLS data, and these may limit the usefulness of the results for some analytic purposes.

Many new lines of empirical productivity research have opened up since the NAS recommendations were published. Among these are studies using firm or establishment level data, studies that relax the assumptions of perfect competition or instantaneous adjustment, and studies designed to expand the scope of productivity measurement to include environmental considerations. These types of studies, which are represented at this conference, examine important issues that cannot be addressed with the productivity data presently published by the BLS. However, significant conceptual and empirical issues need to be resolved before these types of analysis can be incorporated into the BLS program.

It is our expectation that the papers presented at this conference will elucidate both the usefulness and the limitations of the present BLS program. In addition, we expect that the papers, and the discussions of the papers at the conference, will suggest possible new directions for the BLS productivity program.

References

Ball, V.E. and M.J. Harper [1990], "Neoclassical Capital Measures Using Vintage Data: An Application to
Breeding Livestock," Washington: U.S. Bureau of Labor Statistics.

Becker, Gary [1975], Human Capital, New York: Columbia University Press.

Berndt, Ernst R. and David O. Wood [1984], "Energy Price Changes and the Induced Revaluation of Durable Capital in U.S. Manufacturing during the OPEC Decade," MIT Energy Lab Report No. 84-003.

Berndt, Ernst R., and David O. Wood, [1975]. "Technology, Prices, and the Derived Demand for Energy."
The Review of Economics and Statistics, LVII, No. 3, August: 259-68.

Berndt, Ernst R. and Jack E. Triplett [1990], Fifty Years of Economic Measurement, Chicago: University of Chicago Press.

Bureau of Labor Statistics [1942], Productivity and Unit Labor Cost in Selected Manufacturing Industries, 1919-1940, February.

Bureau of Labor Statistics [1959], Trends in Output per Man-Hour in the Private Economy, 1909-1958, Bulletin 1249.

Bureau of Labor Statistics [1983], Trends in Multifactor Productivity, 1948-81, Bulletin 2178, Washington:
U.S. Government Printing Office.

Bureau of Labor Statistics [1989], The Impact of Research and Development on Productivity Growth, Bulletin 2178, Washington: U.S. Government Printing Office.

Bureau of Labor Statistics [1993], Labor Composition and U.S. Productivity Growth, 1948-90, Bulletin 2426, Washington: U.S. Government Printing Office.

Bureau of Labor Statistics [1996], "Multifactor Productivity Trends, 1994," Washington: U.S. Department of Labor News Release No. 95-518, January 17, 1996.

Bureau of Labor Statistics [1997], BLS Handbook of Methods, Bulletin 2490, Washington: The U.S. Government Printing Office.

Christensen, Laurits R., and Dale W. Jorgenson [1970], "The Measurement of U.S. Real Capital Input, 1929-1967," *Review of Income and Wealth*, December, pp. 293-320.

Dean, Edwin R. [1996], "Accounting for Productivity Change in Government," in A BLS Reader on Productivity, Bulletin 2474, Washington: The U.S. Government Printing Office, pp. 164-173.

Dean, Edwin R., Michael .J. Harper and Mark K. Sherwood [1996], "Productivity Measurement with Changing Weight Indices of Output and Inputs," in Industry Productivity: International Comparison and Measurement Issues, Paris: The Organization for Economic Co-Operation and Development, pp. 183-215.

Dean, Edwin R., Michael J. Harper, and Phyllis Flohr Otto [1995], "Improvements to the Quarterly Productivity Measures." *Monthly Labor Review* 118, No. 10, October, pp. 27-32.

Dean, Edwin R. and Kent Kunze [1992], "Productivity Measurement in Service Industries," in Zvi Griliches, ed., Output Measurement in the Service Sectors, Chicago: University of Chicago Press, pp. 73-101.

Dean, Edwin R., Kent Kunze and Larry S. Rosenblum [1988], "Productivity Change and the Measurement of Heterogeneous Labor Inputs," presented at the Conference on New Measurement Procedures for U.S. Agricultural Productivity, available from the Bureau of Labor Statistics, Washington.

Denison, Edward F. [1974], Accounting for U.S. Economic Growth, 1929-1969, Washington: The Brookings Institution.

Denison, Edward F. [1985], Trends in American Economic Growth, 1929-1982, Washington: The Brookings Institution.

Diewert, W. Erwin [1976], "Exact and Superlative Index Numbers," Journal of Econometrics, Vol. 4, No. 4, pp. 115-145.

Diewert, W. Erwin [1980], "Aggregation Problems in the Measurement of Capital," in Dan Usher, ed., The Measurement of Capital, Chicago: The University of Chicago Press, pp. 433-528.

Domar, Evsey D. [1961], "On the Measurement of Technical Change," *Economic Journal*, LXX1, No. 284, December: 709-729.

Dulberger, Ellen R. [1989], "The Application of a Hedonic Model to a Quality-Adjusted Price Index for Computer Processors," in D.W. Jorgenson and R Landau (eds.), Technology and Capital Formation, Cambridge, MA: The MIT Press, pp. 37-75.

Fraumeni, Barbara M. [1997], "The Measurement of Depreciation in the U.S. National Income and Product Accounts," Survey of Current Business, July, pp. 7-23.

Goldberg, Joseph P. and William T. Moye [1984], The First Hundred Years of the Bureau of Labor Statistics, Bureau of Labor Statistics, Bulletin 2235.

Gollop, F.M. [1979], “Accounting for Intermediate Input: The Link Between Sectoral and Aggregate Measures of Productivity” in Measurement and Interpretation of Productivity, Washington, D.C: National Academy of Sciences, pp. 318-333.

Gollop, F.M. [1981] "Growth Accounting in an Open Economy," Boston College Working Papers in Economics, March.

Gorman, John A., John C. Musgrave, Gerald Silverstein and Kathy A. Comins [1985], “Fixed Private Capital in the United States,” *Survey of Current Business*, July, pp. 36-59.

Gullickson, William. [1995], “Measurement of Productivity Growth in U.S. Manufacturing,” *Monthly Labor Review*, July, pp. 13-28.

Gullickson, W. and Michael J. Harper [1987], “Multifactor Productivity in U.S. Manufacturing, 1949-83,” Monthly Labor Review, October, pp. 18-28.

Hall, Robert.E. [1968], “Technical Change and Capital from the Point of View of the Dual,” *Review of Economic Studies*, January, pp. 35-46.

Hall, Robert.E., and Dale.W. Jorgenson [1967], “Tax Policy and Investment Behavior,” *American Economic Review*, Vol. 57, No. 3, June, pp. 391-414.

Harper, Michael J. [1983], “The Measurement of Productive Capital Stock, Capital Wealth, and Capital Services,” Washington: Bureau of Labor Statistics Working Paper No. 128.

Harper, Michael J. and William Gullickson [1986], “Cost Function Models and Accounting for Growth,” presented at the annual meetings of the American Economic Association, New Orleans, and available from the Bureau of Labor Statistics, Washington.

Harper, Michael J., Ernst R. Berndt and David O. Wood [1989], “Rates of Return and Capital Aggregation Using Alternative Rental Prices,” in D.W. Jorgenson and R Landau (eds.), Technology and Capital Formation, Cambridge, MA: The MIT Press, pp. 331-372.

Hulten, Charles R. and Frank C. Wykoff [1981], “The Estimation of Economic Depreciation Using Vintage Asset Prices: An Application of the Box-Cox Power Transformation,” *Journal of Econometrics*, pp. 367-96.

Hulten, Charles R., James W. Robertson and Frank C. Wykoff [1981], “Energy, Obsolescence, and the Productivity Slowdown,” in D.W. Jorgenson and R Landau (eds.), Technology and Capital Formation, Cambridge, MA: The MIT Press, pp. 225-258.

Jablonski, Mary, Kent Kunze and Phyllis Flohr Otto [1990], “Hours at Work: a New Base for BLS Productivity Statistics,” *Monthly Labor Review*, pp. 17-24.

Jorgenson, Dale W. and Zvi Griliches [1967], “The Explanation of Productivity Change,” *Review of Economic Studies* XXXIV(3), No. 99, July: 249-283.

Jorgenson, Dale.W., Frank M. Gollop and Barbara M. Fraumeni, [1987], Productivity and U.S. Economic

Growth, Cambridge, MA: Harvard University Press.

Katz, Arnold and Shelby Herman [1997], "Improved Estimates of Fixed Reproducible Tangible Wealth, 1929-95," *Survey of Current Business*, May, pp. 69-92.

Kendrick, John W. [1976], The Formation and Stocks of Total Capital, New York: Columbia University Press.

Kunze, Kent, Mary Jablonski and Virginia Klarqvist [1995], "BLS Modernizes Industry Labor Productivity Program," *Monthly Labor Review*, July, pp. 3-12.

Mark, Jerome A. and William Waldorf [1983], "Multifactor Productivity: a New BLS Measure," *Monthly Labor Review*, December, pp. 3-13.

Mincer, Jacob [1974], Schooling, Experience and Earnings, New York: Columbia University Press.

National Academy of Sciences [1979], Measurement and Interpretation of Productivity, Washington, DC.

Norsworthy, J. Randolph and Michael J. Harper [1981], "The Role of Capital Formation in the Recent Slowdown in Productivity Growth," in Ali Dogramaci and Nabil R. Adam, eds., Aggregate and Industry-Level Productivity Analyses, Boston: Martinus Nijhoff Publishing, pp. 122-148.

Norsworthy, J.Randolph, Michael J. Harper and Kent Kunze [1979], "The Slowdown in Productivity Growth: Analysis of Some Contributing Factors," *Brookings Papers on Economic Activity*, December, pp. 387-421.

Norsworthy, J. Randolph and David Malmquist [1983], "Input Measurement and Productivity Growth in Japanese and U.S. Manufacturing," *American Economic Review*, December, pp. 947-967.

Oliner, Stephen D. [1993], "Constant-Quality Price Change, Depreciation, and Retirement of Mainframe Computers," in Murray F. Foss, Marilyn E. Manser and Allan H. Young, eds., Price Measurements and Their Uses, Chicago: University of Chicago Press, pp. 19-61.

Rosenblum, Larry, Edwin Dean, Mary Jablonski, and Kent Kunze [1990], "Measuring Components of Labor Composition Change," presented at annual meetings of the American Economic Association, Washington, available from the Bureau of Labor Statistics, Washington.

Samuelson, Paul A. [1947], Foundations of Economic Analysis, Cambridge, MA: Harvard University Press.

Sherwood, Mark K. [1987], "Performance of Multifactor Productivity in the Steel and Motor Vehicle Industries." *Monthly Labor Review*, August, pp. 22-31.

Solow, Robert M. [1957], "Technical Change and the Aggregate Production Function," Review of Economics and Statistics, Vol. 39, No. 3, pp. 312-320.

Sveikauskas, Leo [1986], "The Contribution of R&D to Productivity Growth," *Monthly Labor Review*, March, pp. 16-20.

Tornqvist, Leo [1936], "The Bank of Finland's Consumption Price Index," *Bank of Finland Monthly Bulletin*, No. 10, pp. 1-8.

Triplett, Jack E. [1992], “Measuring the Capital Stock: A Review of Concepts and Data Needs,” presented at a Workshop on the Measurement of Depreciation and Capital Stock of the Conference on Research in Income and Wealth, Washington, and available from the Bureau of Economic Analysis, Washington.

Waldorf, William, Kent Kunze, Larry Rosenblum and Michael Tannen [1986], “New Measures of the Contribution of Education and Experience to U.S. Productivity Growth,” presented at the American Economic Association Meetings, New Orleans, and available from the Bureau of Labor Statistics, Washington.

Young, Allan H. and John C. Musgrave [1980], “Estimation of Capital Stock in the United States,” in Dan Usher, ed., The Measurement of Capital, Chicago: The University of Chicago Press, pp. 23-68.