Preliminary estimates of multifactor productivity growth

Final multifactor productivity measures take more than a year to complete; using a simplified methodology and preliminary data, it is estimated that private business multifactor productivity grew 3.1 percent in 2003 and 3.3 percent in 2004

Peter B. Meyer
and
Michael J. Harper

Peter B. Meyer is a research economist, and Michael J. Harper is the chief of the Division of Productivity Research and Program Development, Office of Productivity and Technology, Bureau of Labor Statistics.
E-mail:
Meyer.Peter@bls.gov
Harper.Mike@bls.gov

Labor productivity growth supports long-term improvements in standards of living. Productivity can increase because of investments in equipment and structures, a more educated and experienced workforce, and improvements in technology. The BLS *multifactor productivity* (MFP) measures are designed to isolate the effects on labor productivity of capital growth and of the changing composition of the labor force. These input effects are reported separately, and multifactor productivity growth represents the unexplained portion of labor productivity growth.

The multifactor productivity measures are designed along the lines of Solow's method of growth accounting.[1] Substantively, multifactor productivity change results from joint influences on economic output of technological change; efficiency improvements (for example, because of better transportation or communications); returns to scale; reallocation of resources (such as shifts of labor among industries); and other factors, after allowing for the effects of capital and labor growth. An example of a source of efficiency improvement is the construction of the interstate highway system. It has been argued that this raised multifactor productivity and, analogously, that the Internet and the World Wide Web have done so.

Multifactor productivity change is defined and measured as the growth rate of output minus the growth rate of measured inputs. Let Y be output, L be a measure of labor inputs, and K be a measure of capital services inputs. Define s to be the share of income paid to labor, and assume that

the remaining fraction ($1-s$) is paid to capital. Delta (Δ) means the change since the previous year, so $\Delta Y/Y$ is the annual growth rate of output. BLS measures the quantities on the right side of the equation below to calculate the growth rate of multifactor productivity.

$$\frac{\Delta MFP}{MFP} = \frac{\Delta Y}{Y} - s\frac{\Delta L}{L} - (1-s)\frac{\Delta K}{K} \quad (1)$$

In the BLS approach, labor and capital inputs are divided further as discussed below. For example, labor input is a weighted combination of hours worked and can be divided into hours and changes in workforce composition. The notation we use later is that labor input $L=H*LC$, where H is a measure of hours worked and LC is an index of labor composition, adjusts for changes in the education and work experience of the employed population. Capital services can increase from growth in productive stocks of assets and from shifts within and across asset classes. A capital-income-weighted average of growth rates yields capital services. BLS publishes both index numbers and growth rates of multifactor productivity that averaged 0.96 percent from 1993 to 2002.

BLS calculates the annual growth of multifactor productivity for the U.S. private business sector. This measure is generally released about 14 months after the end of the year being measured, often called the *target year*.[2] The lag occurs because the process of calcu-

lating multifactor productivity requires detailed data from many sources.[3]

Some users of productivity measures, including policy and budget organizations in the U.S. Government, have made their own preliminary estimates of multifactor productivity while awaiting the official BLS measures. For its frequent short-term economic forecasts, the Federal Reserve routinely needs multifactor productivity growth figures before the BLS measure becomes available. Therefore, Oliner and Sichel of the Federal Reserve developed a method to make forecasts of the Bureau's estimates of multifactor productivity.[4]

This article summarizes a simplified methodology that BLS plans to adopt to make preliminary estimates of private business sector multifactor productivity change available within a few months after the end of target year t. The simplified methodology involves making estimates of the growth rates of output, and of labor and capital inputs, and of the shares of each input. (See equation 1). The simplified methodology works with fewer categories of capital and labor than the full methodology, as will be described below. The resulting simplified measure, called MFP^S_t, will later be supplanted by the full measure called MFP^F_t when complete data become available. The simplified measure is usually based on information from the full calculation from the previous year and on up-to-date information about approximate rates of change in output, labor, and capital in the target year. The estimates of the rates of change use information from the National Income and Product Accounts (NIPA) and other sources that become available early in the year following the target year.

The simplified methodology is designed to estimate multifactor productivity in a way that closely approximates that which is calculated by the full methodology, using the same basic structure and assumptions. For example, both methodologies estimate a productive capital stock for each of several kinds of assets. The productive stock is an aggregate of past investments weighted by estimates of their declining capacity to contribute to production because of deterioration and obsolescence. In the simplified method, such stocks are estimated for only a few summary asset categories instead of many detailed ones. In addition, rates of deterioration are determined from the recent average rate over all asset types in a class as developed in the full method. High-tech computer-related capital is still kept separate from other equipment in the simplified model because this category has grown substantially (representing half of nominal investment in the late 1990s) and has been influential on productivity trends in recent years.

The simplified methodology is relatively transparent and robust. Simplicity will help make the estimate available as early as possible. The procedure is transparently related to the full measure, and has been designed to approximate the full measure with fairly modest degrees of random error and

bias. The computation is robust in that it is designed to work even when there are changes in accounting categories or procedures within the statistical agencies. For this reason, published data series were used wherever possible, not data series used only internally to the BLS or BEA. Although this may slightly lower the accuracy of the simplified measure, it reduces potential obstacles to producing the measure at an early date. The procedure is also meant to be relatively robust to structural change in the economy. A carefully tuned procedure might make better estimates for the 1990s data series than this one, but it might also be more sensitive to unexpected economic changes in the future.[5]

There is a tradeoff between meeting these goals of simplicity, transparency, and robustness and the natural goal of reducing the discrepancy between the preliminary statistic and the full-method statistic. BLS expects to evaluate this methodology when there is a longer data series of simplified and full measure statistics with which to work.[6] The accuracy of the simplified measure should improve with experience.

The purpose of this article is to describe the simplified method and the evaluation of its reliability. The article first reviews the estimation procedure for each component of multifactor productivity, providing summary statistics on the reliability of each estimate. After summarizing the simplified method and results for output, labor input, and eight components of capital, the article discusses the assembly of these estimates into the simplified measure of multifactor productivity. Contributions of errors in each component to this measure are discussed, and it is noted that these errors often offset. The resulting simplified multifactor productivity measure is fairly reliable. This article also reports and evaluates simplified estimates of productivity prepared for the second year ahead of the last year for which full model estimates are available. These "second-year" estimates are denoted MFP^{S2}_t. The latest published BLS measures of multifactor productivity are for the year 2002. Finally, this article presents preliminary estimates of multifactor productivity for 2003 and 2004 using the simplified methodologies.

The methodology is tested using annual data for each year since 1993. The simplified measures are estimated for each year, extrapolating from the previous year's full estimation. To evaluate the usefulness of this approximation, the simplified estimate for each year t, denoted MFP^S_t, is compared with the most recently published full measure for that same year, MFP^F_t.

The evaluations in this article use the most recently available data for the full model, and therefore examine how well the simplified methodology replicates the full methodology for a given version of the data. In practice, when the BLS revises its simplified estimate to obtain a full estimate, the revision will reflect both the difference in methodologies and also any concurrent revisions to the underlying source data that will become available.[7]

Estimating output and labor inputs

Background. The BLS private business multifactor productivity measures compare output to the combined inputs of labor and capital. The output measures used by BLS are derived from gross domestic product (GDP) and other data from the National Income and Product Accounts (NIPA) for BLS by the Bureau of Economic Analysis (BEA). The NIPA measures of "final product" exclude the value of intermediate inputs like the leather used to make shoes, and these output measures are appropriately compared to labor and capital inputs.[8]

Productivity measures are meaningful only if outputs and inputs are measured independently. The NIPA measures of real output for general government, nonprofit institutions, private households and owner-occupied dwellings are excluded from published productivity measures in part because they depend on input measures to derive estimates of real output.[9]

BLS publishes measures of labor productivity (output per hour worked) for the business sector on a quarterly and annual basis in its Productivity and Costs (P&C) news releases.[10] BLS publishes annual measures of multifactor productivity for the *private* business sector. The private business sector differs only slightly from the business sector in that it excludes the BEA estimate of the output of government enterprises. Government enterprises include the U.S. Postal Service and local government water and sewage services among other activities.[11] The private business sector accounts for about three-quarters of U.S. Gross Domestic Product.[12]

The simplified method of measuring multifactor productivity estimates output growth and labor hours growth by applying the growth rates of output and hours in the business sector—from the published P&C measures—to the previous year's measures for the *private* business sector. The data for the simplified estimate are available soon after the conclusion of each year.

Next, we describe the simplified approach and characterize how well the simplified estimate of each variable approximates the full computation. Exhibit 1 summarizes the inputs to the simplified multifactor productivity calculation.

Exhibit 1. Components of simplified MFP calculation	
Component of multifactor productivity (MFP) calculation	**Sources and methods**
Structures and equipment investment (each of six categories)	Apply growth rates of new investment from NIPA tables listed in exhibit A-1 in the appendix to BLS private business sector investment level from the previous year's "full-MFP" report
Depreciation rates on existing capital assets	Hold constant the depreciation rates in the most recent full-MFP report
Structures and equipment productive capital stocks	By perpetual inventory method; deduct estimated depreciation of the previous year's stock of each asset type and then add new investment
Inventory capital stock	The previous year's stock in the full-MFP report is extrapolated with the percentage change in the NIPA inventory series for the business sector (see exhibit A-1 in the appendix)
Land capital stock	Extrapolated using the structures capital stock
Income shares of capital categories	Detailed asset shares from the previous year's full-MFP report are aggregated into these eight categories and assumed constant
Capital service inputs	Chain index combining stocks of the eight categories of equipment, structures, inventories and land, weighted by capital-income shares
Labor hours	Extrapolated from hours in the Productivity and Costs (P&C) news release
Labor composition	Computed from previous year's wage coefficients and current year hours from the Current Population Survey
Labor share	Previous year's full-MFP labor share is adjusted for change in labor share in P&C
Output in private business	Extrapolated from output measure in P&C

Procedures for estimating each component are discussed below. For each component, table 1 presents estimates corresponding to the full and simplified methodologies and the gap between these estimates, expressed by the average absolute value of the difference in the growth rates of the variables calculated from the full and simplified approaches. Errors in capital and labor figures are measured in growth rates because these are the form relevant to multifactor productivity calculation. The errors in growth rates are the ones directly relevant to the this calculation, because multifactor productivity is defined to be the difference between the growth rates of output and of inputs. Errors in levels are shown in table A-1 in the appendix.

Output. The simplified estimate of output, Y^S_t, comes from the following computation. From the previous year's full multifactor productivity measures, we obtain the private business sector output level in year *t-1*, Y^F_{t-1}. From BLS's Productivity and Costs (P&C) news releases, we obtain the percentage change in business sector output from year *t-1* to year *t*. We make the assumption that the slightly smaller private business sector grew by the same percentage. This gives us an estimate of private business sector output in year *t*. On average, this assumption is reasonable because the two sectors cover nearly identical portions of the economy, although there are fluctuations in accuracy attributable to the use of preliminary data and the difference in scope. Over the 1993–2002 period, when output growth averaged 3.8 percent per year, the absolute value of the difference between annual growth rates of output (that is, $/Y^F_t - Y^S_t/ /Y^F_{t-1}$) averaged 0.05 percent.

Labor inputs. The simplified measure of hours worked, H^S_t, comes from applying the percent change in hours worked in the business sector from the P&C report to the measure of private business hours in the previous year's multifactor productivity report, H^F_{t-1}. The hours measure is based mainly on the BLS Current Establishment Survey, but is supplemented by information from the Current Population Survey (CPS). On average, the simplified estimate of the growth rate of hours worked differs from the full estimates in the most recent multifactor productivity data, H^F_t, by 0.04 percent.

For the *labor composition* measure in the full methodology, the hours worked measure is adjusted for changes in the composition of the workforce. Rather than simply adding up hours worked, labor composition input is derived by aggregating the hours for groups of workers after weighting the hours of each group by shares in total compensation.[13] The

Table 1.	Differences in growth rates of MFP components between the simplified and full methodologies				
[in percent]					
Estimated component (capital stock, labor input, output, or MFP)	Full model annual change, average (1993–2002)	Simplified model annual change, average	Average discrepancy in annual change between models	Annual change in second year, average (1994–2002)	Average discrepancy in second-year change
Capital services	4.38	4.30	0.28	4.1	0.46
Structures stock	1.74	1.76	.09	1.9	.12
Computer stock	30.4	29.9	3.4	31.8	5.3
Software stock	13.6	13.2	3.1	13.9	2.4
Other information technology stock	7.2	7.0	.71	7.7	.4
All non-information technology equipment stock	3.2	3.2	.39	3.5	.5
Rental residence stock	1.1	1.1	.23	1.3	.4
Inventory stock	3.8	3.9	.34	4.0	.4
Land stock	.6	.5	1.3	.6	2.5
Labor services	2.0	1.6	.24	1.8	.24
Labor hours	1.8	1.8	.04	1.6	.07
Labor composition	.5	.4	.23	.4	.25
Output	3.8	4.0	.05	3.9	.05
MFP change	.96	.87	.22	1.07	.19

NOTE: "Discrepancy" means absolute value of differences in growth rates, expressed in percentages, from the previous year to the target year.

groups are classified into about 1,000 types based on their education, experience, and gender. The *labor composition index* is the ratio of the labor input measure to the simple hours worked measure. The labor composition index reflects the effects on productivity of changes in the education and experience of the workforce.

In the full methodology, the labor composition measure is constructed from data from the March Supplement to the CPS. Hours worked for each group are obtained from the survey data. The relationship between wage levels and education and work experience is estimated by a linear regression, from which it is possible to estimate wages for each group.[14] Then the shares of all labor income received by each group are estimated. Each group's income is its hours worked multiplied by its estimated wages. These shares are used to construct the measure of labor composition, which is a Tornqvist chain index of the groups.[15] After excluding the effects of hours growth, on average the labor composition index rose by 0.4 percent annually between 1973 and 2001 as the working population became more educated and more experienced.

A simplified estimate of the labor composition index is developed here. An estimate of the distribution of hours worked, by education, work experience and gender, is constructed from the CPS for the middle month of each quarter of the target year. The information used to measure the work experience of each group of workers is also less complete than in the full method. It relies in part on more complete information from the previous year. Furthermore, in the simplified method, measures of hourly wages for each education-experience group are drawn from the previous year. Provided that the *relative* wages for each group have not changed substantially, these wage rates should provide a strong basis for constructing income share weights for each subgroup of the workforce. Shifts in hourly wage rates contribute to labor composition growth over long periods of time, but historically account for little of the year-to-year change in labor composition. Once hours and wage rates are estimated, a Tornqvist index of a simplified labor composition index is calculated. Again, subtracting hours growth, the average absolute value of the difference between the simplified and full estimates of labor composition from 1993–2002 is 0.25 percent.

The labor input figure for the multifactor productivity calculation is then the labor composition index multiplied by hours worked. On average from 1994 to 2002, the simplified aggregate labor input growth differs from the full procedure by an average absolute value of 0.24 percent.

Because labor represents two-thirds of the input costs, this difference by itself would lead to approximately a 0.16-percent difference between the multifactor productivity estimated by the simplified method and the full method—although in some years, errors in other components (capital, labor share, or output) may be in the opposite direction, and therefore off-

setting in their effects of the multifactor productivity measure. Overall, roughly half of the discrepancy between the full model and simplified model multifactor productivity measures comes from variation in labor composition. The other half comes from capital estimation.

Measures of capital inputs

Background. The BLS multifactor productivity measures reflect the contributions of growth in capital service inputs, as well as labor inputs. The full procedures used to estimate capital are complex. Before describing the simplified procedures used to measure capital, it is helpful first to summarize how capital inputs are measured in the full procedure.

Capital includes fixed reproducible business assets (equipment and structures), inventories, and land. The BLS capital input concept is designed to reflect the flow of services from these assets. These capital services measures are constructed through three stages of aggregation, two of which are reflected in the simplified methodology. The first stage involves vintage aggregation, where past investments in each of 74 types of asset are deflated, weighted and added together, resulting in *productive capital stocks.* This procedure is sometimes called the perpetual inventory method (PIM). In addition, capital stocks are measured, by methods other than PIM, for three types of inventories and for land, completing a set of 78 categories of assets. The second stage combines stocks for the 78 types of assets, using estimates of implicit rental prices to form an index of capital inputs, and the third stage involves aggregation of capital inputs across a set of industries. In the full methodology, the first two stages are repeated for each of 57 detailed industries.[16]

The PIM is designed to adjust older capital goods for deterioration and obsolescence that reduce their productivity. The BLS specification of the PIM assumes that investments only slowly lose their effectiveness, like cars and light bulbs do. In the full methodology, we assume that the productivity of equipment declines as a function of lifetime (L)[17], age (τ), and that the fraction

$$\frac{L - \tau}{L - .5\tau}$$

of the investment remains productive.[18] Similarly, structures are assumed to remain productive according to the slower-moving fraction

$$\frac{L - \tau}{L - .75\tau}$$

The parameters of the efficiency formula (average service life and shape) represent the effects of obsolescence and deterio-

ration of past investments. BLS has made efforts to fit them to evidence on declining equipment productivity. Chart 1 shows how an investment in structures with a 10-year life span would decline in productivity according to this relationship:

The simplified calculation groups the 78 asset types into the following 8 asset classes:

    Structures
    Computers and peripherals
    Software
    Communication and other information technology
    Equipment other than the three information technology
      categories
    Rental residences
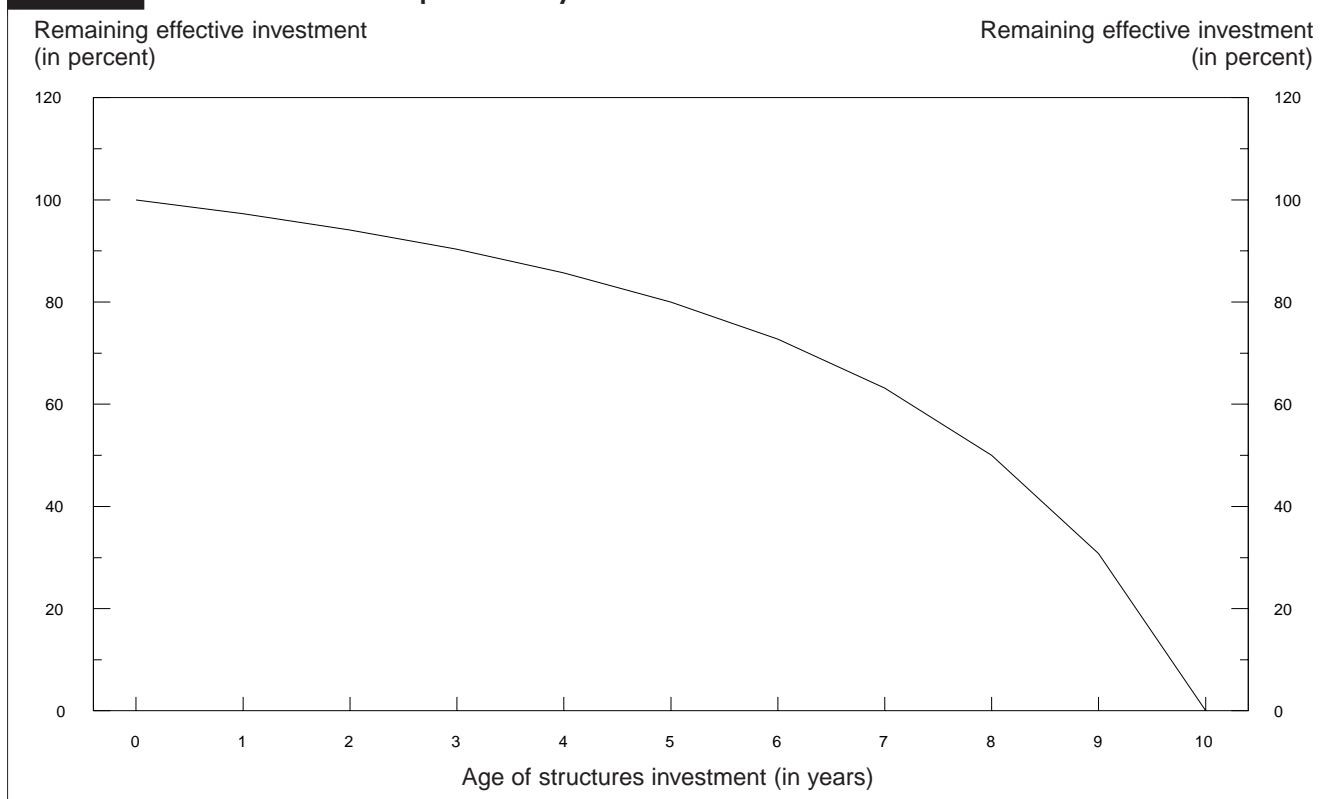   Inventories
    Land

For the first six of these categories, we calculate a productive capital stock by applying the PIM to data on investment published by the BEA during February following the target year. Exhibit A-1 in the appendix specifies the tables from which we have drawn source data. Investment by nonprofit institutions is included in the data that are available early, whereas the full-method multifactor productivity estimates exclude this. However, for most of the six categories, movements in the two investment series track one another closely. So the simplified method uses the percentage changes of the series that are available early to extrapolate the previous year's level of investment in each category. This provides an estimate of the level of investment in the target year. Then an estimate of the productive capital stock of that asset type is constructed as the sum of the new investment and of prior investments (weighted by remaining efficiency). Efficiency is assumed to decay at a rate derived from the full method for the previous year.

Productive stocks of inventories and land are estimated without using a PIM calculation in both the simplified and full methods. However, the simplified estimates are constructed using different sources and simpler methods, which we will discuss below. Once stocks are prepared for each of the eight categories, the simplified procedure assigns cost shares to each and the eight are aggregated into a unified measure of capital service inputs. Category cost shares in the target year are assumed to be unchanged from the cost shares in the previous year, available from the full calculation.[19]

Below we discuss the construction of each of the eight capital input components and assess the difference between the

Chart 1.   **Assumed decline in productivity of an investment over time**

Remaining effective investment (in percent)

Age of structures investment (in years)

simplified procedure and the full procedure in each recent year. The comparison is made using data available at the end of March 2005.[20] Early estimates for future years will have only preliminary information (for example, on investment) so subsequent revisions would reflect the incorporation of final data as well as the more complete methodology.

In a later section, we list the components used to generate the major sector multifactor productivity estimates as published by the BLS and the components estimated by this procedure that uses data of the kind available shortly after the end of each target year. Details on the capital stock errors are shown in table 1 and table A-1 in the appendix.

Structures. An early estimate of business investment in structures is published by the BEA in February of the year following the target year. This estimate includes nonprofits, whereas multifactor productivity calculations exclude them. For the target year *t*, the simplified procedure adjusts the investment figure from the full multifactor productivity calculation in year *t-1* using the movement in BEA's early estimate. Because structures investment is stable from year to year, this estimate for investment is reasonable. Over the 1993–2002 period this method produces, on average, a 1.8-percent discrepancy in the estimate of the percentage change of annual investment into structures compared to the later full estimate.

The next step in converting investment figures to a capital stock requires two procedures. First, we apply a deterioration rate to the productive capital stock existing the previous year, year *t-1*. The deterioration rate for the simplified measure is based on the average deterioration rate for the asset class. We apply the last known rate to the stock in year *t-1*, to produce an estimate of the remaining stock of used assets in year *t*. Second, we add the estimated new investment to get an estimate for structures in the private business sector in year *t*. Because deterioration of structures is slow, this produces accurate estimates for the stock of structures. Over the 1993–2002 period, the absolute value of the difference between the growth rate of the stock of structures measure by the two methods averaged 0.09 percent.

The calculations for the other asset categories are analogous where possible, though they are less accurate than the structures estimate. Equipment deteriorates more quickly than structures, so differences in recent investment estimates have a greater effect on the total capital stocks for equipment than for structures.

Equipment. We separate information processing equipment and software from other categories of equipment. This improves our estimate of multifactor productivity because high-tech investment grew so much in the 1990s and has such a high rate of obsolescence. As in Oliner and Sichel's work,

three categories of information processing investment are distinguished: computers and peripherals; software; and communications and other information technology equipment. All other equipment, taken together, makes up the fourth equipment category.

For each of the equipment categories, investment estimates are calculated as they are for structures. Capital stocks are constructed in the same way as for structures. Capital stocks are reasonably well estimated for two of the categories but poorly estimated for computers and software. Because computer investment was booming and volatile with short life cycles and quickly evolving applications, our simple linear projections were not very close to the full measure in these categories. Much of this discrepancy is attributable to the differences between the early estimate of investment in computers and the later full estimate, an average absolute difference of 13.9 percent, as shown in table A-1 in the appendix. Another, smaller part of the discrepancy of 2.6 percent between the simplified and full estimates of the productive stock of computers is attributable to the depreciation rate that is inferred on previous computer stocks, which fluctuated widely in the 1990s and which was therefore not well estimated by the simplified procedure. These differences contribute substantially to the discrepancy in the final simplified measure of multifactor productivity.

Rental residences. Investment figures for this category are not available early enough after the target year to be used in the simplified calculation. The simplified estimates simply assume investment was the same in year *t* as it was in year *t-1*. This estimate for investment is not very accurate, but new investment is small compared to the existing housing capital stock, so the absolute discrepancy between the two measures of the growth rates of the stock averages only 0.2 percent.

Inventories. The full MFP calculation defines inventory capital for each industry to be a weighted average of the values of private business inventory stocks in recent quarters. BEA's aggregate inventory investment figures for the whole business sector taken together are available soon after the target year ends, and percentage changes from the previous year replicate the aggregate inventory stock in the full model well.

Land. In the full calculations, land stocks are not calculated as an accumulation of past investments. Rather, nonfarm land stock is assumed to have one of three fixed proportions to the structures stocks depending on whether the land is used for residential structures, manufacturing structures, or other structures. The simplified calculation uses the overall ratio of the official capital stock of land to that of structures from year *t-1*, and applies this ratio again to the estimated value of struc-

tures in year *t*, which was estimated previously. This gives estimates of the growth rates of the productive stock of land that differ from the full estimates by 1.3 percent on average. The discrepancy is largely attributable to farmland, which in the full estimation is measured with data from the U.S. Department of Agriculture. In our simplified calculations, farmland is in effect estimated from farm structures.

Capital services. Having computed simplified estimates of each type of productive capital stock, we proceed to estimate aggregate capital services provided in the target year. We assume that capital services are proportional to the productive stocks for each of the eight types of assets.[21] The productive stocks are combined into a measure of combined capital services inputs using implicit rental prices to determine weights for each type of capital. BLS uses BEA's measures of property income and allocates a portion of this income to each type of asset. The resulting capital income shares do not vary much from year to year. To estimate the simplified measure of combined capital service inputs for year *t*, these asset shares are taken to be the same as in year *t-1*.

Shares for categories of capital inputs and for labor input. Capital income is apportioned to various asset types by assuming the same distribution as in the previous year's full multifactor productivity estimation. For capital types aside from equipment, this introduces only small errors, but the computer and software categories grew a lot. Details of this are in tables 1 and 2.

On average, rental residences accounted for 10 percent of capital income over the 1993–2002 period; inventories accounted for 7 percent; and land, 11 percent. Structures accounted for a declining share, averaging about 28 percent. Equipment of all kinds together rose from about 42 percent to 49 percent, because of growth in computer and software investment in this period.

Capital and labor inputs are then combined using a Tornqvist index formula to create a single index of combined inputs. The capital and labor shares are estimated from changes in the corresponding figures from the BLS Productivity and Cost measures. In the full calculation, labor's share was in the 66-69 percent range. The absolute values of discrepancies from the fully-estimated figure in the simplified estimates of this share average 0.76 percent.

Estimates of multifactor productivity

All of the components discussed above are combined to make a simplified multifactor productivity estimate. The focus of this article is to assess the accuracy of the simplified method. During the 1993–2002 test period, the average of the absolute values of the annual errors between the percentage change in the preliminary (first year ahead) estimate and the published multifactor productivity was 0.22 percent. Table 2 presents an analysis of how much each component contributed to that error. Output errors contribute directly to multifactor productivity error, and input errors for specific input components can contribute in proportion to their weights in total input. In the final column of table 2, the input catego-

Table 2.	Approximate magnitudes of error, by source, for 1993–2002		
[in percent]			
Components	**Range of share of capital income**	**Average absolute error in growth estimate, from table 1**	**Approximate absolute error induced into MFP**
(1)	**(2)**	**(3)**	**Product of averages of (1), (2), and (3)**
Capital services (31.5 to 34 percent of inputs):			
Structures	25.3 to 30.3	0.09	0.01
Computers	3.6 to 6.1	3.4	.06
Software	4.4 to 7.6	3.1	.06
Other information and communications technology	8.3 to 9.3	.71	.02
Other equipment	25.0 to 27.9	.39	.03
Rental residences	9.2 to 10.4	.23	.01
Inventories	5.6 to 8.4	.34	.01
Land	9.6 to 11.5	1.3	.05
Labor services (66 to 68.5 percent of inputs):			
Hours worked	All	.04	.03
Labor composition	All	.23	.15
Output	All	.05	.05
Total			.47
Net effect on MFP		.22	

ries have been multiplied by their average cost share weights during the test period to assess their potential contribution to measurement error in multifactor productivity. For example, the growth of computer stock was estimated with an average absolute error of 3.4 percent, but their input cost share was small, averaging about 1.7 percent of the value of all labor and capital inputs. We estimate they contribute only 0.06 percent to the multifactor productivity error. Not all sources of error can be identified in this share-weighted framework. Asset shares are assumed to be the same in year t as in year $t-1$, and this is a source of some of the discrepancy between the simplified and full measures, especially for computers and software. However, in assembling the components into a multifactor productivity measure, the error contributions of the capital categories, of labor, and of output often offset. As a result, the total component contribution, of about 0.47 percent for the period, was reflected in a multifactor productivity error of only 0.22 percent.

Table 3 presents annual time series for the simplified (columns 1) and full (column 2) estimates of multifactor productivity for recent years. The trends in these measures, presented near the bottom of the columns, are very similar. Annual errors (differences) in the simplified measure are presented in column 3. Because some errors are positive and some negative, the average of this column is very small: –0.09 percent. However, this represents only the difference in trends. To assess the effectiveness of the simplified method, we averaged the absolute values of column 3. That figure was 0.22 percent, as we mentioned earlier. Table 3 also presents the second-year-ahead estimates, MFP^{S2}_t (column 4). These were constructed by applying the simplified methodology for two consecutive years. The data presented are growth rates of multifactor productivity for the second year. The second-year simplified estimates (column 4) are compared to the published measures (column 2) in column 5. The average absolute error, during 1994–2002, for the second year estimates was 0.19 percent. By comparison, the average of published multifactor productivity growth rates is 0.96 percent, and they fluctuate substantially from one year to the next. The simplified estimates may serve as fairly reliable preliminary numbers. The accuracy of the second year estimates is comparable to that of first-year estimates, reflecting the stability of input shares and the similarity of the data used to estimate growth rates. While the simplified method can provide reasonable measures for a few years, it is not capable of replacing the full method. The simplified model draws heavily on the most recent full model for data on rental prices, cost shares, and deterioration rates. These values gradually change over
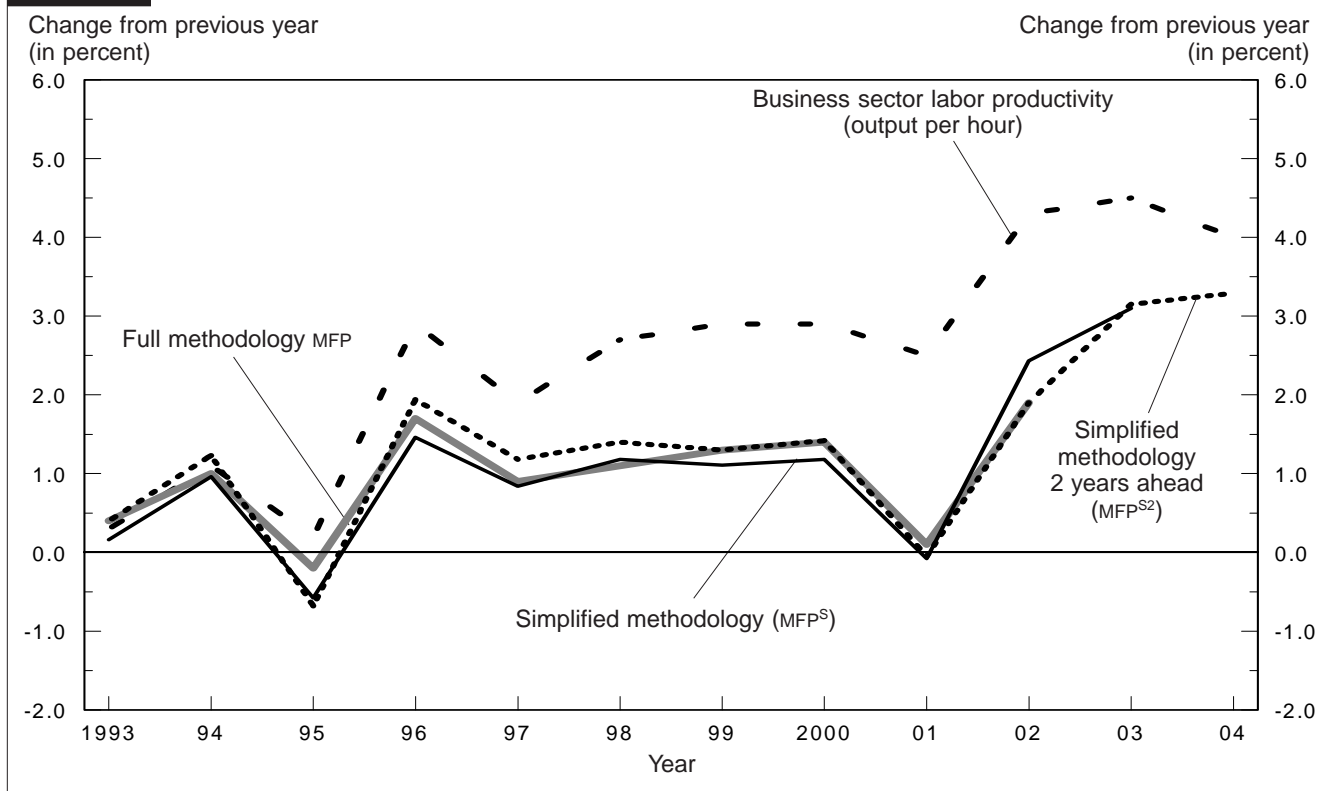
	Table 3. Multifactor productivity (MFP) change estimates by simplified and full procedures					
	[In percent]					
Year	Simplified estimate of MFP change (MFP^S)	Full MFP change estimate (MFP^F)	Discrepancy of 1-year simplified estimate from full estimate (1)–(2)	Simplified estimate of MFP change 2nd year after last full model, MFP^{S2}	Discrepancy between simplified 2nd-year and full estimates (4)–(2)	Best estimate of the MFP series, based on (1), (2), or (4)
	(1)	(2)	(3)	(4)	(5)	(6)
1993	0.16	0.40	−0.24			0.4
1994	.96	1.00	−.04	1.23	−0.23	1.0
1995	−.58	−.20	−.38	−.68	.48	−.2
1996	1.46	1.70	−.24	1.94	−.24	1.7
1997	.84	0.90	−.06	1.18	−.28	0.9
1998	1.18	1.10	.08	1.40	−.30	1.1
1999	1.11	1.30	−.19	1.30	0.00	1.3
2000	1.18	1.40	−.22	1.42	−.02	1.4
2001	−.08	.10	−.18	−.05	.15	0.1
2002	2.43	1.90	.53	1.90	0.00	1.9
2003	3.10			3.15		3.1
2004				3.29		3.3
Average	.87 (1993–2002)	.96 (1993–2002)	−.09 (1993–2002)	1.07 (1994–2002)	−.05 (1994–2002)	
Mean absolute error:			.22 (1993–2002)		.19 (1994–2002)	

NOTE: Figures reflect percent changes from previous year's private business sector MFP.

Chart 2.   Productivity measures

Chart 2. Productivity measures. Change from previous year (in percent). Y-axis ranges from -2.0 to 6.0 on both left and right sides. X-axis shows years 1993, 94, 95, 96, 97, 98, 99, 2000, 01, 02, 03, 04. Series shown: Business sector labor productivity (output per hour), Full methodology MFP, Simplified methodology (MFP^S), Simplified methodology 2 years ahead (MFP^S2).

time, and so the simplified model will tend to become inaccurate unless data from the full model are available for a recent year.

Table 3 also includes a series providing our best current estimate of a multifactor productivity time series (column 6). This column is the published full multifactor productivity measure (column 2) for 1993–2002, but then reflects the simplified estimate for 2003 (column 1), and the simplified estimate for the second year ahead for 2004 (column 4). Private business multifactor productivity grew 3.1 percent in 2003, and 3.3 percent in 2004. The last time this published series grew by more than 3 percent was in 1976. Rapid private business multifactor productivity growth in these recent years occurred at a time of high business sector labor productivity growth rates of 4.5 percent in 2003 and 4.0 percent in 2004—reported in the BLS Productivity and Costs news release. Capital growth and labor composition account for the difference between trends in labor productivity and multifactor productivity. The labor composition index grew 0.6 percent in 2003 and 0.2 percent in 2004, compared with a trend of 0.4 percent during the previous 10 years. In both 2003 and 2004, capital inputs grew 2.6 percent, less than their average of 4.5 percent per year during the previous 10 years.

The annual rates of change in the full and simplified estimates are graphed in chart 2 along with growth in labor pro-

ductivity. While there are noticeable differences between the simplified and full estimates, the movements are very similar. BLS presents multifactor productivity measures in the context of a framework that explains changes in labor productivity. Aside from multifactor productivity, labor productivity growth reflects the contributions of capital and of labor composition. In chart 2, the simplified multifactor productivity measures account for about the same fraction of labor productivity growth as do the full measures.

Conclusion. The simplified method uses preliminary information to estimate the components of multifactor productivity. The method is relatively transparent and avoids any kind of model that fits the 1990s but might not apply in the future. Based on the span of years for which we made the comparison, the largest sources of the discrepancy between this multifactor productivity estimate and the full measure come from differences in estimates of information technology capital and labor composition.

In the future, BLS expects to makes these simplified method multifactor productivity measures available before the results from the full methodology can be ready. The results of the full methodology can be published as revisions to the preliminary statistics.   □

Notes

[1] Robert Solow, "Technical Change and the Aggregate Production Function," *The Review of Economics and Statistics*, August 1957, pp. 312–20.

[2] The target year is sometimes called the *reference year*. Changes are measured between the target year and the previous year. In this study the present year is never measured, only past years.

[3] Most of the data items are obtained shortly after the year is over from the National Income and Product Accounts (NIPA) published by the Bureau of Economic Analysis (BEA), and from BLS labor data sources. The MFP calculation also requires information on investment expenditures and property income at the industry level from BEA and this takes longer to produce and obtain.

[4] Their measures were reported by Oliner, Stephen D. and Daniel E. Sichel, "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?" *Journal of Economic Perspectives*, Fall 2000, pp. 3–22. Our measure is similar, with less detail on equipment and structures than their 60 asset categories, but adding measures of inventories and land. The authors are indebted to Dan Sichel, who kindly discussed this work with us and who also provided valuable comments on an earlier draft of this article.

[5] For example, in the 1990s, computer purchases rose dramatically as a fraction of all business investment. If particular categories of investment continue to grow rapidly, more accurate estimates would take recent trends into account. Instead, the calculation simply used the asset shares from the most recent year for which full calculation is available.

[6] For example, the calculation could incorporate empirically observed relationships between the state of the business cycle and components of the calculation (such as the labor force composition and the shares of durable goods in investment) to make slightly more accurate estimates.

[7] Revisions to the underlying data can be substantial. Edge, Laubach, and Williams (2004) discuss the significance of using real time data in evolving expectations about productivity trends; see Edge, Rochelle M., Thomas Laubach, and John C. Williams, "Learning and Shifts in Long-Run Productivity Growth," Working Paper No. 2004–04 (San Francisco, Federal Reserve Board of San Francisco, 2004). Orphanides (2001) demonstrates that monetary policy can look meaningfully different in retrospect when considered in the context of the economic data actually available to policymakers, not the best measures later available. (See Orphanides, Athanasios, "Monetary Policy Rules Based on Real-Time Data," *The American Economic Review*, Sept. 2001, pp. 964–85.) Though we recognize the issue, this study does not measure how much this would have affected preliminary MFP measures in recent years.

[8] Gullickson and Harper (1999) discussed why this is the appropriate concept of output to compare to capital and labor inputs at the aggregate level. See William Gullickson and Michael J. Harper, "Possible Measurement Bias in Aggregate Productivity Growth," *Monthly Labor Review*, February 1999, pp. 47–67.

[9] Output from these sectors is included in GDP, but the estimates for the value of output are largely based on inputs or input costs and assumptions about their productivity change. If these sectors were included in aggregate productivity measures, the assumptions about their productivity would affect the measure.

[10] These are available on the Internet at **http://www.bls.gov/schedule/archives/ prod_nr.htm**.

[11] Government enterprises are those activities of government that bring in approximately enough revenue to cover their variable costs. They generate approximately 1.3 percent of GDP. Government enterprises are excluded from MFP because of difficulties in estimating an income share for capital. Government enterprise capital is often heavily subsidized. Revenues often are sufficient to cover operating costs but insufficient to repay capital costs.

[12] In recent years, nonprofits and households produced 11.5 percent of GDP, general government 11.3 percent, and government enterprises 1.3 percent. Sources

for those approximations are BEA's online NIPA Table 1.3.5 on the Internet at **http:/ /www.bea.gov/bea/dn/nipaweb** and "Value Added by Industry in Current Dollars as a Percentage of Gross Domestic Product" table in the Industry Economic Accounts available on the Internet at **http://www.bea.gov/bea/industry/ gpotables/gpo_action.cfm?anon=619&table_id=2921&format_type=0**; (visited June 2004).

BLS also publishes multifactor productivity growth estimates for subsets of private business, such as the following: private business excluding farms; manufacturing; durable manufacturing; nondurable manufacturing; and for selected industries. There are also "KLEMS" multifactor productivity growth that take more inputs into account: capital, labor, materials, energy, and purchased business services. Access to these estimates is available on the Internet at **http://www.bls.gov/ mfp/**. This article does not consider preliminary estimates for these other statistics.

[13] In theory, firms competing for workers and trying to make profits will minimize costs by paying each type of worker a wage that equals the worker's "marginal product" or labor productivity.

[14] Other researchers, such as Jorgenson, Gollop and Fraumeni (1987) have used hourly wages directly instead of inferring them from a wage regression. See Jorgenson, Dale, Frank Gollop, and Barbara Fraumeni, *Productivity and U.S. Economic Growth* (Harvard University Press, 1987).

[15] A chain index is a time series assembled by adjusting successive year's observations by growth rates. The Tornqvist growth rate is an aggregate of growth rates of the hours worked by each group, weighted by their average shares in labor costs in successive years. For more on the index, see **http://www.bls.gov/mfp/ mprlabor.pdf** and *Labor Composition and U.S. Productivity Growth, 1948-90*, Bulletin 2426 (Bureau of Labor Statistics, Dec. 1993).

[16] The full methodology also treats investments by corporations differently than other investments. For further information on the construction of the capital stock for the multifactor calculation, see *Handbook of Methods*, Bulletin 2490 (Bureau of Labor Statistics, April 1997), p. 107; see also Harper, Michael J., "Estimating Capital Inputs for Productivity Measurement: An Overview of U.S. Concepts and Methods," *International Statistical Review* Vol. 67, 1999, pp. 327–37.

[17] Service lives of individual assets are assumed to have a normal distribution that is truncated at age zero and at twice the average service life. The average service lifetimes used in this calculation are consistent with the depreciation rates that BEA uses when estimating the net national product. In some cases, the service lifetime changes over calendar time.

[18] The relationship of the productivity of a capital investment to its age and lifespan represented by these equations are sometimes called *efficiency schedules*. These particular efficiency schedules are *hyperbolic* functions of age.

[19] In the full methodology, asset-type cost shares are determined by allocating NIPA property income (the difference between revenues and labor cost) to the assets, under the assumption each asset type earns the same rate of return. Property income data comes from the BEA's GPO (Gross Product Originating) reports. The stock of each type, and structural rental price formulas for each type are used. For further details see *Trends in Multifactor Productivity*, Bulletin 2178 (Bureau of Labor Statistics, Sept. 1983), especially pp. 49–50.

[20] In the comparison of the full method to the simplified method over a series of years, the investment data are drawn in slightly different categories from the ones used at the time. First, investment amounts for all years are taken in year 2000 dollars, based on chained-dollar adjustments between years which vary by the kind of investment good. Second, they are drawn in from NAICS (North American Industrial Classification System) category data whereas the figures historically used for the MFP calculation had been in SIC (Standard Industrial Classification) categories. Third, investments for all years are also taken as restated by the BEA's December 2003 comprehensive revisions. These changes introduce small differences between the multifactor productivity estimated by what is called the full methodology here and the multifactor productivity figures the BLS published for those years.

[21] In the full procedure, the capital services from each of the eight components has been constructed from finer subcomponents. Our simplified procedure overlooks some composition effects that emerge from working with the greater detail. It might be possible to improve our simplified procedure by trying to estimate these composition effects within the components. We have not done so for these estimates.

APPENDIX: Sources of data and average discrepancies in levels of investment and capital stocks

Exhibit A–1.	Data sources for investment in the simplified multifactor productivity (MFP) calculation
Component of MFP calculation	**Source for investment data**
Structures investment	Tables 5.4.6A and 5.4.6B
Computers investment	Table 5.3.5 (deflated by price index privately sent from BEA)
Inventories stock	Tables 5.7.6A and 5.7.6B
Software	Table 5.3.6 or Table 5.5.6
Other information processing equipment	Table 5.3.6
Residential structures	Table 5.3.6
Other equipment	Line 16 of Table 5.3.6
Land stock	Imputed from structures as discussed in text

NOTE: Investment data come from tables from the Bureau of Economic Analysis, available on the Internet at **http://www.bea.gov/dn/nipaweb/**. Figures in year-2000 dollars are used in the simplified MFP calculation. Where possible, data without seasonal adjustments are used.

Table A-1.	Differences in levels between simplified and full methods

[in percent]

Measured component of multifactor productivity (MFP)	Average discrepancy between full and simplified estimates, 1993–2002	Average discrepancy between full and 2-year simplified estimates, 1994–2002 (cumulative, in levels)
Structures investment	1.8	2.2
Productive stock of structures	.1	.2
Computers and peripherals investment	13.9	24.1
Productive stock	2.6	3.9
Software investment	1.0	1.1
Productive stock	2.7	5.1
Communications and other IT equipment investment	1.8	1.9
Productive stock	.7	1.0
Other equipment investment	1.0	1.8
Productive stock	.4	.8
Rental residences investment	8.6	10.2
Productive stock	.2	.7
Inventories stock	.3	.6
Land stock	1.3	3.8
Labor hours (1994–2002)	.04	.07
Labor compensation index	.23	.25
Labor input (the above two combined), 1994–2002	.24	.24
Share of income paid to labor	.76	.67
Output estimates (Y^F_t vs. Y^S_t)	.06	.10
MFP estimates (MFP^S vs. MFP^F)	**.22**	**.19**

NOTE: MFP discrepancies are annual averages of absolute differences in percentage changes from preceding years.