Research on Preliminary Estimates of Multifactor Productivity Growth

Preliminary and incompleteraft
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Abstract. The BLS publishes measures of the annual growth of multifactor productivity (MFP) for the U.S. private business sector more than a year after the target year is over. This paper summarizes a methodology to make preliminary estimates of private business sector multifactor productivity change available within several months after the end of a target year, based on less complete but up-to-date published economic data available and the most recent available complete computation of MFP. This paper presents estimates for 2002 and 2003 using the simplified methodology. Comparing the two methods on annual data since 1993, most of the discrepancy between this MFP estimate and the full measure comes from differences in estimates of computer and software capital and labor composition.

The business labor productivity series from the Bureau of Labor Statistics (BLS) that measures output per hour of the U.S. workforce is of interest to observers because productivity growth is essential for long term improvements in standards of living. The BLS publishes quarterly estimates of U.S. business labor productivity based upon preliminary data approximately a month following the end of each quarter.

Labor productivity can increase because of investments in equipment and structures, a more educated and experienced work force, and improvements in technology. There

[1] First a disclaimer: Results and conclusions in this exploratory research are those of the authors and are not official findings of the Bureau of Labor Statistics. We are indebted to Dan Sichel of the Federal Reserve Board, who described to us how Oliner and Sichel (2000) forecasted MFP. Every step of the BLS work was a team effort. Ryan Forshay implemented the algorithm discussed here in the official database system and made two-year forecasts. Larry Rosenblum and Leo Sveikauskas suggested many improvements in this document. Steve Rosenthal and Randy Kinoshita wrote and ran many of the programs generating the official MFP statistics. We thank all of them for co-creating this project. The authors are responsible for any errors.

are standard ways of measuring the effects of the changing composition of inputs on productivity, and the BLS *multifactor productivity* measures are designed to distinguish the effects of such changes following the Solow's (1957) methodology of growth accounting, to be defined below.

The BLS calculates the annual growth of multifactor productivity (MFP) for the U.S. private business sector. This measure is generally released about 14 months after the end of the year being measured, which we call the *target year*.[2] The lag occurs because the process of calculating MFP requires detailed data from many sources. 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. However the MFP calculation also requires information on investment and property income at the industry level from BEA and this takes longer to obtain. The 2002 calculation is taking far longer than the usual 14 months because the statistical agencies are changing from the Standard Industrial Classification (SIC) category system to the North American Industrial Classification System (NAICS). In the past, major data revisions have caused prolonged lags in publishing MFP.

Some users of productivity measures, including policy and budget organizations in the U.S. government, have made their own preliminary estimates of MFP while awaiting the official BLS measures. The Federal Reserve makes short term economic forecasts and therefore needs multifactor productivity growth figures before the BLS measure becomes available. Dan Sichel and Stephen Oliner of the Federal Reserve developed a method to make early MFP forecasts[3] and we are indebted to Sichel who kindly discussed this work with us.

This paper summarizes a simplified methodology that BLS plans to adopt to make preliminary estimates of private business sector multifactor productivity change available

[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] Their measures were used in Oliner and Sichel (2000). Our measure is similar but has less detail on equipment and structures than their 60 asset categories, but adds measures of inventories and land.

within a few months after the end of a target year. The resulting simplified measure, called MFP^S_t, will later be replaced by the full measure called MFP^F_t when more complete data becomes available. The simplified measure is based on the full calculation from a previous year (t-1 usually) and up-to-date information about approximate rates of change in output, labor and capital between years t-1 and t. The estimates of the rates of change use information from the NIPA and other sources that become available early in the following year.

The simplified methodology is designed to estimate MFP in a way that closely approximates the MFP calculated by the full methodology, using the same basic structure and assumptions. Both methodologies estimate a productive capital stock for each of several kinds of productive 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 model. 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 in productivity trends in recent years.

We test the proposed methodology on annual data for each year since 1993. The simplified measures are estimated for each year, extrapolating from the previous year's full estimation. In order 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. This paper reviews the estimation procedure for each component of the estimation, and provides summary statistics on their reliability. The paper also reports and evaluates simplified estimates of productivity prepared for two years ahead of the last year for which full model estimates are available. These "second-year-out" estimates are denoted MFP^{S2}_t. The latest published BLS measures of MFP are for the year 2001. This paper presents preliminary estimates for 2002 and 2003 using the simplified methodologies.

The evaluations in this paper use the most recently available versions of all data series, 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.[4]

Conceptually, multifactor productivity change is the growth rate of output minus the growth rate of measured inputs. We apply this accounting system. Let Y be output (such as GDP), 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 the remaining fraction (1-s) is paid to capital. Delta (Δ) means the change since the previous year, so ΔY/Y is approximately the growth rate of output.

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

BLS measures the quantities on the right side, and in this accounting structure defines the growth rate, ΔMFP/MFP, to be the residual. BLS publishes both index numbers and growth rates of MFP which average .82% per year over the 1993-2001 period we study here.

Substantively, MFP change can result from improvements in resource allocation (through transportation or communication for example), some kinds of improvements in

[4] Revisions to the underlying data can be substantial. Edge, Laubach, and Williams (2001) discuss the significance of using real time data in evolving expectations about productivity trends. 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. Though we recognize the issue, this study does not measure how much this would have affected preliminary MFP measures in recent years.

technology, economies of scale, changes in capacity utilization, and other influences in the economy. In the BLS approach, labor and capital inputs are subdivided 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 will 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 which adjusts for changes in the education and work experience of the employed population. Capital services arise 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: $\Delta K/K=\Sigma\ (v_i \Delta K_i/K_i)$.

Estimating Output and Labor Inputs for the Simplified MFP

The BLS private business multifactor productivity measures compare output to the combined inputs of labor and capital. The simplified method estimates output growth and labor hours growth simply by applying the growth rates observed for these variables in the business sector to the private business sector. The business sector differs only slightly from the *private* business sector, since the business sector also includes government enterprises such as the U.S. Postal Service and local government water and sewage services.[5] Business sector output data are available from the NIPAs soon after the conclusion of each year, as are the BLS data on hours worked. Thus, BLS is able to publish annual estimates of labor productivity for the business sector each February for the preceding year.

MFP is meaningful only in contexts where we can measure output, capital inputs, and also labor inputs. It is difficult to measure the real output of government and nonprofit institutions, and so the BLS excludes these from all of its published

[5] Government enterprises are those activities of government that bring in approximately enough revenue to cover their variable costs. They generate approximately 1.3% of GDP. Exact figures describing government enterprise are not known in time for the simplified calculation.

productivity measures.[6] MFP is therefore measured only for the private business sector, which accounts for about three-quarters of U.S. product.[7]

BLS measures business sector output on the basis of Gross Domestic Product (GDP) data published by the Bureau of Economic Analysis (BEA). The concept of "product" is the value of output, minus the value of intermediate inputs like the leather used to make shoes. Both output and inputs are usually measured by revenue. Gullickson and Harper (1999) discussed why this is the appropriate concept of output to compare to capital and labor inputs at the aggregate level.

In the next few pages we describe the simplified approach and characterize how well the simplified estimate of each variable approximates the full computation. Table 1 summarizes the inputs to the simplified MFP calculation to be discussed below.

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[6] Most of the output from these sectors is not sold in markets. While output from these sectors is included in GDP, the estimates are largely based on inputs or input costs. Such estimates depend on assumptions about their productivity change, and so it is best to exclude these activities from aggregate productivity measures, otherwise the assumptions about their productivity will affect the measure. Private household workers are also not included in productivity measures, because even when we have measures of the output we do not have complete measures of the capital, such as vacuum cleaners and lawn mowers used in their work. Owner-occupied housing has an imputed output but we do not have measures of the labor and capital used to maintain it, so it too is left out of productivity measures. Government enterprises are left out because we do not have measures of their capital assets.

[7] In recent years, nonprofits and households produced 11.5% of GDP, general government 11.3%, and government enterprises 1.3%. Sources for those approximations are BEA's online NIPA Table 1.3.5 at http://www.bea.gov/bea/dn/nipaweb and the table "Value Added by Industry in Current Dollars as a Percentage of Gross Domestic Product" table in the Industry Economic Accounts at http://www.bea.gov/bea/industry/gpotables/gpo_action.cfm?anon=619&table_id=2921&format_type=0; visited in June 2004.

BLS also publishes MFP growth estimates for subsets of private business, such as: private business excluding farms; manufacturing; durable manufacturing; nondurable manufacturing; and for selected industries. There are also "KLEMS" multifactor productivity growth which take more inputs into account: capital, labor, materials, energy, and purchased business services. For access to these estimates, visit http://www.bls.gov/mfp/. This paper does not consider preliminary estimates for these other statistics.

Table 1. Components of simplified MFP calculation

Component of MFP calculation	Sources and methods
Structures and equipment investment	Apply NIPA business sector growth rates of new investment to BLS private business sector investment series from earlier full MFP calculation
Depreciation rates on existing capital assets	Apply most recent available rates estimated in full-MFP calculation
Structures and equipment capital	By perpetual inventory method; apply depreciation rate above to existing stock, and add new investment from above
Capital services	Chain index of eight asset types, weighted by capital-income shares
Capital income shares	Apply most recent available estimates from full-MFP calculation
Inventory capital	Apply percentage change in NIPA business sector to last estimated full-MFP stocks
Land capital	Taken to be a fixed proportion of structures capital
Labor hours	Apply percentage growth as in overall business sector, from preliminary data
Labor composition	Linear projection of past two years
Labor share	Drawn from aggregate labor productivity data
Output in private business	Apply percentage growth as in overall business sector, from preliminary data

Later in Table 3 we present estimates for each component of the MFP calculation corresponding to the full and simplified methodologies for one or two years ahead, along with 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 MFP calculation. Errors in levels, which are more relevant for investment data, are shown in Appendix D.

Output

The simplified estimate of output, Y^S_t, comes from the following computation. From the previous year's full MFP measures we obtain the private business sector output level in year t-1, Y^F_{t-1}. From BLS's labor productivity measures 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, our assumption is valid, although there are fluctuations in accuracy attributable to the use of preliminary data and the difference in scope. Over the 1993-2001 period, when output growth averaged 3.9% per year, the absolute value of the difference between annual growth rates estimated in Y^S_t and Y^F_t averaged 0.18% over 1993-2001 and never exceeded 0.42%.

Labor inputs

Similarly the simplified measure of hours worked, H^S_t, comes from applying the percent change in business hours from the labor productivity report to the measure of private business hours in the previous year's MFP report, H^F_{t-1}. On average, the simplified estimate of the growth rate of hours worked differs from the full estimates in the most recent MFP data, H^F_t, by 0.18%.

The full MFP measures of labor input also include an adjustment to labor hours for changes in the composition of the workforce. This estimates how much of the observed increase in output per hour may be attributable to changes in the education and experience of the workforce. It does this by adjusting hours of work by a labor composition index which changes over the years with education and experience in the working population.[8] Full labor composition would be updated from year t-1 to year t

[8] One does not need to know the details of the index to understand the estimation here, but here is how it is defined. A Tornqvist index of labor input is calculated by weighting changes in hours for groups of workers by their share of labor costs. The workforce is divided into about 1000 education by experience cells and measured using household survey data from the March supplement to the annual Current Population Survey (CPS), which is available around October of the same year. Each group is treated as a distinct resource with potentially a unique marginal product of labor. Hours worked for each group are taken directly from the same CPS household survey. Hourly wages for each group are then inferred by applying known coefficients from annual regressions of wage on education and experience and other characteristics. (Others, such as Jorgenson, Gollop and Fraumeni (1987) have used hourly wages directly.) Since estimated wages and hours for each group are now known, the fractional share of all labor income received by each group in each year can be computed to produce the index of labor input. Changes in the index of labor services can be decomposed into changes in aggregate hours worked and a residual termed *labor composition* or labor quality. Changes in the labor composition index measure changes in the average marginal product of labor assuming average real wages correspond to average marginal products. On average the index rose by .4% annually between 1973 and 2001 as the working population became overall more educated and more experienced. For more on the index see http://www.bls.gov/mfp/mprlabor.pdf and *Labor Composition and U.S. Productivity Growth, 1948-90*.

using the CPS Income Supplement data collected in March of year t, which refers to calendar year t-1. These data are not available until August or September of year t. To obtain a simplified estimate we make the strong assumption that an index of composition effects will grow from year t-1 to year t at the same average rate as it did from year t-3 to t-1. The two-year trend measure is meant to help apply trends not fluctuations. The absolute value of the differences between the growth rate measured by the simplified estimate and the growth rate measured by the full estimates of this annual composition index over 1993-2001 averages 0.44%.

The labor input figure for the MFP calculation is the labor composition index multiplied by hours worked. On average from 1993 to 2001 the simplified aggregate labor input differs from the official figures using the full procedure by an average absolute value of 0.45%.

Because labor represents two-thirds of the inputs, this difference by itself would lead to approximately a 0.30% difference between the MFP 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. We think more accurate preliminary measures of labor input are feasible, by focusing on the composition component. (Estimates from the simplified method for estimating labor hours differ from the full estimates only because of the small difference in the scope of coverage, business versus private business.) We are exploring ways to make a more accurate preliminary estimate of the labor composition index.

Overall about half of the discrepancy between the full model and simplified model MFP measures comes from variation in output or labor inputs. The other half comes from capital estimation.

Two Measures of Capital Inputs

The BLS multifactor productivity measures help identify the contribution of capital to growth in output. The full procedures used to estimate capital are complex. Before describing the simplified procedures used to measure capital, it will be helpful first to review how BLS measures capital inputs in the full procedure.

Capital includes fixed reproducible business assets (equipment and structures), inventories, and land. The BLS capital input concept is designed to estimate 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 aggregation of past investments for various types of assets, resulting in *productive capital stocks,* the second stage combines productive stocks for different 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 from a list of industries. In the full methodology the first two stages are repeated for each of the detailed industries. The simplified methodology omits separate consideration of the industry dimension because the necessary industry data are not available until considerably after a year ends. Appendix A lists the asset types included in the full methodology and Appendix B lists the industries.

In the full MFP calculation BLS uses estimates of the distribution of service lifetimes for each of various kinds of assets, and makes the assumption that this distribution has not changed over time.[9] During the lifetime, investments decline in productive effectiveness because of deterioration or obsolescence. This *service input* measure is not a measure of the asset's market value. The distinction between each asset's service flow and its value becomes important when we assign weights in order to aggregate different types of assets together into a stock.

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[9] 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.

For example, the market value of a new car declines quickly after purchase, although the car's effectiveness at delivering transportation services remains roughly constant for several years. The difference can be attributed to recognition by potential buyers of the car's accumulating wear and tear. The amount of service input ascribed to a vehicle for the MFP calculation would relate to its effectiveness rather than its value. Another common experience is that personal computers depreciate rapidly. Each dollar invested in a computer must yield greater returns in the short run than would a dollar invested in a building, because a computer becomes obsolete in a few years while the building may be counted on to provide services for decades.

The capital stock calculation assumes that investments lose their effectiveness slowly at first, like cars and light bulbs do. In the full methodology we assume that the productivity of equipment declines as a function of age (τ), lifetime (L), and that the fraction $\frac{L-\tau}{L-.5\tau}$ of the investment remains productive.[10] 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 deterioration of past investments. BLS has made efforts to fit them to evidence on declining equipment productivity. Figure 1 shows how an investment in structures with a ten-year life span would decline in productivity according to this relationship:

[10] 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.

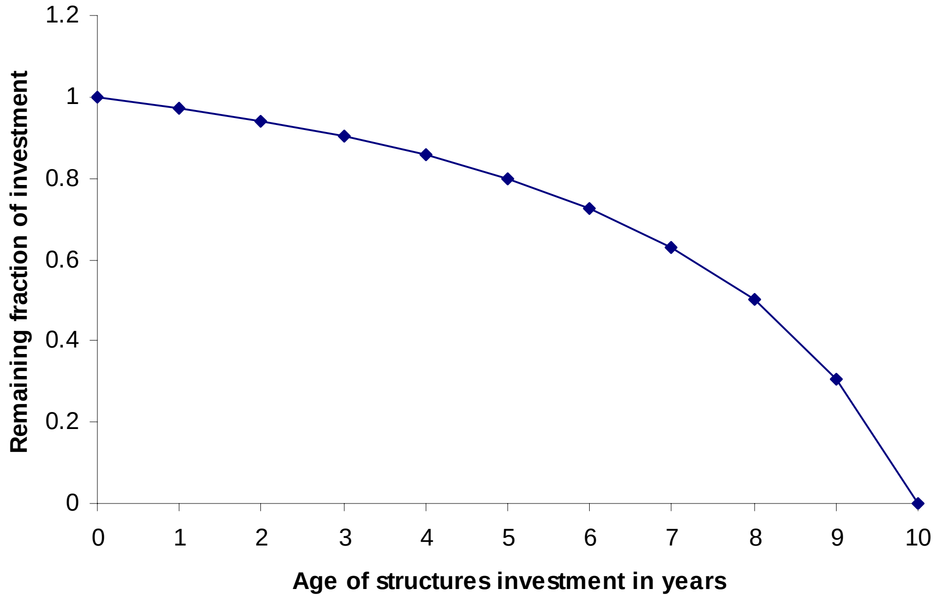

Figure 1. Assumed decline in productivity of an investment over time

The full methodology distinguishes investments into 78 categories of assets in 57 industry categories. These categories are listed in Appendices A and B.[11] The simplified calculation does not distinguish between industries, and groups the 78 asset types into the following eight asset classes:

Structures
Computers and peripherals
Software
Communication and other information technology
Other equipment (outside those three information technology categories)
Rental residences
Inventories
Land

For most of these categories we use information published by the BEA during February following the target year. Appendix C shows the sources. There are

[11] 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 BLS (1997, p. 107) and Harper (1999).

differences between investment figures from this source, used for the simplified measures, and the investment data most recently used in the full model:

(1) The latest investment figures are drawn 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.

(2) The figures follow BEA's December 2003 comprehensive revisions, and are in year 2000 dollars, based on a chained-dollar adjustment between years. The most recent full-method MFP calculations were done before the comprehensive revisions.

(3) Investment by nonprofit institutions is included in the sources, whereas the full-method MFP estimates exclude this.

The percentage changes in investment figures that are available from the BEA soon after the end of the target year predict fairly well the percentage change in the investment figures relevant to the MFP calculation for most investment categories. We estimate the amount of investment in each asset in the target year and construct an estimate of the capital stock. We also estimate the share of capital income the asset generates in proportion to the aggregate capital stock. These are assumed to be the same as the asset shares in the last year for which the full model's calculations are available.[12]

Below we discuss the inputs to the procedure and the degree of difference between the simplified procedure and the full procedure in each recent year. The comparison is made using data available at the end of May, 2004. Early estimates for future years will have only preliminary information (on investment, for example) 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 MFP estimates as published by the BLS and the components estimated by this procedure which

[12] In the full methodology, asset-type shares are determined by allocating property income (the difference between revenues and labor cost) to 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 *BLS Bulletin 2178*, especially pp. 49-50.

uses data of the kind available within about four months of the end of each target year. Details on all the capital stock errors are shown in Table 2 and Appendix D.

Structures

An 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 MFP calculations exclude them. For the target year *t*, the simplified procedure constructs an estimate using data that are routinely available shortly after the end of the year by multiplying the percentage change in BEA's investment figure by the investment figure last known from the full MFP calculation in year t-1. Because structures investment is stable from year to year, this estimate for investment is close to accurate. Over the 1993-2001 period this method produces, on average, a 2.1% discrepancy in the estimate of the level 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 1993-2001 period, the absolute value of the difference between the growth rate of the stock of structures measure by the two methods averaged 0.1%.

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 (IPES) from other categories of equipment. This helps make a good estimate of MFP because high tech investment grew so much in the 1990s and has such a high rate of obsolescence. As in Oliner and Sichel (2000), 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. Presumably 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. These inaccuracies contribute substantially to the discrepancy in the final simplified measure of MFP.

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 is not very accurate, but it is used only to construct a capital stock, and since new investment is small compared to the used capital stock of housing, the differences in stocks between the simplified and full procedures are small compared to the differences in investment. Forecast errors averaged 0.3% for levels and for growth rates of the stock.

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 a 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 structures in year t, which was estimated previously. This gives estimates of the productive stock of land which differ from the full estimates by 0.5% on average. The discrepancy is attributable to farmland, which in the full estimation is measured with data from the 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 an aggregate capital stock. 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. In the official figures, each of the types of capital accounts for a share of overall capital income. These figures are available from the official figures for the previous year, and 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 they were the same as in the previous full MFP estimation. For capital types aside from equipment, this introduces only small errors but the computer and software categories grew a lot, as shown here:

	Structures	Computers	Software	Other IT/Comm	Other Equipment	Rental Residences	Inventories	Land
1993	29.5%	3.8%	4.6%	8.4%	24.7%	10.0%	6.0%	13.0%
2001	25.8%	4.7%	7.8%	8.3%	26.2%	9.8%	5.7%	11.7%

On average, rental residences accounted for 10% of capital income over the 1993-2001 period, inventories accounted for 6%, and land 12%. Structures accounted for a declining share, averaging about 28%. Equipment of all kinds together rose from about 40% to 47%, 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 BLS's aggregate labor productivity measurement group. In the full calculation, labor's share was 68.1% of income in 1993, fell to 66.0% in 1997, then rose to 68.5% in 2001. The absolute values of discrepancies from the fully-estimated figure in the simplified estimates of this share average .27%.

Estimates of multifactor productivity

All of the estimates discussed above are combined to make an MFP estimate. Table 2 presents the simplified and full estimates for recent years. The two-year-ahead estimates, MFP^{S2}_t apply the simplified methodology to build estimates two years forward from a given year of results from the full model. It is relevant because our estimate for 2003 is computed in this way.

Table 2. MFP change estimates by simplified and full procedures

Estimates are percent changes from previous year's MFP

Year	**Simplified estimate of MFP change (MFP^S) (1)**	**Published full MFP change estimate (MFP^F) (2)**	**Discrepancy of one-year simplified estimate from full estimate (1)-(2)**	**Simplified estimate of MFP change two years after last full model, MFP^{S2} (4)**	**Discrepancy between simplified two-year and full estimates (4)-(2)**
1993	-0.51%	**0.50%**	-1.01%		
1994	1.83%	**1.10%**	0.73%	0.57%	-0.53%
1995	0.01%	**0.30%**	-0.29%	-0.87%	-1.17%
1996	2.20%	**1.60%**	0.60%	1.56%	-0.04%
1997	1.42%	**1.20%**	0.22%	1.02%	-0.18%
1998	1.36%	**1.30%**	0.06%	1.17%	-0.13%
1999	1.79%	**0.90%**	0.89%	1.29%	0.39%
2000	1.06%	**1.50%**	-0.44%	0.81%	-0.69%
2001	0.05%	**-1.00%**	1.05%	-0.23%	0.77%
2002	1.95%			2.83%	
2003				3.12%	
Average	1.02% (1993-2001)	.82% (1993-2001)	.20% (1993-2001)	.67% (1994-2001)	-.20% (1994-2001)
Mean absolute error, 1993-2001			.59%		--
Mean absolute error, 1994-2001			.54%		.49%

On average the absolute value of the discrepancy between the simplified estimate and the full estimate is 0.54%. Errors for the second year out average 0.49%. The average of the absolute value of the published MFP growth figures is 1.2%, so errors of this magnitude are sizeable, but may be low enough that the simplified results would represent reasonable preliminary numbers. The full estimate could be made available later.

The full and simplified estimates are graphed in figure 2. The vertical axis measures the change in multifactor productivity from the previous year. Labor productivity is higher than MFP because of the contributions of capital and of labor composition, which are not accounted for in the labor productivity measure. While there are noticeable differences between the simplified and full estimates, the stylized facts are similar. The direction of change, for example, is the same in both measures almost every year.

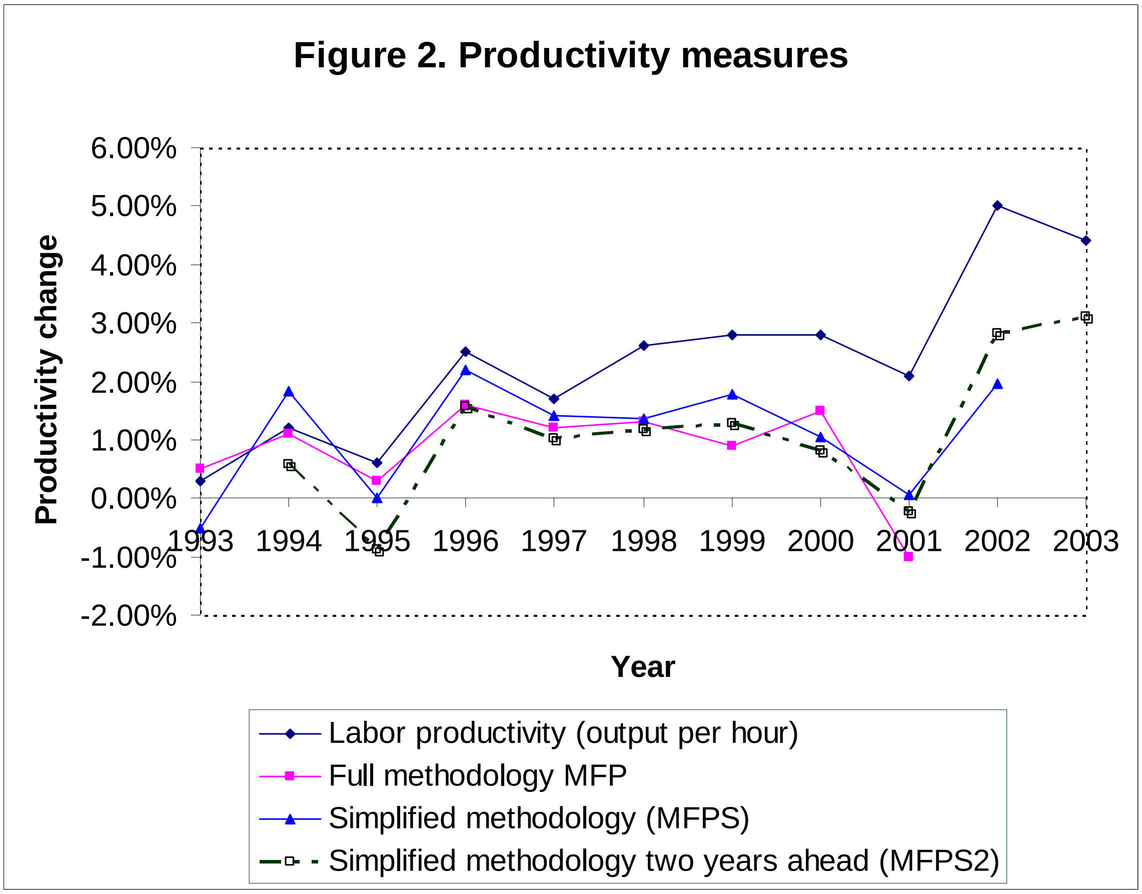

Table 3 summarizes the errors in the components and in the resulting MFP estimate. The errors in growth rates are the ones directly relevant to the MFP calculation, since MFP is defined by the difference between growth rates of output and growth rates of inputs.

Table 3. Differences between components of the simplified MFP calculations from the full methodology, expressed in growth rates

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

Estimated component (capital stock, labor input, output, or MFP)	Full model annual change, average (1993-2001)	Simplified model annual change, average	Average discrepancy in annual change between models	Annual change in second year, average (1994-2001)	Average discrepancy in second-year change
Capital services		2.98%	.16%	2.91%	.59%
Structures	1.85%	1.89%	.08%	1.95%	.13%
Computers	34.5%	35.0%	6.99%	37.2%	2.20%
Software	13.7%	13.9%	1.48%	14.5%	6.78%
Other IT and communications equipment	6.0%	6.3%	.45%	6.1%	1.36%
All non-IT Equipment	3.3%	3.4%	.18%	3.4%	.81%
Rental Residences	1.0%	1.0%	.30%	1.2%	.47%
Inventories	3.7%	3.8%	.19%	3.8%	.22%
Land	1.4%	1.4%	.48%	1.5%	1.08%
Labor services	2.2%	1.9%	.45%		.44%
Labor hours	1.8%	1.7%	.18%	1.4%	.22%
Labor Composition	.4%	.2%	.44%	.3%	.52%
Output	3.9%	3.9%	.18%	3.8%	.18%
MFP change	.82%	1.02%	.59%	.67%	.49%

The greatest sources of error appear to come from estimating labor composition, computer investment, and software investment. Errors in future years could be smaller than those shown here once both official and preliminary estimates are based entirely on NAICS and in constant year-2000 dollars. We anticipate that the preliminary computation will benefit from our experience in using it and improved methods could lead to declining errors. If annual computer investments are more stable in the future, this would help the simplified estimating procedure deliver better results. Investments, stocks, and labor's income share are separated in a comparison of predicted levels in Appendix D.

Conclusion

We have used simple projections of the components of MFP to make our estimates, partly to have a quick and transparent methodology, and also to avoid any kind of model which fits the 1990s but might not apply in the future. Based on the span of years for which we made the comparison, most of the discrepancy between this MFP estimate and the full measure comes from differences in estimates of computer and software capital and labor composition.

These simplified-method multifactor productivity measures can be available to users earlier than the results of the full methodology, especially during the period when it is necessary to switch to the NAICS industry category system. We expect to make simplified estimates available as soon as the methodology is finalized and plan to publish calculations using the full methodology as revisions when possible. If we publish preliminary MFP estimates for 2002 and 2003 using the simplified methodology discussed here, we expect to incorporate the actual labor composition index at that time. In future years, we may make preliminary estimates of the labor composition index in a more precise way than was done here.

Appendix A. NIPA-based asset categories used in the full MFP calculation

The classifications used in the full multifactor productivity calculation come from BEA's SIC-based NIPA classification codes which have 80 asset categories and 61 industry categories. 78 asset categories are used in the official MFP calculation, and the industries are compressed into a list of 57.   The simplified method uses eight asset classes and does not distinguish industries from one another.

Household Furniture
Other Furniture
Other Fabricated Metal Products
Steam Engines and Turbines
Internal combustion Engines
Farm Tractors
Construction Tractors
Agricultural Machinery excluding tractors
Construction Machinery excluding tractors
Mining and Oilfield Machinery
Metalworking Machinery
Special Industry Machinery, n.e.c.
General Industrial Equipment incl. Materials Handling
Office and Accounting Machinery
Service Industry Machinery
Communications Equipment
Electrical Transmission, Distribution, and Industrial Apparatus
Household Appliances
Other Electrical Equipment
Trucks, Buses, and Truck Trailers

Autos

Aircraft
Ships and Boats
Railroad Equipment
Instruments
Photocopying and Related Equipment
Other Nonresidential Equipment

Industrial Buildings
Mobile Offices
Office Buildings

Commercial Warehouses

Other Commercial Buildings
Educational Buildings
Hospital and Institutional Buildings
Hotels and Motels
Amusement and Recreational Buildings
All other Nonfarm Buildings
Other Railroad Structures
Telecommunications structures
Electric Light and Power structures
Gas structures
Local Transit structures

Petroleum Pipelines
Nonresidential farm structures
Mining: Petroleum and Natural Gas
Other mining equipment
Other Nonresidential Structures
Railroad Replacement Track
Nuclear Fuel
Mainframe Computers
Personal Computers (PCs)
Direct access storage devices
Printers
Terminals
Tape Drives

Storage Devices
Cable and wire
Integrated Systems
Software, pre-packaged

Software, custom
Software, own-account
New farm residences for tenants with 1-4 units and farm landlord
New farm residences for tenants with 1-4 units and nonfarm landlord
Tenant-occupied mobile homes
New nonfarm residences for tenants, 1-4 units

Additions and alterations to 1-4 unit nonfarm residences for tenants
Major replacements for 1-4 unit nonfarm residences for tenants
New nonfarm residences, with five or more units for tenants
Additions and alterations to nonfarm residences with five or more units for tenants
Major replacements in nonfarm residences with five or more units for tenants
Equipment for nonfarm residences with 1-4 units for tenants
Equipment for nonfarm residences with five or more units for tenants
Land
Materials Inventory

Work-in-Process Inventory
Finished Goods Inventory

Appendix B. NIPA-based industry categories used in full MFP calculation

Farms
Agricultural services, forestry, and fisheries
Metal mining
Coal mining
Oil and gas extraction
Nonmetallic minerals, except fuels
Construction
Lumber and wood products
Furniture and fixtures
Stone, clay, and glass products
Primary metal industries
Fabricated metal products
Industrial machinery and equipment
Electronic and other electric equipment
Vehicles and transportation equipment
Instruments and related products
Miscellaneous manufacturing industries
Food and kindred products
Tobacco manufactures
Textile mill products
Apparel and other textile products
Paper and allied products
Printing and publishing
Chemicals and allied products
Petroleum and coal products
Rubber and miscellaneous plastics products
Leather and leather products
Railroad transportation
Local and interurban passenger transit
Trucking and warehousing
Water transportation
Transportation by air
Pipelines, except natural gas
Transportation services
Telephone and telegraph
Radio and television
Electric, gas, and sanitary services
Wholesale trade
Retail trade
Depository financial institutions (Federal Reserve banks, commercial, and mutual)
Non-depository financial institutions
Security and commodity brokers
Insurance carriers
Insurance agents, brokers, and service
Real estate
Holding and other investment offices
Hotels and other lodging places
Personal services
Business services
Auto repair, services, and parking
Miscellaneous repair services
Motion pictures
Amusement and recreation services
Health services
Legal services
Educational services
Social services, museums, membership organizations, engineering and management services, and services NEC

Appendix C. Data sources on investment for the simplified MFP calculation

Investment data come from BEA tables reachable at http://www.bea.gov/bea/dn/nipaweb/SelectTable.asp. Figures in year-2000 dollars are used in the simplified MFP calculation. Where possible, data without seasonal adjustments are used.

Component of MFP calculation	Source for investment data
Structures investment	Tables 5.4.6A and 5.4.6B (recheck)
Computers investment	Table 5.3.5. (deflated by price index privately sent from BEA)
Inventories stock	Table 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 5.3.6
Land stock	Imputed from structures as discussed in text

Appendix D. Differences between components of MFP calculation (in levels)

Annual averages of absolute differences in percentage changes from preceding years

Measured component of MFP	Average discrepancy between full and simplified estimate 1993-2001	Average discrepancy between full and two-year simplified estimates, 1994-2001 (cumulative, in levels)
Structures investment	2.1%	2.7%
Productive stock of structures	.1%	.1%
Computers and peripherals investment	14.2%	26.6%
Productive stock	5.2%	4.8%
Software investment	2.8%	2.7%
Productive stock	1.3%	6.5%
Communications and other IT equipment investment	2.1%	2.9%
Productive stock	.4%	1.2%
Other equipment investment	1.1%	2.0%
Productive stock	.2%	.9%
Rental residences investment	9.6%	10.8%
Productive stock	.3%	.6%
Inventories	.2%	.3%
Land	.5%	1.5%
Labor hours	.22%	.35%
Labor composition index	.35%	.64%
Labor input (the above two combined)	.45%	.60%
Share of income paid to labor	.77%	1.63%
Output estimates (Y^F_t vs. Y^S_t)	.17%	.17%
MFP estimates (MFP^S vs. MFP^F)	**.59%**	**.49%**

Note: Investment differences were measured over the 1993-2001 period, and capital stock errors over the 1994-2001 period because to construct capital stocks we need deterioration rates that are calculated based on earlier years.

Bibliography

Bureau of Economic Analysis, U.S. Commerce Department. *NIPA Tables*. http://www.bea.gov/bea/dn/nipaweb/SelectTable.asp.

Bureau of Labor Statistics, U.S. Labor Department. *Handbook of Methods*. Bulletin 2490, April 1997.

Bureau of Labor Statistics, U.S. Labor Department. *Labor Composition and US Productivity Growth, 1948-90.* Bulletin 2426, December 1993.

Bureau of Labor Statistics, U.S. Labor Department. *Trends in Multifactor Productivity, 1948-81*. Bulletin 2178, September 1983.

Bureau of Labor Statistics. 2004. Updates regarding labor productivity and multifactor productivity. http://www.bls.gov/lpc/home.htm and http://www.bls.gov/mfp/home.htm

Edge, Rochelle M., Thomas Laubach, and John C. Williams. 2004. "Learning and Shifts in Long-Run Productivity Growth." Federal Reserve Board of San Francisco Working Paper 2004-04.

Gullickson, William, and Harper, Michael J. 1999. "Possible Measurement Bias in Aggregate Productivity Growth." *Monthly Labor Review*, February.

Harper, Michael J., 1999. "Estimating Capital Inputs for Productivity Measurement: An Overview of U.S. Concepts and Methods," *International Statistical Review* 67: 327-337.

Jorgenson, Dale, Frank Gollop and Barbara Fraumeni. 1987. *Productivity and U.S. Economic Growth*. Harvard University Press.

Oliner, Stephen D., and Daniel E. Sichel, (2000), "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?" *Journal of Economic Perspectives* 14:4 (Fall), 3-22.

Orphanides, Athanasios. 2001. "Monetary Policy Rules Based on Real-Time Data." *The American Economic Review*, 91:4 (Sept, 2001), pp. 964-985.

Solow, Robert. 1957. "Technical Change and the Aggregate Production Function." *The Review of Economics and Statistics* 39:3, (Aug. 1957), pp 312-320.