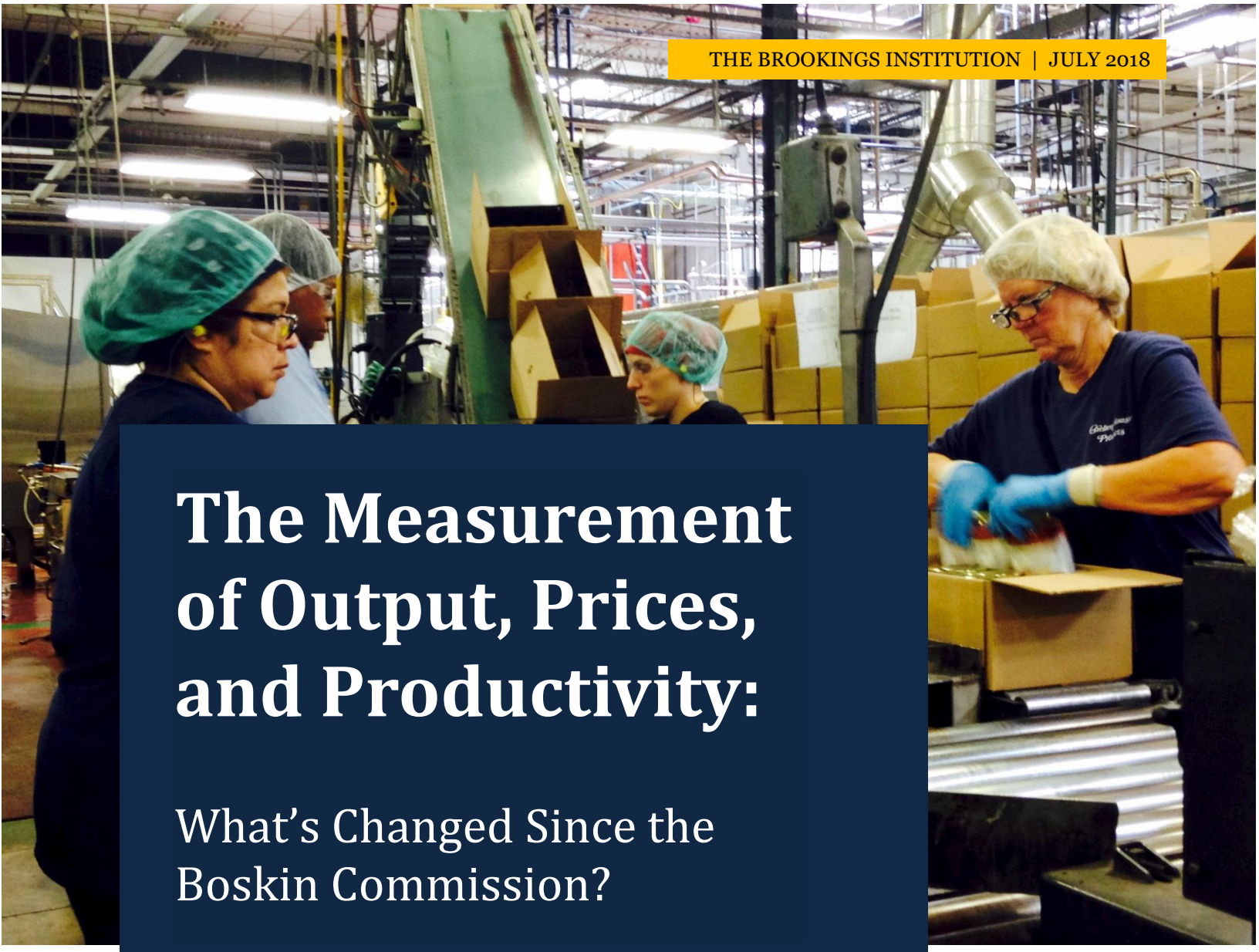

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# The Measurement of Output, Prices, and Productivity:

## What's Changed Since the Boskin Commission?

Brent R. Moulton

FORMERLY OF THE BUREAU OF ECONOMIC ANALYSIS

Hutchins Center on Fiscal & Monetary Policy at BROOKINGS

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## ABOUT PRODUCTIVITY MEASUREMENT INITIATIVE

This report is the product of the Productivity Measurement Initiative under The Hutchins Center on Fiscal and Monetary Policy at The Brookings Institution. The Intiative responds to the need and appetite for (a) examination and clarification of the concepts, purpose and relevance to policy debates of the "output" that comprises the numerator in the productivity measure, e.g. GDP vs welfare and (b) particular attention to the difficult measurement issues in rapidly changing, harder-to-measure and growing sectors of the economy, e.g. health care and information services.


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# Glossary

**Chain-type index** – A price or quantity index that updates the weights period by period, thereby maintaining weights that are based on each period's expenditure patterns. A chain-type index is calculated by multiplying, period-by-period, the indexes for each pair of periods, where the indexes for each pair of periods could be Laspeyres, Fisher, or Tornqvist, etc.

**Cost-of-living index** – A theoretical price index that measures the change in the cost of obtaining a fixed level of economic well-being, or utility. Although it's not possible to directly measure a cost-of-living index, it can be closely approximated using a superlative index.

**Divisia index** – A theoretical price or quantity index that is measured in continuous time. In practice, a Divisia index is approximated by chain-type price or quantity indexes where the chaining takes place at the highest practical frequency.

**Fisher index** – A price or quantity index formula that compares prices or quantities from two periods, using weights that are drawn from expenditures for both periods. The Fisher index is calculated as the geometric mean of the Laspeyres index (which uses weights from the earlier period) and the Paasche index (which uses weights from the latter period) and is a superlative index that closely approximates the conceptual cost-of-living index.

**GDP, expenditure approach** – The sum of final consumption spending by households, nonprofit institutions serving households, and general government, plus private and government gross investment, plus exports, less imports.

**GDP, income approach** – The sum of incomes derived directly from the use of capital or labor by resident producers—compensation of employees, gross operating surplus, and taxes (less subsidies) on production and imports.

**GDP, production approach** – The sum of the gross value added of all producers that reside within the nation's economy. Conceptually, the three approaches to measuring GDP should be the same.

**Geometric mean index –** A price index that is used at the lowest level of aggregation in the CPI (that is, for one of the basic item/area categories below which there is no expenditure information available for aggregating individual prices). For example, if there are *N* prices each with equal sampling weights, the geometric mean index would be the *N*th root of the product of the items' relative price changes.

**Labor productivity** – Output per hour worked.

**Laspeyres index** – A price or quantity index that measures the relative change in the price of a fixed basket of goods and services reflecting expenditures in an earlier period, or the change in quantities

holding prices fixed at their values in an earlier period. The Laspeyres index does not take account of a buyer's ability to substitute between items when relative prices change.

**Lower level substitution bias** – A bias that arises when prices at the lowest level of item classification are aggregated using a formula that systematically overstates the price change. Lower level substitution bias has been addressed by switching to the geometric mean index.

**Matched-model index** – A price index in which, to the extent possible, the sample of models being repriced is held fixed.

**Multifactor productivity** – Output per unit of combined inputs, including labor and capital services.

**Offshoring bias** – The bias arising from not accounting for the benefits accruing to domestic buyers from the opportunity to switch to lower cost new imported sources.

**Outlet bias** – The bias arising from not accounting for the benefits accruing to domestic consumers from the opportunity to switch to lower cost new retail outlets.

**Paasche index** – A price or quantity index that measures the relative change in the price of a fixed basket of goods and services reflecting expenditures in the later period, or the change in quantities holding prices fixed at their values in the later period. The Paasche index (like the Laspeyres index) does not take account of a buyer's ability to substitute between items when relative prices change.

**Private nonfarm business sector** – The sector of the economy that consists of private nonfarm businesses and excludes government, nonprofit institutions, and household and domestic employees.

**Sample rotation** – The periodic replacement or updating of a sample of items or outlets in a price index. When a sample is rotated, the index for the new sample is "linked" to the index from the old sample.

**Superlative index** – A price or quantity index that is associated with a "flexible" aggregator function—that is, an aggregator that provides a second-order approximation to an arbitrary production, cost, or utility function. This property means that a superlative price index (such as the Fisher or Tornqvist index) can provide a close approximation to a cost-of-living index even if we don't know the functional form of the underlying utility index, or that a superlative quantity index can accurately measure productivity even if we don't know the functional form of the underlying production function.

**Tornqvist index** – A price or quantity index formula that compares prices or quantities from two periods, using weights that are drawn from expenditures for both periods. The Tornqvist index is calculated as a geometric mean of the relative changes in prices or quantity, using weights that averages of the expenditure shares in the two periods. Like the Fisher index, the Tornqvist index is a superlative index that closely approximates the conceptual cost-of-living index.

**Upper level substitution bias** – The bias of a price index that arises from use of a fixed-weight or Laspeyres price index, in comparison with a superlative price index that allows consumers to substitute between higher and lower cost items while keeping utility constant.

# Introduction

In a dynamic economy, the nation's statistical system faces a perennial challenge in accounting for the effects of innovation on new products and quality changes. Despite efforts to stay abreast of these changes, the view of many economists is that mismeasurement has led to long-term understatement of changes in living standards and productivity. For example, Feldstein (2017) writes that official GDP statistics provide "at best a lower bound on the true real growth rate with no indication of the size of the underestimation." Furthermore, since 2004, and especially since 2010, productivity growth has substantially slowed, raising concerns about the prospects for long-run growth in living standards (Baily and Montalbano, 2016). This productivity slowdown has brought renewed attention to bias in the statistics that feed into the calculations. While Syverson (2017) and Byrne, Fernald and Reinsdorf (2016) conclude that mismeasurement explains little of the recent slowdown, users of economic data continue to be troubled by persistent biases and the challenges of accurately measuring changes in productivity and living standards.

This paper endeavors to shed some light on these issues by focusing on the efforts made by the US statistical agencies—especially the Bureau of Labor Statistics (BLS) and the Bureau of Economic Analysis (BEA)—to improve the price and volume statistics that are used in calculating real gross domestic product (GDP) and productivity measures. I use as my starting point the *Final Report of the Advisory Commission to Study the Consumer Price Index*, commonly known as the Boskin Commission (Boskin et al., 1996), which kicked off major efforts to improve core economic statistics. I document how official measurement methods have changed and improved since 1996. I conclude that the overall bias of the Consumer Price Index has fallen from about 1.1 percent in 1996 to about 0.85 percent today. Because the CPI and other price indexes are used as deflators in the estimation of productivity, these improvements in the CPI and similar improvements in the Producer Price Index (PPI) have fed directly into reducing bias in the productivity statistics. Despite the continuing challenges in economic measurement, I don't see any evidence that the overall bias has worsened since 1996. I catalog changes in methodology that have affected real output or prices since January 1997. I also offer three recommendations on ways to renew progress on reducing or eliminating bias in multifactor productivity, GDP growth, and related price indexes.

The US statistical agencies made many important changes following the Boskin Commission recommendations, some of which were in the works before the commission report. In particular, the Bureau of Labor Statistics overhauled the CPI, adopting a better method for estimating lower-level price indexes and improving sampling procedures, while expanding the use of hedonic methods for quality adjustment. The PPI greatly expanded its coverage of services, allowing for improved analyses of industries and full industry coverage for multifactor productivity analysis. GDP statistics were upgraded, with new coverage of investment in intangible intellectual property and improved measurement of hard-to-measure categories such as financial services.

The most critical issues in productivity measurement relate to the measurement of price change. Real output—the numerator in the productivity calculation—is generally not observed directly. Instead, price indexes are used to determine how much of the change in the sales of a particular good or service is due to price changes and how much is due to changes in real output, that is the quantity or quality of that good

or service. For this method to work, the price index needs to hold quality constant, but that can be very difficult to do. How much of the increase in spending on health care, for instance, reflects better quality as opposed to higher prices for the same services? Unmeasured improvements in quality can have significant impacts on long-term trends in measured productivity.

This paper begins with background on the Boskin Commission. Section I provides an overview of the methodologies that are used in calculating multifactor productivity. Section II discusses changes in CPI methods, and Section III covers the other major price programs—the PPI, export price index, and import price index. Section IV discusses changes made to the scope of output covered by the private nonfarm business sector. It also discusses the expansion of the GDP accounts to include intellectual property products such as computer software, research and development, and entertainment, literary, and artistic originals. Section V discusses changes in the economic environment, such as the relative growth of services and diminution of goods production, and the role of offshoring and globalization. Section VI concludes and offers a few recommendations for further progress in economic measurement.

# Background: The Boskin Commission

The US Senate appointed the Boskin Commission (chaired by Michael Boskin of Stanford University) in 1995 to study possible bias in computation of the Consumer Price Index, a measure of inflation experienced by consumers. Its final report released in December 1996 estimated that, relative to a true cost-of-living index, the CPI had an upward bias of 1.1 percentage points per year, with a plausible range of 0.8 to 1.6 percentage points.

**Table 1. Boskin Commission (1996) estimates of CPI biases**

(percentage points per year)

| Sources of Bias | Estimate |
|---|---|
| Upper Level Substitution | 0.15 |
| Lower Level Substitution | 0.25 |
| New Products/Quality Change | 0.60 |
| New Outlets | 0.10 |
| **Total** | **1.10** |
| **Plausible range** | **(0.80–1.60)** |

*Source: Boskin et al. (1996), p. 44.*

The Boskin Commission focused specifically on the CPI and the effects on the federal budget of its programmatic uses, such as for cost-of-living adjustments for Social Security and other benefit programs and for escalation of income tax brackets. But other national statistics, such as GDP and productivity, use

CPI component indexes for deflation, and many types of CPI bias also carry over to statistics that are deflated with other price indexes. Because similar methodologies are used in the estimation of other price statistics, such as the BLS producer, export, and import price indexes, some of the same biases can affect those indexes as well.

The Commission considered four underlying sources of CPI bias: upper-level substitution bias (that is, the bias from using a fixed-weight Laspeyres formula that doesn't allow for substitution); lower-level substitution bias (a bias in theformula used to aggregate the price changes of items within an expenditure category); new products/quality change bias (bias due to inadequate quality adjustment for improved products or to the tardy introduction of new products); and new outlets bias (failure to capture lower prices that consumers receive when new, lower-cost retail outlets enter a market).

Many actions were taken in the aftermath of the Boskin Commission. The BLS immediately took several important steps to ameliorate several of these biases (Abraham, Greenlees, and Moulton, 1998), such as adopting (beginning in January 1999) the geometric mean formula for aggregating the elementary-level price indexes, which largely eliminated the lower-level substitution bias (Dalton, Greenless, and Stewart, 1998). Section II describes other steps also taken.

In 1999, the US General Accounting Office (2000) asked four of the five members of the Boskin Commission to provide updated estimates of the remaining CPI bias. They ranged from 0.73 to 0.90 percentage point per year.[1]

The National Research Council (2002) presented a report by a multidisciplinary panel of 13 experts, chaired by Charles L. Schultze, which considered the conceptual framework and measurement basis for the CPI. The panel did not attempt to provide an estimate of bias, but rather focused on providing consensus recommendations for the BLS to utilize in its subsequent work to improve the CPI. In comparison with the Boskin Commission, the Schultze panel took a more nuanced and rigorous approach to basic issues, such as whether the basis for the CPI should be a cost-of-living index. A true cost-of-living index would measure the change in the cost of obtaining a fixed level of economic well-being, or utility. The panel concluded that the CPI should not be based on an unconditional cost-of-living index, but could be based on a conditional cost-of-living index restricted to private goods and services and holding the environmental background factors constant. The Schultze panel also presented detailed recommendations for an experimental medical care price index based on the cost of treating various diagnoses.

Lebow and Rudd (2003) provided an extensive review of the research underlying CPI bias, and offered new analysis that suggested the upper-level substitution bias had increased since the Boskin Commission. They also added an analysis of systematic biases in the weights for the CPI, which are derived from the consumer expenditure survey, concluding that weighting bias contributed another 0.1 percentage point to an upward CPI bias. [4] Lebow and Rudd's estimate of CPI bias was about 0.9 percentage point per year.

The 10th anniversary of the Boskin Commission Report was a moment to consider its impact. The *International Productivity Monitor* featured an article by Commission member Robert J. Gordon (2006) that reviewed the report and subsequent debates about its conclusions. Gordon concluded that, while the Commission may have overstated the quality and new product bias, that effect was more than offset by evidence that they had understated the substitution bias. In the same issue, articles by Baily (2006),

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1. Zvi Griliches, the fifth member of the Boskin Commission, was unable to respond due to illness.

Berndt (2006), Greenlees (2006), and Triplett (2006) explored various aspects of the report's impact. The BLS also noted the 10th anniversary with a retrospective article by Johnson, Reed, and Stewart (2006) in the *Monthly Labor Review*, which described the changes made in response to the report and their impact.

An important research advance after the release of the Boskin Report was enhanced availability of new sources of microdata for measuring prices and inflation. For example, during the early 2000s, BLS began making its microdata available to researchers, who utilized the data for study of CPI measurement issues. Pakes (2003, 2005) examined potential uses of hedonic methods in the CPI, especially focusing on personal computers. Bils (2009) examined CPI microdata on durables goods and concluded that the quality change from the introduction of new models was undercounted, resulting in a quality bias of 2 percentage points per year for durable goods, about double the bias that had been estimated for that category by the Boskin Commission.

Another relatively new type of microdata is barcode, or scanner data, which are available from several private sources. Hausman and Leibtag (2009) examined barcode data collected from households to obtain better estimates of outlet substitution bias for food sold by supercenters (such as Wal-Mart), mass merchandisers (such as Target), and club stores (such as Costco). Broda and Weinstein (2010) and Redding and Weinstein (2016) analyzed barcode data using models of product innovation that allow for the entry and exit of new products. These models and data enabled them to estimate the bias in conventional "fixed-goods" indexes like the CPI.

Brynjolfsson and Oh (2012) observed that digital services that are available for free on the Internet, such as Google, Facebook, and Wikipedia, are not counted in GDP final expenditures. (For digital services funded by advertising, the output is classified as intermediate inputs to the industry purchasing the advertising. Services provided by volunteers, such as producing the content of the Wikipedia digital encyclopedia, is not counted in GDP at all.) They attempted to measure the consumer surplus by measuring the time spent on the Internet and obtained a large estimate of more than $100 billion. Another approach was taken by Nakamura, Samuels, and Soloveichik (2016), who noted that GDP is a measure of production valued at market prices and does not conventionally attempt to measure consumer surplus. Furthermore, they noted that besides funding digital services, advertising is used to fund many other, older services, such as television and print media, and that the growth of digital services has been accompanied by a decline in advertising in those other types of media. Using a supply-side approach that measures the resources used in the creation of digital services while also accounting for the decline of advertising support for other types of media, they obtained smaller values than Brynjolfsson and Oh for the effects of free services funded by advertising. Much of the increase in advertising-supported Internet services is offset by the decline in advertising support for print media.

In contrast to the extensive interest in the CPI, relatively less attention has been given to measurement issues associated with other price programs, such as the BLS producer, export, and import price indexes. A notable exception is Triplett and Bosworth (2004), who analyzed price and productivity measurement issues for services industries and provide recommendations for the new BLS PPIs for the services sector. Their analysis also includes a prototype set of industry productivity accounts.

During the first decade of the 21st century, increased use of offshoring—a process in which imported intermediate inputs take the place of domestically sourced inputs—contributed to a substantial decline in US manufacturing employment and a sharp increase in imports. In principle, GDP calculations should account for the shift from domestic to foreign sourcing. But because standard producer and import price indexes used for deflating components of GDP do not track the substitution of foreign sourced

intermediate inputs for domestically sourced goods, offshoring led to a bias in real GDP and productivity statistics. This failure of price indexes to track changes in sourcing is a variant of the "outlet substitution bias" discussed by the Boskin Commission; however because it is related to imports, it results in an *upward* bias to real GDP and productivity (based on an upward bias to price indexes for intermediate consumption, which are subtracted from output in the calculation of value added/GDP). The offshoring bias associated with imports has been studied by Houseman et al. (2011), Nakamura and Steinsson (2012), and several papers in Houseman and Mandel (2015).

A similar bias affects the investment and capital services measures. In principle, investment prices should be measured from the perspective of the buyer or investor—how much does it cost to buy a computer, an aircraft, or software program? In practice, prices of investment goods are measured using a weighted average of producer and import prices—prices that are collected from sellers, domestic or imported, and which do not account for substitution to lower priced sellers. Just as it would be desirable to use a buyer-oriented input-price index to measure intermediate inputs, it would also be desirable to use a buyer-oriented investment price index to measure capital investment.

# I. Overview of the measurement methods used for output, prices, and productivity

Productivity measures the efficiency of economic production—how units of inputs, such as labor and capital, are converted into units of output. Over prolonged periods, growth in productivity is the main source of improvements in a population's standard of living, as represented by growth in real GDP or real consumption per capita.

## I.A Labor and multifactor productivity concepts and methods

The Bureau of Labor Statistics has conducted studies of output per hour in individual industries since 1898, and has regularly published labor productivity for major sectors since 1959 (see Bureau of Labor Statistics, 2008; Bureau of Labor Statistics, no date). The rate of growth in labor productivity is equal to the rate of growth in output minus the rate of growth in labor hours. Formally, labor productivity, $\pi_{t,0}$, in year $t$ (relative to a reference year 0) for a major sector of the economy is calculated as the ratio of a quantity index[2] of the sector's output (or value added) in year $t$ to a quantity index of labor input, or hours worked, in year $t$:

$$(1)\quad \pi_{t,0} = \frac{\text{Quantity index of output (or value added)}}{\text{Quantity index of labor input (hours worked)}}$$

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2. A *quantity index* (or *volume index*) measures the proportionate changes in quantities of goods and services between two time periods. Generally, the overall proportional change in value of an aggregate, such as output or expenditures, can be decomposed into price changes and quantity changes, with any changes in quality of the goods and services attributed to quantity change.

Labor productivity contrasts with *multifactor productivity* (MFP), which BLS has published on a regular basis since 1983 (see Dean and Harper, 2001). Rather than the denominator accounting for a single input (labor), the denominator accounts for a *bundle* of inputs—typically including both labor and capital. Capital-labor MFP in year *t* is calculated as the ratio of a quantity index of output to a quantity index of combined labor and capital input:

$$(2) \quad A_{t,0} = \frac{\text{Quantity index of output (or value added)}}{\text{Quantity index of combined labor and capital input}}$$

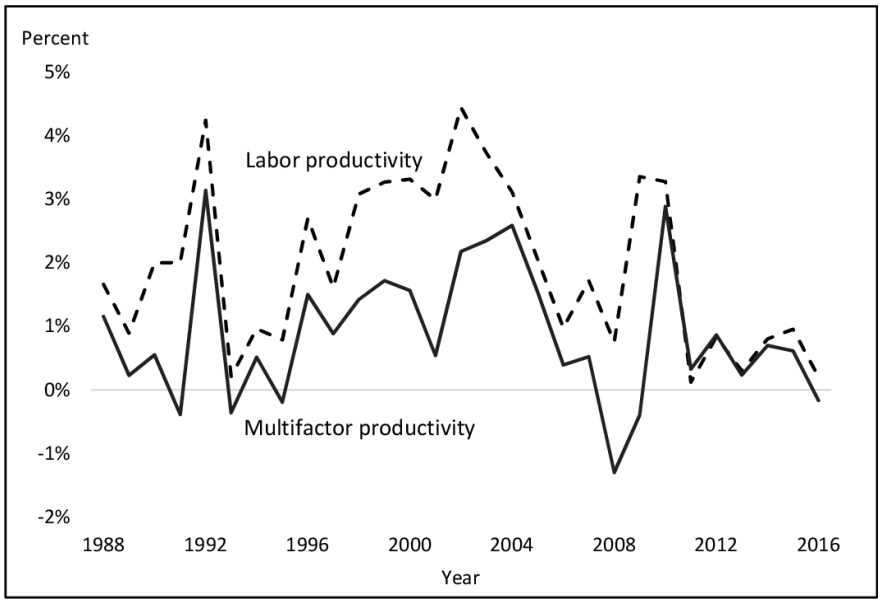
Capital-labor MFP can be expressed as the difference in the rate of growth of a Divisia index of output and a Divisia index of inputs. Let $Q$ denote the index of output, $L$ and $K$ denote indexes of labor and capital inputs, and $s_L$ and $s_K$ denote the shares of labor and capital in overall spending for primary inputs. Then the percent change in capital-labor MFP can be written as (see Organisation for Economic Cooperation and Development (OECD, 2001):

$$(3) \quad \frac{\partial A}{\partial t} = \frac{d\ln Q}{dt} - s_L \frac{\partial \ln L}{\partial t} - s_K \frac{\partial \ln K}{\partial t}$$

Both labor productivity and MFP growth accelerated from 1995 through 2004 and have decelerated since 2004, though the acceleration and deceleration were more pronounced for labor productivity than for MFP (Figure 1; Table 2). Furthermore, since 2010 the gap between labor productivity and MFP has essentially closed, as capital services inputs have grown at about the same rate as labor input. Prior to 2010, capital services usually grew more rapidly than labor input, which helped drive the growth in labor productivity.

**Figure 1. Labor productivity and multifactor productivity, US private nonfarm business**

Annual percent change, 1988 to 2016




*Source: Bureau of Labor Statistics, https://www.bls.gov/news.release/pdf/prod3.pdf.*

**Table 2. Labor productivity and multifactor productivity, US private nonfarm business**

Average annual rates of change over selected periods

| Productivity Measure | 1995–2004 | 2004–2016 |
|---|---|---|
| Labor productivity | 3.1% | 1.3% |
| Multifactor productivity | 1.6% | 0.4% |

*Source: Bureau of Labor Statistics, https://www.bls.gov/news.release/pdf/prod3.pdf.*

This paper focuses on BLS's featured measure of MFP for the private nonfarm business sector.[3] The methodologies are summarized in Bureau of Labor Statistics (2007). The BLS major sector MFP measure is produced annually and compares the growth in sector output to the combined effects of growth in labor and capital inputs. The sector output is the same as BEA's value added of the nonfarm business sector, except that the output of government enterprises (public-sector enterprises that are primarily engaged in producing output for sale) is omitted because of difficulties in measuring the impact of subsidies for those enterprises. Labor and capital inputs are aggregated using a Tornqvist chain index, with the shares of labor and capital costs used as weights. The labor index includes adjustments for labor composition, and the components of capital services are aggregated using rental price formulas.

In discussing the BLS methodology for MFP, a few technical points should be noted:

- The numerator of the BLS MFP calculation for major sectors is value added—that is, the total output of the sector *less* the intermediate goods and services consumed in production. (Note that, in contrast to GDP, the MFP numerator doesn't cover the government, nonprofit, or household sectors.) The denominator is an index of *primary* inputs—that is, labor and capital services. In contrast, for MFP of individual industries, the numerator used by BLS is total output for the sector, and the denominator is a weighted index of capital, labor, energy, non-energy materials, and purchased business services inputs (Bureau of Labor Statistics, 1997a). According to OECD (2001), "At the aggregate level of the economy, gross-output and value-added based measures converge when the gross-output measures are defined as sectoral output. Sectoral output is a measure of production corrected for deliveries within a given sector."
- The measurement of capital services in MFP tends to be closely related to the measurement of investment in fixed capital assets. Although this paper does not detail how capital services are measured (see BLS, 2006), I note that the estimates begin with estimates of productive capital stocks, which are based on data on past investment along with estimates of how an asset's services deteriorate over its service life. The prices applied to capital services are generally the same as, or closely related to, the prices for investment. The implication of

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3. Productivity measurement for the government, nonprofit, and household sectors raises many interesting issues that are important for international comparisons, but which are beyond the scope of this paper.

these relationships is that, over the long run, changes to measured investment are often partly offset by changes to measured capital services, which reduce the overall effects on MFP. This factor tends to dampen the impact of improved quality adjustment of high-tech investment goods and of the recent expansion of fixed investment in GDP to include intellectual property products.

- For MFP, the measure of labor input is adjusted for changes in labor composition in addition to changes in hours worked. The measure of labor input thus adjusts for improvements in education and for changes in the age and sex distribution of the workforce based on an assumption that differences in wages among types of workers reflect differences in their productivity (BLS, 2016).

## I.B GDP for nonfarm business sector

The Bureau of Economic Analysis is responsible for compiling the national economic accounts, including GDP statistics, which are the source for the value-added measure used as the numerator in the major sector productivity statistics. BEA's methodologies affect the scope and coverage of GDP and the deflators used for various GDP components. When major changes are introduced to national economic accounts, BEA's general policy is to attempt to back-cast the changes to maintain consistency in the time series. BEA's national economic accounts are largely, though not entirely, consistent with the international guidelines, *System of National Accounts 2008* (Commission of the European Communities et al., 2009). Bureau of Economic Analysis (2016) explains the national income and product accounts methodology.

GDP can be defined using three approaches, which in principle should all be identical:

- *Production approach* – GDP is the sum of gross value added of all resident producer units, valued at purchasers' prices (where gross value added is equal to output less intermediate consumption);
- *Expenditure approach* – GDP is the sum of expenditures on final uses of goods and services valued at purchasers' prices (that is, household and government consumption expenditures, gross capital formation, and exports of goods and services) less the value of imports of goods and services;
- *Income approach* – GDP is the sum of incomes derived directly from the use of capital or labor by resident producer units (compensation of employees, gross operating surplus/mixed income, and taxes (less subsidies) on production and imports).

In US accounts, the production and expenditure approaches are reconciled and published as GDP,[4] while the income approach is estimated separately and published as "gross domestic income," with a

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4. For quarterly and annual estimates, the expenditure approach is estimated first, and then the production approach is derived and reconciled to the total from the expenditure approach. However, Howells and Wasshausen (2016) report that BEA is planning to begin preparing "advance" input-output tables that would allow for earlier feedback and partial reconciliation between the production and expenditure approaches. For benchmark years (that is, every five years when an economic census takes place), BEA fully reconciles the production and expenditure approaches as a step in the estimation of GDP.

statistical discrepancy presented showing the difference between estimates of GDP and of gross domestic income.

In BEA's national income and product accounts, the value added of the nonfarm business sector is derived, in current dollars, based on a combination of the expenditure and income approaches. First, the expenditure approach is used to derive the estimate of total GDP, and then income-based estimates of value added for non-business sectors—general government, nonprofit institutions serving households, and the services of owner-occupied housing and the compensation paid to household workers—are subtracted, leaving the value added of the business sector as a residual. Value added of general government is equal to the compensation paid to its employees and the consumption of fixed capital for fixed assets owned and used by general government. A similar calculation is used for nonprofit institutions serving households. Because general government and nonprofit institutions do not sell most of their output, the output is valued based on the costs of the inputs used in its production. For owner-occupied housing, the output is valued based on "rental equivalence"—that is, the rentals paid for equivalent tenant-occupied housing, and the value of intermediate inputs, such as maintenance and repair, is subtracted to derive value added. To go from the value added of the business sector to the value added of the nonfarm business sector, BEA subtracts the value added of the farm sector, which is estimated using the production approach.

I note that not all "government consumption and gross investment" is excluded from private nonfarm business output. The output attributable to government employees and government-owned fixed capital assets is excluded, but government purchases of goods and services from the private sector (such as services of government contractors) remain part of private nonfarm business output. In recent years, roughly one-third of government consumption expenditures is attributable to purchases from the private sector that are included in private nonfarm business output; see National Income and Product Accounts (NIPA) Table 3.10.5 ("Government Consumption Expenditures and General Government Gross Output").

BEA's estimates of value added for the business sector and the nonfarm business sector are presented in NIPA Tables 1.3.5 ("Gross Value Added by Sector") and 1.3.6 ("Real Gross Value Added by Sector, Chained Dollars"). BLS makes one additional adjustment to these data before using them as the numerator of MFP for the private nonfarm business sector. The value added of government (or public-sector) enterprises, which are counted as part of the business sector in BEA's estimates, is subtracted to restrict the scope to private-sector businesses. These government enterprises are government agencies that cover a substantial proportion of their operating costs by selling goods and services to the public, such as the US Postal Service and public water and sewage agencies. In 2017, households and nonprofits produced 12.6 percent of GDP, general government produced 11.6 percent, government enterprises produced 1.1 percent, farms produced 0.7 percent, and private nonfarm businesses produced 74.0 percent.

To obtain real GDP, nominal changes for each of about 2,000 GDP components are split into changes in prices and changes in real expenditures using one of three methods:

- The most common method is *deflation*. According to this method, the nominal expenditures for a component of GDP are deflated using an appropriate price index, usually based on BLS consumer, producer, export, or import price indexes, though the monthly BLS price indexes may need to be aggregated to quarterly frequency. Generally, components of personal consumption expenditures (PCE) are deflated using CPIs, components of private investment

and government spending are deflated using PPIs, exports are deflated using export price indexes, and imports are deflated using import price indexes (though exceptions are made when a BLS price index doesn't match the GDP category).[5]

- The second method for deriving changes in real expenditures is *quantity extrapolation*, which is used when a price index isn't available, but an appropriate measure exists for the real quantity or volume of goods or services. In this method, the nominal expenditures are divided by the volume index to obtain an implicit price index. This method is used for deriving real expenditures and implicit prices for certain financial services and for a few other components of the accounts.
- The third method, *direct valuation*, is the least commonly used. When both high quality price and quantity measures exist, the nominal expenditures may be derived as price times quantity. Direct valuation is used, for example, for the measurement of gasoline expenditures.

Once BEA has consistent sets of estimates for nominal expenditures, prices, and real expenditures for each component of GDP, the estimates are combined using chain-type price and quantity indexes based on the Fisher formula. For each pair of adjacent periods (which may be months, quarters or years) BEA creates Laspeyres and Paasche indexes for relative price and quantity changes. For example, the Laspeyres and Paasche *quantity* indexes from period *t–1* to period *t* are:

$$(4) \qquad Q_t^L = \frac{\sum p_{t-1} q_t}{\sum p_{t-1} q_{t-1}},$$

$$(5) \qquad Q_t^P = \frac{\sum p_t q_t}{\sum p_t q_{t-1}},$$

where $p_t$ and $q_t$ are the prices and quantities in period *t* for each component commodity within the aggregate. The Fisher quantity index is the geometric mean of the Laspeyres and Paasche indexes:

$$(6) \qquad Q_t^F = \sqrt{Q_t^L \times Q_t^P}$$

The indexes are then "chained" by multiplying together the Fisher indexes for each adjacent period:

$$(7) \qquad Q_t^{chain} = Q_0^F \times Q_1^F \times Q_2^F \times \ldots \times Q_t^F.$$

(The Fisher *price* index is based on the same general set of formulas, except that the prices and quantities are reversed.)

Note that the weights for each period in the chain-type index are always current, in that they are based on the prices and quantities of the two periods being compared. This contrasts with fixed-weight indexes, such as the headline CPI, which are often based on weights several years out of date. Also, the

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5. For more information, see Table 2 of Bureau of Economic Analysis (2017).

Fisher formula is a "superlative" index formula, which takes account of consumer behavior in substituting from goods that have become relatively more expensive toward goods that have become relatively less expensive. This feature means that the chain-type Fisher price index is closer to a true cost-of-living index by largely eliminating the upper-level substitution bias. And the use of a superlative index formula for measuring real GDP means that it is closer to the true change in volume of economic output. In Appendix A, I provide a brief explanation of the theory of the cost-of-living index and compare it with the theory of the output price index that underlies the PPI.

Because deflation is by far the most common method, the methodologies used for constructing price indexes play a critical role in measuring real output and productivity. I next turn to the methodologies of the major BLS price index programs that provide most of the GDP deflators.

## I.C Consumer Price Index methods

Bureau of Labor Statistics (2018) describes the methods used to estimate the CPI and Groshen et al. (2017) recently provided an excellent overview of how quality change and new goods are treated in the BLS price index programs. This section briefly describes CPI sample selection, estimation and weighting methods, and quality adjustment procedures.

The CPI produces price indexes for consumer spending by two target populations: all urban consumers (the "CPI-U" population) and urban wage earners and clerical workers (the "CPI-W" population). The CPI-U population covers about 93 percent of the US population—all civilian, non-institutional population living in US core-based statistical areas (Paben, Johnson, and Schilp, 2016). The CPI-W represents only about 28 percent of the total US population and is, importantly, used for annual cost-of-living adjustments to benefits for Social Security and Supplemental Security Income. The CPI-U components, however, are used for the deflation of components of real GDP and it consequently is the important index population for measurement of MFP.

CPI samples are culled from samples of urban areas, retail or services outlets, and items sold at the outlets. Because this review focuses on national-level statistics, I do not describe the sampling of urban areas. The sample of outlets is based on the telephone point-of-purchase survey (TPOPS), which provides frame data on the retail outlets from which households are purchasing goods and services. Based on responses to this survey, a sample of outlets is selected, with about 27,000 outlets visited each month and with prices collected for about 83,000 individual goods and services. Additionally, a housing survey collects rents and rental equivalence for a sample of 43,000 units.

These observations in these samples are organized into about 8,018 *elementary* cells, each representing one of 211 item categories times 38 areas, and an *elementary index* is calculated for each cell to serve as the first step in CPI aggregation. The samples of non-housing outlets and items in each elementary cell are refreshed over a four-year cycle in a continuous rotation matrix scheme, a process also known as *sample rotation*. The housing samples are also now rotated at six-year intervals. When samples are rotated, the component index estimated from the new sample of items and outlets is linked to the index based on the previous sample. The selection of outlets and of items within each elementary cell is based on probability proportional to expenditure to ensure a representative sample.

Once the sample has been selected, a computer-assisted data collection system provides electronic checklists of item specifications to ensure that the data collector can identify the same item upon each return to the outlet. Prices are collected either monthly or bimonthly, depending on the commodity

category and the urban area size. Each month, data collection is scheduled for one of three pricing periods that are of variable length and cover the entire month. New goods can enter the sample only during either the regular four-year sample updates or when an item in an existing sample is no longer available and needs to be replaced. That is, BLS sampling methods do not actively search out new goods as they are introduced to the market, though BLS occasionally initiates an outlet sample in less than four years to get new products into the sample more quickly.

According to Groshen et al. (2017), during the 12 months ending November 2014, CPI data collectors could re-price the specified commodities and services sample item 73 percent of the time. Of the remaining 27 percent, 22 percent reflected temporarily unavailable items, such those that were only available in certain seasons. The other 5 percent were items that permanently disappeared, triggering the selection of a replacement and a quality adjustment procedure.

When a sample item becomes permanently unavailable, the CPI data collector tries to find a similar item at the same outlet to take its place. If its characteristics are very similar to those of the disappearing item, the replacement item is deemed to be directly comparable, and the price of the replacement item is simply used in the price change estimation as if it were the original item; in 2014, these cases represented three-fifths of CPI item replacements. The remaining two-fifths of replacements were handled using either direct quality adjustment or imputation. Direct quality adjustments come from hedonic regressions, which allow the BLS commodity analyst to include an estimate of the value for the difference in quality (as summarized by the coefficients of commodity characteristics from a regression of price on characteristics), or from manufacturers' data on the cost of producing the higher quality item. When information is not available for direct quality adjustment, one of two imputation methods is used for estimating the change in relative price of the old item that has disappeared from the sample.[6] The following month, the price change of the new item is then linked into the index sample.

Although economists often assume that the quality bias of traditional price indexes is always upward, biases can be either upward or downward, so their direction and magnitude must be established empirically. For the imputation method of quality adjustment, OECD (2006, p. 27) describes the effects as "one of the most misunderstood aspects of price index numbers." Imputation is based on the assumption that the quality-adjusted price change can be inferred from related items whose quality did not change, and imputes the quality-adjusted price change from the price changes of those related items. But sellers often time their price changes (either increases or decreases) to coincide with quality changes. This suggest that imputed price changes—which are based on items not experiencing any quality change—may be smaller in absolute magnitude than the price changes of the items whose quality is changing. If the prices for that category are generally decreasing (as, for example, in the case of computers and electronic goods), the imputed price change would understate the appropriate quality-adjusted price decline. Conversely, if prices in the category are generally increasing (as, for example, for some services), the imputed price change could understate the appropriate quality-adjusted price increase. In other words, the imputation method of adjusting for quality change is biased in the direction of showing little or no change in prices, which can be either upward or downward in direction depending on the direction of

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6. The two imputation methods are the cell-relative method and the class-mean method. Both impute the price change using the mean price change of observation that did not experience substitution. The former uses all such observations in the cell, whereas the latter uses only the comparable and quality-adjusted replacement observations, which is appropriate for goods that experience periodic introduction of new lines or models. See Bureau of Labor Statistics (2018).

price change for the item category. In contrast, quality adjustments based on production cost, which are more commonly used for the PPI than for the CPI, are based on manufacturers' estimates of how much it cost to make changes in production conditions to build the item with its new characteristics. Because manufacturers may find it easier to report all cost changes rather than just those associated with the quality change, adjustments using this method may "overstate the value of quality changes" and thus understate the pure price changes (OECD 2006, p. 35).

It should be emphasized that direct quality adjustments are only applied when an item disappears from the sample. While this timing allows BLS to handle many "routine" quality adjustments, such as the replacement of an old car or television model by a newer replacement, the introduction of entirely new products often does not immediately lead to the disappearance of older items. For example, when smartphones were first introduced to the market, basic cellphones remained available for several years (and, indeed, are still available, albeit with a quite small market share). Thus, smartphones probably entered the CPI sample primarily through sample rotation rather than through item replacement, since initially a disappearing basic cellphone probably would have been replaced in the sample by a similar basic cellphone rather than by a smartphone. Similarly, the introduction of ride-sharing services such as Uber and Lyft didn't cause traditional taxi services to disappear; rather, these services probably also entered the CPI sample primarily through sample rotation rather than through item replacement. This is important because when the sample is rotated at four-year intervals, BLS does not attempt to adjust for quality differences. The new sample is simply linked to the old sample, even if the items in the new sample are substantially less expensive than in the old sample. Quality adjustment is only considered when an item disappears and needs to be replaced. Moulton, LaFleur, and Moses (1998) presented evidence that much of the "quality change for televisions is not of a type captured by the routine replacements that occur because of sample attrition."

Similarly, new outlets are only introduced through sample rotation; as such, if new outlets provide, on average, lower prices than old outlets for the same goods, these lower prices are never reflected in the CPI, but instead are treated as entirely due to quality differences. This is the source of the outlet bias studied by Reinsdorf (1993) and included in the Boskin Commission's CPI bias estimates. Hausman and Leibtag (2009), using scanner data on household purchases of food, found that supercenters, mass merchandisers, and club stores—a category of outlets that grew rapidly during the 1980s and 1990s and reached 25 percent of food expenditures by 2003—charged prices that were about 27 percent lower than traditional supermarkets. They found that a CPI for food that captures the effects of outlet substitution rose 0.32 percentage point per year more slowly—a similar estimate to Reinsdorf's. BLS researchers Greenlees and McClelland (2011), however, found evidence suggesting that much of the price differences between the new and old outlets were attributable to quality differences.

In the CPI, estimation and aggregation of individual prices into an overall index takes place at two levels. At the first, or lower level, prices for categories of items and urban areas ("strata") are aggregated without availability of household expenditure data for weighting. From 1978 through 1998, BLS had attempted to use a modified Laspeyres formula for these elementary aggregates, but because weighting information was not available, the resulting estimates were shown to have systematic upward bias—see

research by Reinsdorf (1998), Moulton (1993), and Reinsdorf and Moulton (1996).[7] Beginning in 1999, BLS has instead primarily used the geometric mean formula, which as discussed below largely avoids this bias. Subsequently, the use of the geometric mean formula has been recommended by the international manual (ILO, 2004) and is now widely used by statistical agencies throughout the world.

For the upper level of aggregation—that is, combining the elementary indexes for the item-area strata to calculate higher-level aggregates up to the all-items CPI-U and CPI-W—BLS continues to use a fixed-weight Laspeyres (or modified Laspeyres) formula. BLS also produces the chained CPI for All Urban Consumers (C-CPI-U), which uses chain-weighting and the superlative Törnqvist formula.[8] With the enactment of the Tax Cuts and Jobs Act of 2017, the chained CPI is now used for the adjustment of income tax brackets for inflation. From December 1999 through December 2016, the average annual growth rate of the chained CPI was 0.26 percentage point lower than that of the featured CPI-U, suggesting that upper-level substitution bias is about a quarter percentage point per year. Because MFP statistics are based on GDP data that are estimated using chained indexes and the Fisher formula, these statistics are generally not affected by the headline CPI's upper-level substitution bias.

To summarize, CPI's lower-level substitution bias has now been largely eliminated, and the chained CPI, GDP, and MFP avoid upper-level substitution bias by using chained indexes. But to the extent that BLS methods do not fully adjust for quality change, new goods, or new outlets, those CPI biases are also reflected in GDP and MFP statistics.

## I.D Producer, export, and import price index methods

Bureau of Labor Statistics (2015) describes the methods used to estimate the Producer Price Index, a family of indexes that measure changes over time in the prices received by domestic producers of goods and services. The PPI measures prices from the perspective of the seller, which means it excludes subsidies, sales and excise taxes, and distribution costs that may be included in the CPI. The PPI also typically captures goods at an earlier stage in the process of production and distribution than the CPI; for example, the PPI measures the prices received by manufacturers of a good rather than the prices paid by consumers at a retail store.[9] The PPI includes intermediate goods and services used as inputs in production not included in the CPI and excludes imported goods and services. The PPI data are presented using three types of classifications: Industry classification (the North American Industry Classification System, or NAICS), commodity classification, and a commodity-based final demand-intermediate demand system.[10]

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7. Reinsdorf first identified this issue for the US CPI in a presentation at the Allied Social Sciences Associations meeting in January 1993. Dalén (1992) had reported similar findings for Swedish CPI estimates. Because weighting information is not available, the bias might be better described as a statistical bias rather than as a type of substitution bias.

8. The Fisher and Törnqvist formulas are both "superlative" indexes that can, under certain assumption, provide close approximations to a cost-of-living index—see Appendix A. In practice, the two formulas usually tend to produce similar estimates of price change.

9. For retail and wholesale trade, the PPIs measure the changes in margins, which are the relevant producer price for these industries.

10. The PPI program also produces a limited number of net-input-to-industry indexes.

PPIs are available for nearly all goods-producing sectors of the US economy, and now cover about 72 percent of the service sector's output. The expansion in coverage of the service sector has been one of the PPI program's major accomplishments over the last 20 years. Prior to the mid-1990s, the PPI was not close to covering most service industries.[11] While the new coverage of services followed the same general strategy for price measurement as that for goods—that is, representative samples of services were selected, described in detail, and repriced each month—in some cases, special methods had to be employed. For example, in some cases respondents are asked to report a price for a standardized service that may or may not have actually been provided during the reporting period. With each new services industry, BLS conducted research to identify and define the industry's output and to identify quality characteristics that could be used to derive a constant-quality price index.[12]

The PPI collects about 88,000 price quotations each month for products from about 21,000 establishments. BLS emphasizes that businesses need to report transaction prices rather than list prices, and include all discounts, premiums, rebates, and allowances. Less than 20 percent of collected prices are based on list prices, according to BLS estimates.

Because the same product is priced each month, adjustments are needed when a product is replaced by an updated version or when a product's characteristics change. For goods that undergo periodic model changes, BLS applies an explicit quality adjustment that is usually based on the collection of data from companies on the costs they incurred relating to the quality change. If, however, the respondent is unable to provide this information, BLS assumes that the difference in price between the old item and the new one is entirely due to differences in quality. For a few high-tech industries, the PPI uses quality adjustments based on hedonic regressions, which BLS has been actively trying to expand where possible.[13]

PPI indexes are calculated using a modified Laspeyres formula, and use net output values of shipments for goods and revenue data for services as weights. The weights are based on data from the five-year economic censuses and are typically incorporated with a lag of about four to five years after the census year.

BLS (1997b) describes the methods used to estimate the export and import price indexes. The import and export prices cover nearly all merchandise trade categories and selected categories of international services. Import and export price indexes are aggregated using the Laspeyres formula with weights based on trade value figures from the Census Bureau. The sample of US exporters is derived from shippers' export declarations, and the sample of importers is derived from entry documents. Respondents are asked to provide prices for actual transactions, though estimated or list prices may be accepted when transaction prices are not available. The index includes prices associated with intra-company transfers, regardless of whether they are market-based.

Import and export price indexes are matched-model indexes; that is, the same items are re-priced each month. If there is a substantive change in the item, the quality difference is generally handled either by direct quality adjustment using information from respondents (or, in the case of computers, from the

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11. Prior to the availability of services-sector PPIs, for measuring prices and quantities of services for which CPIs weren't available, BEA had to rely on indirect indicators such as wages or employment.

12. See Swick, Bathgate, and Horrigan (2006).

13. For more information on quality adjustment, see Bureau of Labor Statistics (2014), "Quality Adjustment in the Producer Price Index."

PPI hedonic model), or by "linking," which essentially assumes that the difference in price between the old item and the new one reflects quality differences. The international price program now uses some quality adjustments based on hedonic methods, but characteristics' information is frequently unavailable, making the hedonic approach infeasible. Kim and Reinsdorf (2015) studied the feasibility of expended use of hedonic regressions for quality adjustment.

# II. Improvements to the Consumer Price Index

This section discusses some of the major changes made to the Consumer Price Index since publication of the 1996 *Final Report* of the Boskin Commission. Appendix Table B1 provides a comprehensive list of major changes in methodology that could affect the growth of the CPI or its components (and thus, indirectly, may affect real GDP and measured MFP). It should be noted, however, that not all methodological improvements are cataloged in the table. For example, I do not include methodologies, such as seasonal adjustment, that affect the timing of price change but not the long-term trend. Similarly, I do not catalog methodological changes that focus on topics such as geographic sampling (because my focus is on the national CPI) or on improvements to processing and estimation systems that are designed to facilitate efficient production of the data.

During the period leading up to, and immediately after, release of the Boskin Commission report, BLS greatly expanded its work on CPI bias. In the December 1993 *Monthly Labor Review,* BLS summarized its own research on biases. The issue included articles reviewing the relationship between CPI and a conceptual cost-of-living index (Fixler, 1993), providing estimates of upper-level substitution bias (Aizcorbe and Jackman, 1993), and giving an example of research on hedonic quality adjustment (Kokoski, 1993). An article by Moulton (1993) presented some early work on the new issue of lower-level substitution bias, which was identified by BLS's Marshall Reinsdorf in 1993 (Reinsdorf, 1993; Reinsdorf, 1994). This issue explored how to combine individual price quotes for a specific item category, such as apples, to get the elementary lowest-level price index, which would then be aggregated with other price indexes to derive the all-items CPI.

By January 1995, BLS had implemented steps to reduce the most significant biases associated with the lower-level substitution problem. But it had not yet decided whether to take the step of dropping the old estimator, which was based on a modified Laspeyres concept, versus moving to the geometric formula that had been suggested by Dalén (1992) and Moulton (1993). By the time of the release of the Boskin Commission's *Final Report,* BLS had conducted additional research on the issue (e.g., Reinsdorf and Moulton, 1996; Reinsdorf, 1998) and Diewert (1995) had recommended the geometric index formula, which was based on index number theory. Nevertheless, BLS senior management remained concerned that making such a fundamental change to the framework for the CPI would need a stronger basis of theoretical and empirical support.

In the follow-up to the Boskin Commission's clear recommendation that "BLS should move to geometric means at the elementary aggregates level," BLS was under pressure to reach a decision. In April 1998, Commissioner Katharine Abraham announced that for most items, the CPI would adopt, effective in January 1999, the geometric mean formula for the first stage of aggregating the prices for the lowest, or elementary, level of aggregation. Dalton, Greenlees, and Stewart (1998) provided an explanation of BLS's

decision and a description of how it would be implemented. Evidence that consumers regularly substitute or shift their spending within these elementary categories—for example, increasing spending on a particular brand of ice cream when it goes on sale—led to the adoption. Use of the geometric mean more accurately reflects consumer spending within these categories because it allows for substitution, whereas a fixed-weight index does not. A few item categories were excluded from the use of the geometric mean index because of limited opportunities for item substitution within those categories. The impact on the all-items CPI was to reduce its growth by about 0.2 percentage point per year; I estimate that the effect on private nonfarm business output was to increase its growth by about 0.15 percentage point per year. (Appendix Table B1 provides a comprehensive list of improvements made to the CPI since 1997.)

An important associated aspect of this change is that BLS began producing a CPI research series that back-casts the various methodological improvements and corrections, providing a time series dating back to 1978 that accounts for methodological changes (Stewart and Reed, 1999). Using this series, the CPI-U-RS, BEA also carried these changes back to 1978 in GDP statistics, thereby reducing bias over an extended period.[14]

BLS also undertook additional actions to address quality adjustment and other biases identified by the Boskin Commission. One of the first changes was to begin using a hedonic regression model to quality adjust personal computers purchased by households. Since the BLS PPI program had already developed hedonic regressions for quality adjusting the PPI for computers, the CPI was initially able to use the coefficients from those regressions to adjust computer prices for quality change. The estimated effect of adopting this method was large—lowering price changes for the CPI for computers by about 6.5 percentage points per year. Additional research was soon underway on hedonic quality adjustments for other components.

Hedonic quality adjustments for televisions were adopted in 1999, and adjustments for video and audio equipment, for major appliances such as refrigerators, washing machines, and dryers, and for college textbooks soon followed. An interesting finding: After the initial substantial impact of hedonic quality adjustment on computers, the measured impact on most of these other items was relatively small, and sometimes actually led to higher measured rates of inflation.

As the Boskin Commission carried out its mandate, the CPI undertook its once-a-decade major revision, which had been planned before CPI bias became the center of attention. Consequently, major elements of the CPI revision were statistical improvements, such as the item classification structure, the survey and process used for selecting outlets, and the housing sample. Some of these improvements clearly would help BLS address the biases discussed by the Boskin Commission—for example, the revamped item structure helped BLS data collectors to identify and classify newer goods and services like personal computers and cellular telephone services. But it was not possible to quantify the impact of most of these statistical improvements on the overall CPI bias.

While there have been some major improvements to CPI methods over the last decade—for example, BLS started regularly rotating the housing sample and began quality adjusting wireless telephone services (see Appendix Table B1)—improvements to CPI methods appear to have slowed since the first six years after the Boskin Commission *Final Report*. While I can't fully account for the slowdown, it is possible that

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14. Because the BLS had started using the modified Laspeyres formula at the elementary level in 1978, that year was the natural breaking point; the empirical research on the bias wasn't applicable to the pre-1978 period.

BLS was initially able to advance quickly by going after "low hanging fruit"—methodological changes that could be made with a relatively modest investment. Presumably, at some point BLS also had to turn its attention to IT and survey operations issues, which are important to the functioning of the program but are not covered in this paper. It's also possible that the mixed results of the later hedonic models and a general reduction in attention to CPI bias led to a more conservative approach to making methodological improvements. Finally, a tight budget environment has undoubtedly limited the ability of BLS to invest in some CPI improvements. I'm cognizant that BLS has continued research on improving the CPI and am heartened that BLS staff are interested in addressing recent criticisms of the agency's statistics.

# III. Changes to other major price indexes

This section discusses some of the major changes made to the Producer Price Index program and to export and import price indexes since 1997. Appendix Table B2 provides a comprehensive list of the major changes in methodology that might affect the growth of these indexes.

Most of the methodological improvements in the PPI program over this period represent the introduction of new service-sector price indexes. Price indexes were added for many important service-sector categories that carry substantial weight in the deflation of GDP and the measurement of private nonfarm business-sector output. For example, within personal consumption expenditures (PCE) for health care services, PPIs are used for the deflation of physicians' offices, hospitals, proprietary and government nursing homes, home health care services, medical care laboratories, and diagnostic imaging centers. New service-sector PPIs are also used for the deflation of various financial services within PCE. BEA used a new price index for pre-packaged software (Hill, 1998) when it expanded the coverage of fixed investment in GDP to include computer software, starting in October 1999.

Not all the new service-sector PPIs could be used in the deflation of expenditure-based GDP. For example, other producers primarily use several services categories as intermediate inputs. For distributive industries such as wholesale and retail trade, the expenditure-based GDP estimates rely on CPIs that measure the price paid by the consumer rather than separately valuing the retail and wholesale margins as measured by the PPIs. Looking more broadly, however, nearly all the new PPIs are used by BEA's industry accounts or in BLS industry productivity estimates, and are important for measuring the contributions of industries to GDP or productivity growth.

New price indexes for nonresidential construction were another PPI initiative introduced in the mid-2000s. The lack of price deflators for investment in nonresidential structures had been a long-standing gap in GDP source data, which BEA had previously attempted to fill with several ad hoc price measures from various sources. A PPI initiative allowed the development of new price indexes for several types of nonresidential construction, which BEA now uses to deflate roughly two-thirds of expenditures on investment in nonresidential structures (nearly 4 percent of private nonfarm business-sector value added).

Finally, the PPI program introduced augmented sampling of pharmaceutical prices and improved the way it handled generic drugs. The program also introduced quality adjustments for the hospital PPI, using data collected by the Department of Health and Human Services (HHS) in its Hospital Compare database. These data capture changes in care that are indicative of changes in service quality according to a panel of

experts who were responsible for designing the database. HHS regularly updates the database but has recently stopped measuring some of the conditions used by the PPI.[15]

Changes to the export and import price indexes are also reported in Appendix Table B2. Compared with the CPI and PPI programs, there have been fewer methodological changes to the BLS international price program. The most notable improvement was the move in 2004 to annual reweighting, which is important because the commodity mix of exports and imports can change significantly from year to year. There were also some expansions to the coverage of imports and exports of services, but unfortunately these expansions were reversed by budget cuts in 2008 that eliminated many of the international services price indexes.

# IV. Improvements to the measurement of real GDP and MFP

Over the last 20 years, BEA has made many improvements to the measurement of real gross domestic product and, to keep the analysis manageable, I focus only on a subset. My primary interest is on measurement factors that influence longer-term trends in multifactor productivity. Consequently, I do not attempt, for example, to catalog BEA's efforts to improve the accuracy of early GDP estimates, even though that is one of the main ways the public judges the reliability of GDP estimates. Indeed, many or most of the improvements to nominal GDP affect the quarterly or annual estimates, yet it is the five-year benchmark estimates that primarily determine long-term trends in nominal GDP growth. Thus, I mostly focus on improvements to the deflators, which tend to have the largest impact on long-term trends in real GDP and productivity. Also, I focus on BEA's periodic conceptual changes to the scope of transactions covered by GDP. Many of these changes reflect periodic updates in the international standards for national accounts—the latest version is *System of National Accounts 2008*. These changes in standards, in turn, are motivated by real changes to a modern, increasingly globalized economy.

Appendix Table B3 lists the conceptual and statistical changes to GDP that I've identified as potentially affecting long-term trends in private nonfarm business MFP.

As mentioned, one of the main ways that changes to GDP affect MFP, other than through changes to deflators, is through the periodic changes to the scope and coverage of GDP. The first major conceptual change, described by Moulton, Parker, and Seskin (1999), was BEA's recognition of spending on computer software as fixed investment. Previously, purchased software had been counted as intermediate consumption, and software developed by a business's own employees ("own-account software") had simply been treated as part of the cost for producing the business's other output. Recognition that software has the characteristic of an investment good—it lasts more than a year and is used in the production of other goods and services—led to the change, which helped pave the way toward the subsequent recognition of other intangible assets, such as research and development (R&D), in later revisions. Considering software as investment had a large effect on measured GDP growth because the production of software had grown rapidly, especially during the 1980s and 1990s, to a level of 2.4 percent

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15. See Bureau of Labor Statistics, Health Quality Valuation Team (2008).

of nominal GDP by 1999. Thus, recognition of software as investment led to notable upward revisions to GDP growth.

During that same period, BEA was actively working to push forward the frontier on quality-adjusted price indexes. During the 1980s, BEA had worked with IBM to develop early quality-adjusted computer price indexes for GDP; during the 1990s that work moved forward and expanded to other topics like semiconductors and telephone-switching equipment. BEA didn't see itself supplanting BLS as a producer of price indexes—rather it hoped that its own work would help BLS move forward in producing quality-adjusted PPIs and CPIs that BEA would be able to use as deflators. As BLS developed its own quality-adjusted indexes, BEA gradually dropped its work on hedonic quality adjustments.

The measurement of financial services and insurance became another area of considerable attention for BEA. Over the years, BEA implemented several improvements to the concepts and methods for measuring nominal and real financial services for banking, insurance, and other financial services. In 1999, the BEA changed its volume measure for financial services provided without payment (that is, services that banks can provide to customers from the margin between interest received for loans and interest paid to depositors), switching to a BLS productivity measure that directly counts various bank activities such as checks cleared, ATM transactions, and electronic funds transfers. The new measure raised the measured real growth of these services by 2.8 percentage points per year, boosting the growth of real output of the private nonfarm business sector by 0.1 percentage point per year.

In 2003, BEA began using a reference rate methodology to allocate implicit banking services between borrowers and depositors; previously, the entire implicit service had been assigned to depositors. This change had a negligible effect on the price index and real growth rates, but because most borrower services are classified as intermediates, the change reduced the weight of banking services in GDP final expenditures. Furthermore, because the long-term growth rate of real implicit banking services was close to the growth rate of real output of the private nonfarm business sector, the lower weight had little effect on productivity growth. In the same revision, BEA's treatment of property and casualty insurance services also changed significantly. However, while the changes reduced the volatility of the measured services, the effect on the long-term growth rates was small.

In 2013, the BEA further expanded the asset boundary for GDP by recognizing expenditures for R&D and for entertainment, literary, and artistic originals as fixed investment (BEA, 2013). These changes had fairly large effects on nominal GDP since these types of intangible investments have a long history, going back to BEA's earliest GDP estimates from 1929.

BEA documented the effects of these conceptual changes on nominal GDP, but hasn't provided estimates of the effects on growth rates. For the three major new types of intellectual property products that have been capitalized in GDP—computer software (beginning in 1999), scientific R&D (beginning in 2013), and entertainment, literary, and artistic originals (beginning in 2013)--I've calculated the growth of real output of the private nonfarm business sector excluding investment in each type of asset. The impact of capitalizing each asset type is shown in Table 3.

**Table 3. Impact of capitalization of intellectual property products on real output growth, US private nonfarm business sector**

Impact on average annual growth rate (percentage points), selected periods

| Intellectual Property Product | 1987–1995 | 1995–2004 | 2004–2016 | 1987–2016 |
|---|---|---|---|---|
| Computer software | 0.14% | 0.17% | 0.07% | 0.12% |
| Research and development | 0.00% | –0.01% | 0.03% | 0.01% |
| Entertainment, literary, and artistic originals | 0.01% | 0.00% | 0.00% | 0.00% |

*Source: Calculations by author using chain-type quantity indexes based on BEA NIPA data.*

The capitalization of computer software had a substantial impact, adding between 0.05 to 0.2 percentage point to the measured annual growth of the sector.[16] This impact reflects the relative importance of software as a type of investment and the long-term growth in that investment. On the other hand, the impact of capitalizing R&D has been more modest. Although the relative importance of R&D is large, its growth rate has been similar to that of the total economy, so adding investment in R&D to the GDP calculations has not had a large effect on GDP growth. The capitalization of R&D slightly boosted growth in 2004–2016 and slightly lowered it in 1995–2004. Entertainment, literary, and artistic originals has a smaller relative importance and has also grown at about the same rate as GDP; hence, the impact of its capitalization is small.

Table 3 shows the impact of capitalization on the numerator of the productivity statistics, which for labor productivity is the same as the overall impact. Using the new BEA/BLS industry production accounts, we're also able to measure the contributions of the capital services for intellectual property products that appear in the denominator of the productivity calculations.[17] Contributions of capital services to all-industry growth are shown in Table 4. Note that the contributions in Table 4 are intended to measure the *actual* effects of capital invested in intellectual property products on output growth, whereas the estimates in Table 3 are intended to measure the impact of the change in accounting treatment on *measured* growth. In comparing with Table 3, however, several additional caveats are also needed. First, the BEA/BLS industry productivity tables measure contributions for all industries, including government, nonprofits, and households, rather than just the private nonfarm business sector. Considerable investment in intellectual property products takes place in the government and nonprofit sectors. Second, the period is shorter—the estimates in Table 3 are available from 1987, whereas those in Table 4 are only available beginning in 1997. Third, the basis of calculations differs—Table 3 compares GDP growth rates, with the definition of GDP changed to include or exclude investment in intellectual

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16. Note that Table 3 measures the impact of capitalizing these intellectual property products on the measure of GDP growth, and *not* the impact on GDP growth of investing in these intellectual property products.

17. I thank Matt Russell for pointing me to these data.

property products. In contrast, Table 4 presents "contributions," which compare the aggregate growth rate to a counterfactual in which the component of caapital services doesn't grow at all.[18]

**Table 4. Contributions of capital services of intellectual property products to aggregate value-added growth, US, all industries**

Contribution to average annual growth rate (percentage points), selected periods

| Intellectual Property Product | 1998–2004 | 2004–2015 | 1998–2015 |
|---|---|---|---|
| Computer software | 0.27% | 0.11% | 0.17% |
| Research and development | 0.08% | 0.08% | 0.08% |
| Entertainment, literary, and artistic originals | 0.03% | 0.02% | 0.03% |

*Source: BEA/BLS industry-level production accounts, all-industry contribution tables, https://www.bea.gov/industry/xls/BEA-BLS-industry-level-production-account-1998-2015-CONTR.xlsx.*

The growth contributions shown in Table 4 are larger than those in Table 3, reflecting the differences in scope, period, and concept between the two tables. However, it is unclear the extent to which consistently defined effects of intellectual property products on the productivity numerator (output) would differ from those on the denominator (capital services). That the effect on capital services is larger than the effect on output simply illustrates a long-standing idea in productivity research—that expanding the number of intangible "factors" covered in multifactor productivity measurement can reduce measured MFP (Corrado, Hulten, and Sichel, 2009). Overall, the capitalization of intellectual property products had only a modest impact on labor productivity and appears to have had a small impact on MFP. As such, increased capitalization of intellectual property is not a major factor in explaining the slowdown in measured productivity.

Although this paper focuses primarily on the measurement of GDP by final expenditures and of productivity for the major sectors, it should be recognized that BEA has notably revamped and modernized its industry accounts over the past two decades (Moyer et al., 2004; Lawson et al., 2006). BLS has also greatly expanded the industry coverage of its labor productivity program, due in large part to newly available service-sector PPIs. BEA and BLS have collaborated to develop an industry-level

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18. To see the difference, consider a component that grows at the same rate as GDP; adding it to the definition of GDP doesn't change the growth rate of GDP at all. But because the component is growing, it has a positive contribution to GDP growth. For example, if both GDP and the component are growing at 2 percent per year, and the weight of the component is 5 percent, its contribution to growth is .05×.02, or 0.1 percentage point, even though adding the component to the definition of GDP doesn't change GDP's growth rate.

production account that provides a full decomposition of GDP growth into industry level contributions of capital, labor, and MFP (Fleck et al., 2014).

Health care remains a topic of considerable research by both BEA and BLS, reflecting recommendations of the National Research Council (2002). Both agencies have developed new measures that focus on the treatment of disease rather than by type of service provider (Dunn, Rittmueller, and Whitmire, 2015; Bradley, Hunjan, and Rozental, 2015). The PPI program recently introduced commodity PPIs classified by the International Classification of Diseases. So far, BEA's innovative approaches to measuring health care statistics have mostly been presented in the health care satellite account rather than incorporated into GDP. While promising, this research has not yet had a major impact on measured productivity.

# V. Changes to the economic environment

The US economy continues its long-term movement toward services production and away from goods production. From 1997 to 2016, the share of GDP produced by private services-producing industries has increased from 64.2 percent to 68.9 percent, whereas the share produced by private goods-producing industries has declined from 22.5 percent to 18.2 percent. Within goods production, manufacturing declined from 16.1 percent to 11.7 percent of GDP, with about three-fourths of the decline occurring in the 10 years prior to the Great Recession (1997–2007). Within services production, from 1997 to 2016 the share of professional and business services in GDP increased from 9.8 percent to 12.4 percent, and the share of health care and social assistance increased from 5.9 percent to 7.4 percent. On the other hand, retail trade's share declined from 6.8 percent to 5.9 percent.

Most economic measurement techniques were first developed for measuring goods production and consumption. Some services are fundamentally heterogeneous, making it difficult for BLS to specify units of consistently defined products that can be re-priced each month, and thus requiring BLS to collect prices for a standardized service rather than a service that was actually sold during the period. Thus, the growth of services presents challenges in defining and measuring price change and real output and exposes gaps in the statistical system. The long-term growth of services would have been especially problematic for economic measurement if the statistical agencies had not taken steps to expand and improve their coverage of services, especially by expanding coverage of services' prices. While there continue to be gaps in the measurement of the prices and real output of services, the coverage and quality of the data for this sector have substantially improved since the release of the Boskin Commission report.

The growth of globalization is another factor affecting economic measurement. Trade agreements and legislation that reduced impediments to trade, including the adoption of permanent normal trade relations with China in 2000, spurred innovation in global production arrangements. From 1997 to 2008, imports of goods and services increased rapidly from 12.3 percent to 17.4 percent of GDP. Petroleum prices account for part of the growth; excluding petroleum products, imports as a percent of GDP increased from 11.4 percent in 1997 to 14.2 percent in 2008. In 2009, non-petroleum imports abruptly fell to 11.9 percent of GDP, but rebounded to 13.8 percent in 2016. Exports of goods and services initially fell from 11.1 percent of GDP in 1997 to 9.0 percent in 2003, and then grew to 13.6 percent in 2014, before declining to 11.9 percent in 2016.

Increased globalization raises many concerns about economic measurement. I've already mentioned the offshoring bias examined by Houseman et al. (2011). This is the bias in measuring real GDP that results from the failure of import price indexes to capture the price declines that domestic producers face when switching from higher-priced domestic suppliers to lower-priced foreign suppliers. They estimate that average annual growth in real value added in manufacturing was overestimated by 0.2 to 0.5 percentage point per year from 1997 to 2007, and that MFP growth in manufacturing was overstated by 0.1 to 0.2 percentage point per year. Reinsdorf and Yuskavage (2014) show that the problem is exacerbated by the failure of the import price indexes to capture price declines from switching from higher-priced to lower-priced international suppliers when sources of supply switch from one country to another—they name this broader concept, which also encompasses offshoring bias, "sourcing substitution bias." Their study also examines sourcing substitution in imports of consumer goods. For 1997 to 2007, they estimate the overall impact on MFP to be an overstatement of about 0.1 percentage point per year.

I've also mentioned the omission of imported intermediate goods and services in the major sector-level MFP calculations used by BLS, as described by Eldridge and Harper (2010). The traditional major sector productivity decomposition includes two inputs—labor services and capital services—and omits imported intermediate inputs from the accounting (in contrast with the industry-level MFP calculation, which accounts for intermediate inputs). From 1997 to 2006, adding imported intermediate inputs to the calculation reduced average MFP growth by about 0.1 percentage point per year.[19] Both the offshoring/sourcing substitution bias and the sectoral MFP bias were particularly pronounced during the decade of rapid growth in globalization prior to the Great Recession and would have contributed to the measured MFP slowdown since the Great Recession.

A third way that globalization has affected the measurement of GDP and MFP is through offshore profit shifting. As described by Guvenen et al. (2017), profit shifting occurs when multinational enterprises shift their profits earned from intangible assets (typically, royalties or rentals) to their affiliates in tax havens—countries with very low tax rates.[20] They found that adjusting for tax shifting boosts aggregate productivity growth rates by 0.1 percent per year for 1994 to 2004, 0.25 percent per year for 2004 to 2008, and has little effect after 2008. Note that these effects go in the *opposite* direction of the previous two—that is, the effect of tax shifting was to understate US productivity growth during the decade prior to the Great Recession, whereas the sourcing substitution and sectoral MFP biases tended to overstate productivity growth during that period.

Another major change in the economic environment over the last two decades has been the growing use of the Internet in enabling low-cost provision of services. One aspect has been the so-called "sharing economy"—the provision of services such as transportation (Uber and Lyft) or lodging (Airbnb) through independent contractors sharing self-owned assets. From a measurement perspective, the main challenge of these services is that, while the CPIs eventually include these services in their samples, they probably failed to capture the reduced cost and greater availability of those services. Under the matched model approach used by the CPI, the prices of the newer services would likely not ever have been compared directly to the prices of older services.

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19. There may, however, be an interaction between the Eldridge-Harper sectoral MFP bias and sourcing substitution bias, suggesting that it might not be appropriate to simply add together those two estimates.

20. Aggressive use of transfer pricing may also allow profits from intra-enterprise trade in goods to be shifted to low tax countries.

As I previously noted, Nakamura, Samuels, and Soloveichik (2016) studied the availability of "free" Internet services (that is, services paid for by advertising revenue). They found that adding these services to GDP would produce a slightly higher growth rate, though much of the effect is offset by a decline in consumption of advertising-supported print media. As with other new services, their results are sensitive to how the price changes for these services are measured.

# VI. How much progress has been made? What are the next steps?

Compared with the statistics and methodologies that the US statistical agencies were using in 1996, clear progress has been made on several fronts. The lower-level or elementary substitution bias that affected the CPI has essentially been eliminated. Several new hedonic regression models were introduced for quality adjustment of durable goods, though the impact of the hedonic methodology turned out to be quite a bit smaller than anticipated by the Boskin Commission. CPI weights and samples are now updated much more frequently, enabling new goods and services to enter the sample more rapidly. The CPI housing survey also now has a process that keeps its sample continuously updated. The PPI program has been transformed by a major expansion of its coverage of services, providing deflators for most services produced by US businesses. Gaps in price deflators for investment in nonresidential structures have also largely been filled with newly available PPIs. GDP statistics have moved from covering investment only in tangible equipment and structures to including several major types of intellectual property—computer software; entertainment, literary, and artistic originals; and R&D. Substantial progress has also been made on the measurement of financial services and health care.

## VI.A Updated estimates of bias

To summarize the progress, I revisit the Boskin estimates of CPI bias to see where the bias now stands. Most of my analysis comes from two sources that have reviewed the available literature—from Lebow and Rudd (2003), who studied the numerous BLS CPI methodology improvements in the years after the Boskin Commission Report; and from Byrne, Fernald, and Reinsdorf (2016), who also analyze biases in investment and import prices. I've supplemented these with a few other sources, as well as my own judgmental estimates for a few components that haven't been studied but nevertheless affect GDP and MFP.

In Table 5, the second and third columns show the estimates of CPI bias from the Boskin Commission (1996), as well as from Lebow and Rudd (2003).[21] The fourth column presents my own update of Lebow and Rudd's estimates to reflect the current CPI bias. I've modified two of the estimates. The Lebow and

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21. Groshen et al. (2017) provided estimates of bias for PCE and for private fixed investment in equipment and software that are similar to the estimates I provide in this section. I've expanded on their work by providing judgmental estimates for other GDP components; for PCE and equipment investment, my estimates are based on most of the same sources that they used, though there are minor differences in interpretation.

Rudd estimate of upper-level substitution bias was 0.30, double the Boskin Commission's estimate of 0.15 percentage point. Their estimate, however, was heavily influenced by substantial differences between the chained CPI and the fixed-weight official CPI in 1999 and 2000. Since December 2000, however, the difference has been, on average, smaller (0.23 percentage point per year), so I've lowered the estimate of upper-level substitution bias to 0.25. It's possible that unusual circumstances during 1999 and 2000 (such as the dot-com boom and bust or BLS's switch to geometric means at the lower level) may have contributed to the unusual differences for those years, but they have not persisted.

**Table 5. Updated estimates of CPI and PCE biases**

(percentage points per year)

| | Consumer Price Index | | | PCE | |
|---|---|---|---|---|---|
| **Sources of Bias** | **Boskin Commission (1996)** | **Lebow and Rudd (2003)** | **This paper (2017)** | **This paper from Boskin(1996)** | **This paper (2017)** |
| Upper-Level Substitution | 0.15 | 0.30 | 0.25 | – | – |
| Lower-Level Substitution | 0.25 | 0.05 | 0.05 | 0.25 | 0.05 |
| New Products/Quality Change | 0.60 | 0.37 | 0.37 | 0.60 | 0.34 |
| New Outlets | 0.10 | 0.05 | 0.08 | 0.10 | 0.08 |
| Weighting | – | 0.10 | 0.10 | – | – |
| **Total** | **1.10** | **0.87** | **0.85** | **0.95** | **0.47** |
| **Plausible range** | **(0.80–1.60)** | **(0.30–1.40)** | **(0.30–1.40)** | | |

*Sources: Boskin et al. (1996), p. 44 ; Lebow and Rudd (2003), p. 161; this author's subjective estimates.*

I've also slightly boosted Lebow and Rudd's estimate of outlet substitution bias based on the larger estimates obtained by Hausman and Leibtag (2009) and on the continuing growth of online retail. For the weighting bias, I've looked at the "weight effect" shown in BEA's Table 9.1U (Reconciliation of percent change in the CPI with percent change in the PCE price index), and it suggests that the impact of CPI weight mismeasurement continues to be about 0.10 percentage point per year.

For quality and new goods bias, I note that by 2003 BLS had already made most of their CPI methodological changes addressing these issues, such as hedonics and improved sampling; as such, my starting point was the Lebow-Rudd estimate. A recent paper by Reinsdorf and Schreyer (2017) takes another look at quality and new-goods bias. Their estimates are not directly comparable with those of Lebow and Rudd; they are looking at the average for all OECD countries, and they analyze the case of free

products, which was not considered by Lebow and Rudd. Nevertheless, their estimated quality/new goods bias for 2015 of 0.43 percentage point is close to the Lebow-Rudd estimate of 0.37 percentage point.

In the last two columns of Table 5, I've translated the estimates of CPI bias into the context of the personal consumption expenditures price index. This will be the first step in deriving estimates of bias for value added of the private nonfarm business sector, which are used as the numerator of the major-sector productivity statistics. For 1996, the biases estimated by the Boskin Commission mostly pass through directly to PCE, except for upper-level substitution bias. In early 1996, BEA adopted chain indexes using the superlative Fisher formula, thereby removing upper-level substitution bias. The PCE index also is not subject to the systematic weight mismeasurements that arise from the use of the consumer expenditure survey for CPI weights. The PCE weights are mostly based on business surveys and administrative data reconciled in a supply-use framework, avoiding the reporting biases that arise in the consumer expenditure survey.

For 2017, I estimate that the PCE index's quality/new goods bias is slightly smaller than the CPI's, mostly because the PCE index uses PPIs rather than CPIs for several components of health care. The PPIs for physicians' services, home health care, hospitals, and nursing homes all have consistently estimated inflation rates that are significantly lower than the equivalent CPIs.[22] Dunn, Grosse, and Zuvekas (2016) found that the difference is largely attributable to the broader coverage of the PPIs and PCE index—the CPI covers only consumer out-of-pocket expenditures and thus does not cover Medicare or Medicaid. But even after removing Medicare and Medicaid, the PPI inflation rates are lower. At any rate, quality changes that lead to improvements in health outcomes are probably still largely being missed by both the CPIs and PPIs.

I next estimate the bias for the nonfarm business sector output, which is the productivity numerator. Because output is usually based on deflation, *the biases in measured real output generally have the opposite sign as the equivalent biases in price indexes*. Thus, the biases shown in the next table are mostly negative (the measured output *understates* actual growth in real output). As explained earlier, this series is estimated from GDP data excluding government, nonprofit, farm, and owner-occupied housing value added. Thus, I build up estimates by adding the PCE bias estimates from Table 5 to estimates for private investment, exports (less imports), and government goods and services purchased from private businesses. These estimates are comparable to those derived by Byrne, Fernald, and Reinsdorf (2016), though their estimates were largely based on an industry approach to aggregation, whereas my estimates are based on the expenditure approach.

Table 6 splits the private nonfarm business sector into major components—PCE, private investment in information processing equipment, other equipment, and structures, exports, imports, and government

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22. For example, from 2002 to 2015, the CPI for hospitals increased at a 6.1 percent annual rate, whereas the PPI for hospitals increased at a 3.1 percent rate. The PPI for private health plans, which excludes government payers such as Medicare and Medicaid, increased at a 4.4 percent rate (Dunn, Grosse, and Zuvekas; 2016). Part of the difference between the PPI for private health plans and the CPI may be attributable to self-payers (that is, uninsured patients) covered in the CPI, and part may be due to differences in quality adjustment. The effect of using the PPI instead of the CPI would be larger if BEA used the PPIs for deflating the output of nonprofit hospitals and nursing homes; instead, BEA uses cost-based estimates for nonprofit institutions. Thus, I applied the PPI-CPI differences for hospitals and nursing homes only to the weights for proprietary (for-profit) institutions.

purchases of goods and services from businesses. To understand how measurement has changed since the Boskin Commission, estimates of biases are given for 1996 and for the most recent (2017) measures.

The component bias for PCE is taken directly from Table 5, and its contribution to the total is based on the share of PCE (excluding households and institutions) within private nonfarm business, which was about 75 percent both years. (Again, note that the implied biases for the output measure are negative, in contrast with the positive biases for the CPI and the PCE price index.)

The estimates of bias for information-processing equipment are based on the work of Byrne, Fernald, and Reinsdorf (2016). They found that the mismeasurement of this category has increased, in part because more computer and communications equipment is imported, and the quality adjustments for import price indexes are especially suspect. The impact of this bias on the overall index, however, has fallen from 0.26 percentage point in 1996 to 0.18 percentage point in 2017, as the share of IP investment has shrunk over time.

**Table 6. Estimates of bias for private nonfarm business output**

(percentage points per year)

| | 1996 | | 2017 | |
|---|---|---|---|---|
| **Major Component** | **Component Bias** | **Contribution to Total** | **Component Bias** | **Contribution to Total** |
| PCE | −0.95 | −0.72 | −0.47 | −0.36 |
| Private Investment | | | | |
| Information Processing Equipment | −7.3 | −0.26 | −8.0 | −0.18 |
| Other Equipment | −0.3 | −0.02 | −0.35 | −0.02 |
| Structures | −1.0 | −0.09 | −0.8 | −0.08 |
| Intellectual Property Products | –[a] | –[a] | −1.0 | −0.06 |
| Exports | −0.2 | −0.03 | −0.2 | −0.03 |
| Imports | −0.5 | 0.09 | −0.5 | 0.10 |
| Government Purchases from Business | −0.7 | −0.05 | −0.3 | −0.02 |
| **Total** | – | **−1.08** | – | **−0.65** |

*Source: Author's estimates.* [a] *In 1996, the intellectual property products components were not included in the output measure.*

I have little evidence for other equipment investment. I've estimated the bias at 0.3 percent for 1996 and have assumed that it increased to 0.35 percent in 2017, reflecting the growing share of imported

equipment. Deflators for investment in structures have been a long-standing data gap in federal statistics, and the inadequacies of the proxy deflators previously used by BEA undoubtedly contributed to estimates of negative multifactor productivity growth in the construction sector. By 2017, BEA was able to use several newly available PPIs for construction. But improvements from the new PPIs have been partly offset by poor measurement of the growth in mining structures due to failure to capture dramatic improvements in fracking, as described by Byrne, Fernald, and Reinsdorf (2016).

In 1996, intellectual property products were not yet a part of GDP or productivity measures. Software, R&D, and entertainment originals are now part of GDP investment, but it seems likely that some biases in their price indexes remain. While developing the R&D estimates, BEA experimented with many approaches to price measurement before ultimately adopting a fairly conservative approach. With limited evidence available on its overall magnitude, I've assumed a bias for these products of 1 percent per year, though I recognize that for some types of R&D and software it clearly could be much higher.

For imports, I draw on estimates from Reinsdorf and Yuskavage (2014), which show substantial sourcing bias for durable goods and apparel, as well as quality adjustment bias for information processing equipment. For exports, I use a conservative estimate of bias based on a presumption that sourcing and quality adjustment biases are less pronounced for exports. Finally, for government purchases of goods and services from business, the deflation uses a mixture of CPIs and PPIs. The measurement of this component has benefited from both the overall improvements to the CPI and the expansion of the PPI services prices.

My estimate is that the overall bias of the private nonfarm business output measure has fallen from about 1.1 percent in 1996 to about 0.65 percent today. In comparison, Aghion et al. (2017), using an entirely different method, estimated a recent bias of 0.6 percent for private nonfarm business sector output. Despite the continuing challenges in economic measurement, I don't see any evidence that the overall bias has worsened since 1996. The post-Boskin Commission reduction in bias has mostly been associated with CPI and PPI improvements, which were especially concentrated in the first few years after the publication of the Boskin Commission report—especially 1996 through 2003. However, biases for certain components, such as investment in information processing equipment, have probably gotten worse over time.

## VI.B Challenges and recommendations

Despite much progress, the statistical agencies continue to face significant challenges. Some progress has been offset by changes in the economy, such as increased globalization and the growth of transactions facilitated by the Internet, which have placed hurdles in the way of accurate measurement. While the BLS has made progress in implementing some of the recommendations of the Boskin and Schultze reviews, other problems, such as outlet substitution bias, have not yet been fully addressed. And finally, as I've noted, the statistical agencies' progress in attacking measurement biases appears to have decelerated as budgets tighten and other issues need attention.

I conclude this review with three recommendations for the statistical agencies on ways to renew progress on reducing or eliminating bias in MFP, GDP growth, and related price indexes.

First, BLS and BEA should expand and reconstitute work on the digital economy, focusing particularly on improving the measurement of quality-adjusted prices for information and communications technology (ICT) equipment and associated digital services. In recent years, David Byrne

and a few of his colleagues at the Federal Reserve Board have been doing excellent research on ICT equipment prices, but it would be better if more of that work took place at BLS and BEA, the agencies responsible for producing price indexes and real GDP. I'm encouraged by sessions at the last two meetings of the BEA Advisory Committee on measuring the digital economy[23] and by recent BLS research and improvements to the quality adjustment of microprocessors in the PPI (Sawyer and So, 2017). Work is also moving forward on new digital services, such as cloud data services. It is important for that this work include strong coordination among the statistical agencies.

My second recommendation is that the BLS should reconsider its practice in dealing with product substitution or change by limiting most quality adjustments to cases when an item has disappeared from its sample. As Groshen et al. (2017) explain, "When a match permanently ends in the Consumer Price Index and the same good cannot be tracked from one period to the next, then … the Bureau of Labor Statistics initiates a *quality adjustment procedure* after a replacement good has been established." In other words, quality adjustments are generally made only when an item disappears from the sample.[24] If a new good appears that does not displace its predecessor, it will generally only enter the index when the sample is rotated—and sample rotations are always linked to the old sample without any adjustment for changes in quality.

The BLS practice of limiting quality adjustment to product disappearance was probably motivated by the ideal of re-pricing a fixed basket of goods and services. Although the fixed basket ideal may have been BLS's goal long ago, BLS has acknowledged the cost-of-living index as its conceptual framework and overarching objective since the Boskin Commission (Abraham, Greenlees and Moulton, 1998). In some cases, the arrival of a new version of a product to replace an older one may be a reasonable way to think about quality change; for example, it may describe the periodic refreshing of car models each year, or the periodic release of new versions of computer software. More generally, however, this practice substantially constrains BLS's ability to adjust for quality, new goods, and new outlets.

In a study of hedonic quality adjustment of televisions, for example, Moulton, LaFleur, and Moses (1998) found that a hedonic index that covered all items in the CPI sample decreased 5.7 percent per year from 1993 to 1997. In contrast, the index that only adjusted for items that dropped out of the sample decreased 3.6 percent per year, compared with a decrease of 3.5 percent per year for the simulated CPI—a difference of only 0.1 percentage point. I hypothesize that the most important quality improvements for televisions occurring during that period were introductions of new models with larger screens and better resolution. They were not simply upgrades to older models. These higher-quality televisions did eventually enter the sample, but probably mostly through sample rotation (without quality adjustment) rather than through item replacement and quality adjustment.

The long-standing problem of outlet substitution bias could also be addressed by allowing for quality-adjusted price comparisons to accompany sample replenishment. For example, the rapidly growing share

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23. See the session of the BEA Advisory Committee on November 18, 2016 on measuring the digital economy and the session on May 12, 2017 on measuring quality-adjusted prices. https://bea.gov/about/advisory.htm

24. An exception is that both the CPI and PPI programs, on relatively rare occasions, introduce "directed substitutions," in which replacement items are identified and selected prior to the previous item disappearing from the marketplace with quality adjustments applied to the price comparisons. This method has been used, for example, for computers and for game software publishing, and BLS recently announced that it would begin using this approach for smartphones.

of electronic shopping often provides lower prices as well as more convenience to shoppers. Because CPI samples are drawn from specific outlets, and any item substitutions are also made within the same outlet, new or growing outlets only enter the sample via sample rotation. This means that the prices from the new outlets, that generally grow due to lower quality-adjusted prices, are never directly compared with the prices at the old outlets; the Boskin Commission estimated that this practice resulted in a bias of about 0.1 percentage point per year over the period it considered. A sample replenishment process in which portions of the sample are periodically replaced with comparable items from new outlets, and the prices in the new outlets are directly compared with prices of comparable items in the old outlets, would allow BLS to address and eliminate this bias.

This type of sample replenishment process could even help address new goods bias, at least in cases where the new good is sufficiently like the old good, to allow for a quality-adjusted price comparison. For example, Uber and Lyft are similar in many respects to traditional taxi services. Suppose that the BLS sample included the price of taking a taxi from a certain location to the airport on a Saturday afternoon. The CPI sample could then be replenished with prices for Uber or Lyft, while allowing for direct comparisons of the price difference. For other services, such as a late-night ride home from a bar, Uber or Lyft may provide superior service to a taxi in terms of waiting time or reliability of service, but a quality adjustment might be able to account for those differences. The point is that directly comparing the prices of these new services to traditional items could surely improve the CPI's measurement compared with current practice, which in most cases involves simply linking in samples with these new services, albeit without quality adjustment, at the time of a sample rotation.

My third recommendation is that BLS and BEA should make a concerted, systematic effort to account for the effects of globalization in the measurement of GDP, value added by industry, and productivity. This project would include the production of input price indexes for industries; Alterman (2015) provides an outline of what such an index would entail. This index would require collecting price data from the perspective of the industry buyer, taking account of substitutions to various domestic and offshore sources of supply. In addition, other aspects of globalization such as the imported intermediate inputs bias in major sector MFP and the offshore profit shifting biases should be studied further and addressed.

Asking for this type of research and development in a time of tight statistical agency budgets is difficult, but as the Boskin Commission made clear, the cost of improved statistics is relatively modest compared to the costs of policies conducted with deficient statistics. Accurate statistics are critical for effective implementation of a wide range of economic policy—everything from monetary and fiscal policy for countercyclical macroeconomic policy, to providing cost-of-living adjustments for social security recipients, to providing accurate data for economic research. For the economic statistics to achieve the best potential quality, the effort must involve not only the work of the statistical agencies, but also the cooperative engagement of the economics profession. For economic theory and policy to continue to advance, the profession needs to be engaged in the work improving official economic statistics.

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## APPENDIX A. CONCEPTUAL FRAMEWORKS FOR THE CPI, PPI, AND GDP

In response to a recommendation by the Boskin Commission that the Bureau of Labor Statistics adopt the cost-of-living index as its measurement objective, BLS basically agreed to use the framework as its guide for operational decisions about the Consumer Price Index (Abraham, Greenlees, and Moulton, 1998). But less attention has been given to the questions of whether the producer price and gross domestic product indexes have the same conceptual frameworks or different ones.

The Producer Price Index has traditionally used the output price index developed by Fisher and Shell (1972) and Archibald (1977) as its conceptual framework. This framework is based on a model of a firm engaged in production that maximizes revenue conditional on its technology and inputs.

The framework for price and quantity indexes in GDP and the national accounts is a bit more complicated. Most of the conceptual framework for the national accounts, such as the *System of National Accounts 2008,* is developed in nominal measures or current prices. The accounting framework is based on a general equilibrium model in which every transaction reflects two sides, a supplier and a user. Thus, GDP can be thought of both as output of firms and as final expenditures of consumers and investors. The System of National Accounts chapter on calculation of price and volume indexes is mostly pragmatic and does not dwell on conceptual issues, but the overall framework suggests that SNA could incorporate either or both of the cost-of-living and output price frameworks.

Thinking about the two measurement frameworks and the differences in how they interpret markets where consumers and firms transact does lead to some index number puzzles, however. Let me first introduce some notation to describe these conceptual indexes.

The cost-of-living index is derived from cost functions, which represent the solution to a consumer's cost or expenditure minimization problem.[25] The function *c(p, u)* represents the minimum cost the consumer can pay to reach utility level $u$ given a vector $p$ of prices of consumer goods. Given price vectors for two periods, $p^0$ and $p^1$, a cost of living index is the ratio of the two cost functions:

$$\text{(A.1)} \qquad P_K(p^0, p^1, u) = \frac{c(p^1,u)}{c(p^0,u)}$$

The Konüs cost-of-living index can be contrasted with the Laspeyres price index $P_L$ and the Paasche price index $P_P$, which hold quantities, $q$, fixed at the consumption patterns for period 0 (in the case of the Laspeyres index) and for period 1 (in the case of the Paasche index).

$$\text{(A.2)} \qquad P_L = \frac{\sum p^1 q^0}{\sum p^0 q^0}$$

$$\text{(A.3)} \qquad P_P = \frac{\sum p^1 q^1}{\sum p^0 q^1}$$

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25. Chapter 17 of the international *Consumer Price Index Manual* provides a nice explication of the theory of the cost-of-living index; see ILO et al. (2004).

If $u = f(q)$, then the following the cost-of-living index satisfies the following bounds:

$$P_K(p^0, p^1, u^0) \leq P_L, \text{ and} \tag{A.4}$$

$$P_K(p^0, p^1, u^1) \geq P_P. \tag{A.5}$$

That is, the cost-of-living index that conditions on period 0 consumption patterns and utility is bounded from above by the Laspeyres price index, while the cost-of-living index that conditions on period 1 consumption patterns and utility is bounded from below by the Paasche price index. The Fisher index, which is a geometric average of the Laspeyres and Paasche price index, provides a good (second-order) approximation of the true cost-of-living index.

The Fisher-Shell output price index is the solution to the producing firm's revenue maximization problem.[26] Let $p$ be the vector of output prices for the goods and services produced by the firm, and let $v$ be the vector of inputs used in production. $R(p, v)$ is the solution to the revenue maximization problem given output prices $p$ and inputs $v$. Conditional on technology available in period $t$, the output price index is

$$P^t(p^0, p^1, v) = \frac{R(p^1, v)}{R(p^0, v)} \tag{A.6}$$

Interestingly, the conceptual output price index satisfies different boundary conditions from the cost-of-living index. In particular,

$$P^0(p^0, p^1, v^0) \geq P_L, \text{ and} \tag{A.7}$$

$$P^1(p^0, p^1, v^1) \leq P_P. \tag{A.8}$$

The cost-of-living index is conditional on preferences, while the output price index is conditional on technology and inputs. In practice, statistical agencies calculate unconditional indexes, so it is probably a mistake to identify them too closely with the underlying conceptual indexes. Empirically, the Laspeyres index usually tends to be larger than the Paasche index, which suggests that the bounds from the cost-of-living index theory are more often satisfied than those of the output price index theory. This situation might arise if consumer preferences are mostly stable and change only very slowly, while firm technology and inputs change more rapidly.

The aggregation of households and firms adds additional complexities to the economic theory of these indexes. For example, while an aggregate CPI may be a reasonable approximation of the cost-of-living index for a household near the middle of the income distribution, it may be very different from the cost-of-living index of a very high-income or low-income household. While the economic theory of price indexes gives guidance for how to handle problems like substitution bias, one should be cautious in assuming that official indexes closely approximate the cost-of-living index for any actual househol

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26. Chapter 17 of the international *Producer Price Index Manual* explains the theory of the Fisher-Shell output price index; see IMF (2004).

## APPENDIX B. METHODOLOGICAL CHANGES POTENTIALLY AFFECTING REAL OUTPUT OR PRICES: JANUARY 1997 TO MAY 2017.

**Table B1. Changes in CPI statistical methods and impact on private nonfarm business output**

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **Hospital services, Nursing home services** | January 1997 (*CPIDR*, Jun-96, 7-8, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_199606.pdf; and *MLR*, Dec-96, 40–48, https://www.bls.gov/opub/mlr/1996/12/art6full.pdf) | Reclassify hospital and related services into two main item strata; broaden definition of specific items within strata. | Quantitative estimate not available. BLS article cites "capacity to better reflect changes in costs associated with how treatments are delivered" and "better able to handle new items." | Probably none. BEA uses PPIs to deflate hospital and nursing home services. |
| **All CPI items** | January 1998. (*MLR*, Dec-96, 18–25, https://www.bls.gov/opub/mlr/1996/12/art3full.pdf). | *New item structure* – Introduced fairly sweeping changes to the item classification structure used for defining the CPI market basket. | Quantitative estimate not available. Article discusses recognition of new goods; "blended" items that straddle two item strata; accounting for changes in consumer preferences; and incorporating new views of certain items such as health care and food away from home. | Improvement in data quality, but impact unknown. Affects most CPI deflation items. In 2009, the item classification structure for PCE in BEA's GDP statistics was also updated, bringing the CPI and GDP classifications into closer |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | | | alignment and improving deflation. |
| **Personal computers and peripheral equipment** | January 1998 for CPI-U. (*CPIDR,* Jul-97, 42, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_199707.pdf) Estimates back-cast and incorporated beginning in 1987 for CPI-U-RS, GDP and MFP. (*MLR,* Jun-99, 29–38, https://www.bls.gov/opub/mlr/1999/06/art4full.pdf) | *Quality adjustment*—Begin using coefficients of hedonic regression developed by Bureau of Labor Statistics' PPI program to make direct quality adjustments. | Reduced change of personal computers and peripheral equipment component of CPI approximately 6.5 percentage points per year. | Increased private nonfarm business output growth approximately 0.03 percentage point per year, based on typical share of PCE, computers, and peripheral equipment in sector of about 0.4%. |
| **Used cars and trucks** | January 1998. (*CPIDR,* Feb-98, 11, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_199802.pdf) | *New sample of used cars and trucks* – Consumer trucks (pickup, sport/utility, and van) included in sample for the first time. | Quantitative estimate not available. More representative and up-to-date sample. | Small. |
| **Housing services** | January 1999. (*MLR,* Dec-96, 31–39, https://www.bls.gov/opub/mlr/1996/12/art5full.pdf) | *Housing sample and estimates* – Utilize newly available geographic and mapping software to stratify by sample by geography; improved data collection instrument; new housing review and correction preprocessing system; new estimation formula that | Quantitative estimate not available. Article discusses improvements to stratification and selection of housing units, improved estimation methodology, and modernization of processing systems. | Equivalent rents of owner-occupied housing are not included in private nonfarm business sector. Tenant-occupied housing represents about 3.2% of private nonfarm business output, leading |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | simplifies the application of renter and owner weights to sample units. | | to an increase in data quality of unknown magnitude. |
| **All but 15 items in CPI market basket** | January 1999 for CPI-U. (CPIDR, Apr-98, 6–8, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_199804.pdf; and *MLR*, Oct-98, 3–7, https://www.bls.gov/opub/mlr/1998/10/art1full.pdf) Estimates back-cast and incorporated beginning in 1978 for CPI-U-RS, GDP and MFP. (*MLR*, Jun-99, 29–38, https://www.bls.gov/opub/mlr/1999/06/art4full.pdf) | *Geometric mean formula* introduced for the lower level estimation, in which prices for individual items within a specific stratum are combined to estimate the price change for that stratum. The geometric mean (or Cobb-Douglas-type) formula replaced a previous Laspeyres-type formula that was subject to upward bias and made no allowance for item substitution when relative prices within a detailed category changed. | Reduced all-items CPI growth approximately 0.2 percentage point per year. | Output growth increased about 0.15 percentage point per year on private nonfarm business sector output, based on the relative weight of components deflated by the CPI. |
| **Televisions** | January 1999 (*CPIDR*, Jun-98, 5, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_199806.pdf) Estimates back-cast and incorporated beginning in 1977 for CPI-U-RS, GDP and MFP. (*MLR*, Jun-99, 29–38, | *Quality adjustment*—Begin using hedonic regression for direct quality adjustment of televisions. | Reduced change of television index approximately 0.1 percentage point per year. | Output growth increased approximately 0.0002 percentage point per year, based on typical share of televisions in private nonfarm business sector output of 0.2 to 0.3%. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | https://www.bls.gov/opub/mlr/1999/06/art4full.pdf) | | | |
| **Motor vehicles, Motor fuel** | January 1999 (CPIDR, Sep-98, 4–7, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_199809.pdf) | *Quality adjustment* – Discontinue treatment of modifications to goods made *solely* to meet air quality standards as quality improvements in the CPI. The BLS's rationale is that expenditures for air quality, as a public good, are out of scope for the CPI. | Increased CPI growth for motor vehicle and motor fuel components by unknown amount. | Small reduction in measured output growth. |
| **All items except housing** | Early 1999. (*MLR*, Dec-96, 49–61, https://www.bls.gov/opub/mlr/1996/12/art7full.pdf) | *Selecting CPI outlet samples* – Introduces a new point-of-purchase survey (TPOPS) conducted in a computer-assisted telephone interview environment for selecting outlet samples. | Quantitative estimate not available. Article discusses capability of rotating certain categories more frequently to deal with high attrition or new products; more timely rotation of items into the sample; and reduced respondent burden. | Improved quality of CPI samples used for deflation. |
| **Audio equipment** | January 2000. (*CPIDR*, Oct-99, 4, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_199910.pdf) Audio equipment estimates back- | *Quality adjustment* – Begin using hedonic regression for direct quality adjustment of 12 audio products. | Increased measured price change by 1.4 percent per year. | Output growth reduced approximately 0.003 percentage point per year, based on typical share of audio equipment in private |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | cast and incorporated beginning in 1978 for CPI-U-RS (*CPIDR,* Mar-00, 5–9, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_200003.pdf). Back-cast estimates were not included in GDP or MFP output. | | | nonfarm business sector output of 0.1 to 0.2%. |
| **Other video equipment** | January 2000 (for video cameras) and April 2000 (for VCRs and DVD players). (*CPIDR,* Oct-99, 4, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_199910.pdf; *CPIDR* Jan-00, 4, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_200001.pdf) Estimates back-cast and incorporated beginning in 1987 for CPI-U-RS (*CPIDR,* Mar-00, 5–9, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_200003.pdf). Back-cast estimates were not included in GDP or MFP output. | *Quality adjustment* – Begin using hedonic regression for direct quality adjustment of video cameras, video cassette recorders (VCRs) and digital versatile disc (DVD) players. | Increased measured price change by 0.8 percent per year. | Output growth reduced approximately 0.001 percentage point per year, based on typical share of other video equipment in private nonfarm business sector output of 0.2%. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **Major appliances** | July 2000 (for refrigerators/freezers and microwave ovens) and October 2000 (for washing machines and clothes dryers. (*CPIDR,* Apr-00, 4, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_200004.pdf; and *CPIDR,* Aug-00, 4, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_200008.pdf) | *Quality adjustment* – Begin using hedonic regression for direct quality adjustment of refrigerators/freezers, microwave ovens, washing machines, and clothes dryers. | For microwave ovens, Liegey reports measured price change reduced 0.2 percentage point per year. (http://kitchentech.pro/view/757-245038.html) | Impact small. |
| **Educational books and supplies** | July 2000. (*CPIDR,* Apr-00, 4, https://fraser.stlouisfed.org/files/docs/publications/cpidr/cpi_200004.pdf) | *Quality adjustment* – Begin using hedonic regression for direct quality adjustment of college textbooks. | | |
| **All items** | 2002 | *Weight updates* – CPI weights now updated every two years instead of approximately every 10 years. | | Little, if any effect. GDP and MFP use national accounts weights rather than Consumer Expenditure Survey weights. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **Chained CPI for All Urban Consumers** | August 2002 (Cage, Greenlees, and Jackman; 2003, https://www.bls.gov/cpi/additional-resources/chained-cpi-introduction.pdf) | *Superlative index* – a new CPI that employs a superlative Tornqvist formula and utilizes expenditure data in adjacent time periods to reflect consumer substitution in response to changes in relative prices. | From December 1999 to December 2016, the average annual increase of the chained CPI (C-CPI-U) was 1.88%, compared with 2.27% for the CPI-U. | No effect – MFP is based on superlative Fisher index used in GDP calculations. |
| **Housing** | 2010 (*SCB,* Aug-13, https://doi.org/10.21916/mlr.2013.25) | *Sample rotation* – The samples of housing units used for the rent and owners' equivalent rent components of the CPI are now rotated at six-year intervals, with one-sixth of the sample rotated each year based on the latest available Census Bureau data. | Improved quality and representativeness of sample; quantitative impact not known. | |
| **Wireless telephone services** | 2017 ("How the Consumer Price Index Measures Price Change for Telephone Services," https://www.bls.gov/cpi/factsheets/telephone-services.htm) | *Quality adjustment* – Improved quality adjustment procedures for wireless telephone services. If a replacement is different from its predecessor and the value of the difference in quality can be accurately estimated, a quality adjustment is made. | Improved quality adjustment; quantitative impact not known. | |
| **Smartphones, within "telephone** | April 2018 ("Recent and upcoming methodology changes," | *Sample update and quality adjustment* – "directed substitution" will be employed | Improved sample and quality adjustment; | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **hardware, calculators, and other consumer information items"** | https://www.bls.gov/cpi/notices/2017/methodology-changes.htm) | twice a year to keep the CPI sample of smartphones current with consumer upgrades | quantitative impact not known. | |

*Sources:* *CPIDR: CPI Detailed Report (available from https://fraser.stlouisfed.org/title/58)*
*MLR: Monthly Labor Review (available from https://www.bls.gov/opub/mlr/2017/home.htm)*

**Table B2. Changes in producer, import, and export price index statistical methods and impact on private nonfarm business output**

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **Semiconductor Indexes (SIC 3674; PPI commodity code 1178)** | January 1997 (*PPIDR*, Jan-97, 10-11, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_199701.pdf) | Structure and number of indexes reduced to improve the completeness and continuity of the indexes. Obsolete products will be replaced continuously to maintain the representativeness of the sample. Limited price data collection from secondary sources has been implemented to improve the representativeness of the sample. | | |
| **New PPIs for Home Health Care Services; Legal Services; Engineering Services; Architectural Services (SIC 8082; SIC 8111; SIC 8711; SIC 8712)** | January 1997 (*PPIDR*, Jan-97, 12-13, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_199701.pdf) | New indexes introduced as part of the BLS expansion of PPI coverage of the service sector. Home health care services are skilled nursing or medical care provided at an individual's residence as prescribed by a physician. Legal services measure changes in legal fees received by law firms. Engineering and architectural services indexes measure provision of design, analysis, and consulting services. | | |
| **Import and Export Price Index methodology** | January 1997 (*USIEPI*, Jan-97, https://www.bls.gov/news.rel | The index estimation methodology modified to incorporate the use of sampling weights at the item level. Previously, price relatives for individual | | Should improve the accuracy of indexes and reduce upward lower-level |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **changed to incorporate the use of sampling weights at the item level.** | ease/history/ximpim_022597.txt). | items were averaged using equal weights in the construction of what is referred to as the elementary aggregation. | | substitution bias due to averaging of price relatives in elementary aggregation. |
| **PPI for Large-scale Computers (SIC 3571-11; PPI commodity code 11510-111)** | September 1997. (*PPIDR*, Sep-97, 5–7, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_199709.pdf) | Sample product specifications and prices updated to more accurately reflect current output. Developed hedonic regression model to support quality adjustment for technological changes. Reflects major shift to "open-system" large-scale computers that began in 1994–95 as low-cost, high performance CMOS (complimentary metal oxide) processors were introduced. | | |
| **New PPI for Prepackaged Software (SIC 7372)** | January 1998. (*PPIDR*, Jan-98, 6, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_199801.pdf) | New index introduced as part of the BLS expansion of PPI coverage of the service sector. Prepackaged software establishments are primarily engaged in the design, development, marketing, and production of prepackaged computer software. Measures change in the price of the license for a program. | | |
| **New PPIs for Property and Casualty** | July 1998. (*PPIDR*, Jul-98, 5–6, https://fraser.stlouisfed.org/fi | New indexes introduced as part of the BLS expansion of PPI coverage of the service sector. The SIC 6331 PPI | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **Insurance and for Premiums for Property and Casualty Insurance (SIC 6331; SIC 9331).** | les/docs/publications/ppi/ppi_bls_199807.pdf). | measures changes in the revenue received by insurance companies that sell property and casualty insurance. Price movements are based on revenue received for providing an insurance policy, including premiums and investment income, less a deduction for any dividend paid to the policy holder. The SIC 9331 index measure changes in the premium revenue received by insurance companies do not include investment income or a deduction for the value of any dividend paid. Indexes for SIC 9331 are derived from the same fixed policies reported for SIC 6331. | | |
| **New PPI for Life Insurance (SIC 6311).** | January 1999. (*PPIDR*, Jan-99, 9, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_199901.pdf). | New indexes introduced as part of the BLS expansion of PPI coverage of the service sector. The SIC 6311 PPI measures changes in the revenue received by insurance companies that sell life insurance and annuities. For term, whole, adjustable, credit, and group life, the price includes premium revenue plus investment income. For universal and variable policies, the price is measured by the sum of total fees received for providing the policy, | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | with investment income included as part of compensation to insurers. Annuity prices are measured by fees and interest. | | |
| **PPI for Prepackaged Software (SIC 7372)** | January 1999. (*PPIDR,* Jan-99, 10, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_199901.pdf). | Supplemental sampling instituted to augment the item sample with new products to accurately reflect price movement in an industry characterized by frequent introduction of new products. BLS plans to add further supplemental samples throughout the life of this index. | | |
| **New PPI for the Wireless Telecommunications Industry (SIC 4812)** | July 1999. (*PPIDR,* Jul-99, 6, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_199907.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. The index measures changes in the average revenue received per access line. | | |
| **Improvements to PPI for Physicians (SIC 8011)** | January 2000 (*PPIDR,* Feb-00, 8–9, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200002.pdf). | Began direct collection of Medicare services (previously Medicare services had been collected annually from administrative data). Began identifying and pricing capitated contracts—a method of pre-payment for expected medical utilization that requires the physician practice to assume risk in order to create an incentive for cost saving. | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **New indexes for seven retail trade industries: Grocery Stores (SIC 5411), Meat and Fish (Seafood) Markets (SIC 5421), Fruit and Vegetable Markets (SIC 5431), Candy, Nut, and Confectionary Stores (SIC 5441), Retail Bakeries (SIC 5461), Miscellaneous Food Stores (SIC 5499), and New Car Dealers (SIC 5511).** | July 2000 (*PPIDR,* Jul-00, 8–9, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200007.pdf). | PPI views retailer as a supplier of services and treats the gross margin (the difference between the selling price and the acquisition price) as the relevant price. Weights are based on margin data provided by the Census Bureau. For New Car Dealers, the output is a mixture of gross margin prices for Vehicle Sales and of gross sales prices for Service Labor and Parts. | | None – Retail trade PPIs are not used for deflating expenditure components of GDP (though they are used for the GDP-by-industry estimates). |
| **Quality adjustment for changes to gasoline** | April 2000 (*PPIDR,* Aug-00, 5, https://fraser.stlouisfed.org/fi | Quality adjustment for phase 2 of the EPA's reformulated motor gasoline program (under the Clean Air Act of 1990), which requires stricter | The value of the quality adjustment equal to $0.0028 per | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **resulting from phase 2 of the Reformulated Gasoline Program.** | les/docs/publications/ppi/ppi_bls_200008.pdf). | summertime emission standards beginning May 1, 2000. The quality adjustment was based on cost analysis from a report issued by the Energy Information Administration. | gallon for the industry as a whole. | |
| **Changes to pricing of Medicare portion of Home Health Care Services (SIC 8082) in response to Medicare's new Home Health Prospective Payment System (HHPPS).** | October 2000 (*PPIDR,* Oct-00, 7, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200010.pdf). | Under new reimbursement system, Medicare reimburses home health agencies based on a 60-day episode. Previously, providers were reimbursed for each visit. BLS reselected the sample of Medicare services from each reporting establishment. Prices reflect adjustments and allowances made under the new system. Changes also made to published indexes to eliminate detailed indexes by type of caregiver, which was superfluous under the new payment system. | | |
| **Improved quality adjustment of Computer Microprocessors (PPI code 36741A201)** | January 2001 (*PPIDR,* Oct-00, 5–6, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200010.pdf). | Use benchmark data from the non-profit Standard Performance Evaluation Corporation (SPEC) to measure the value of technological change associated with the introduction of a new microprocessor. | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **New PPIs for 17 retail trade industries. The largest of these industries was Drug Stores and Proprietary Stores (SIC 5912).** | January 2001 (*PPIDR,* Jan-01, 8, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200101.pdf). | PPI views retailer as a supplier of services and treats the gross margin (the difference between the selling price and the acquisition price) as the relevant price. Weights are based on margin data provided by the Census Bureau. | | None – Retail trade PPIs are not used for deflating expenditure components of GDP (though they are used for the GDP-by-industry estimates). |
| **New PPIs for Security Brokers, Dealers, and Investment Banking Companies (SIC 6211).** | January 2001 (*PPIDR*, Jan-01, 9, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200101.pdf). | Indexes measure changes in the revenue received by security brokers, dealers, and investment banking companies, based on sample of price quotations from specific transactions. | | |
| **New PPI for Data Processing Services Industry (SIC 7374).** | January 2002 (*PPIDR,* Jan-02, 8, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200201.pdf). | New PPI for the provision of electronic data processing services. Services include: transaction processing, timesharing data processing, and data entry. Price movements are based on actual transaction prices billed for sample of specified services based on actual contracts. | | |
| **More Retail Trade industries** | January 2002 (*PPIDR,* Jan-02, 9–10, | PPI views retailer as a supplier of services and treats the gross margin | | None – Retail trade PPIs are not used for |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **added to PPI. New indexes introduced: Gasoline service stations (SIC 5541), Boat dealers (SIC 5551), and Recreational vehicle dealers (SIC 5561).** | https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200201.pdf). | (the difference between the selling price and the acquisition price) as the relevant price. Weights are based on margin data provided by Census Bureau. For used boats and used recreational vehicles, prices were based on the average gross margin due to the uniqueness of each transaction. | | deflating expenditure components of GDP (though they are used for the GDP-by-industry estimates). |
| **New PPI for Television Broadcasting Industry (SIC 4833).** | July 2002 (*PPIDR,* Jul-02, 5, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200207.pdf). | Price changes based on rates charged for advertising time, for network affiliation agreements, and for syndicated program sales. For advertising sales, the preferred method is based on total revenue from advertising sales for a specific period divided by the number of spots aired during the period. | | |
| **New PPI for the Investment Advice Industry (SIC 6282).** | January 2003 (*PPIDR,* Jan-03, 8, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200301.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. Includes investment advice lines for: mutual fund management, portfolio management, and financial planning and other advisory services. Price movements for | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | mutual fund managers are based on changes in revenue received for providing investment advice, holding fund's assets fixed. Price movements for portfolio management are based on changes in revenue received holding portfolio's assets fixed. For financial planning, research, and portfolio analysis, based on fee determined from characteristics of document or flat rate charged. | | |
| **New PPI for Insurance Agencies and Brokerages Industry (SIC 6412).** | January 2003 (*PPIDR*, Jan-03, 9, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200301.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. The index measures price change in the commissions received by insurance agents and brokers for the sale of insurance policies, holding price-determining characteristics constant. | | |
| **Conversion of net output indexes from the 1987 Standard Industrial Classification (SIC) to 2002** | January 2004 (*PPIDR*, Jan-03, 5, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200301.pdf). | The North American Industry Classification System conversion involved major definitional changes to many of the previously published SIC-based indexes. | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **North American Industry Classification System (NAICS).** | | | | |
| **New PPIs introduced for 19 additional retail industries, completing the expansion of PPI coverage of the retail trade sector.** | January 2004 (*PPIDR,* Jan-04, 9–11, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200401.pdf). | PPI views retailer as a supplier of services and treats the gross margin (the difference between the selling price and the acquisition price) as the relevant price. Weights are based on margin data provided by Census Bureau. | | None – Retail trade PPIs are not used for deflating expenditure components of GDP (though they are used for the GDP-by-industry estimates). |
| **New PPIs introduced for Electric Power Generation (NAICS 221110) and Electric Bulk Power Transmission and Control (NAICS 221121).** | January 2004 (*PPIDR,* Jan-04, 12, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200401.pdf). | Measures prices received by power-generating establishments and by establishments that operate electric power transmission systems and/or control the transmission of electricity from generating source to distribution centers or electric utilities. | | |
| **Import and Export Price Index to be** | January 2004 (*USIEPI,* Oct-03, https://www.bls.gov/news.rel | Beginning with the release of January 2004 data, US Import and Export Price Indexes will be reweighted using 2002 trade weights. Import and Export Price | | Small improvement in accuracy of indexes. GDP estimates use chain- |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **reweighted annually.** | ease/archives/ximpim_11132003.pdf). | indexes now reweighted annually, with a two-year lag in the weights. | | type weighting of price indexes, including the Import and Export Price indexes, but the adoption of annual reweighting by BLS may improve their accuracy in aggregation at more detailed levels than those used in GDP estimates. |
| **New PPI for Direct Health and Medical Insurance Carriers Industry (NAICS 524114)** | July 2004 (*PPIDR*, Jul-04, 6, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200407.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. The policy underwritten by the insurer represents a unique output, transferring risk to the insurer. The indexes measure the change in the total premium (employee and employer contribution) paid to the insurer plus the return on the invested portion of the premium. Insurance companies are asked to estimate a premium for a "frozen" policy using current charges applied to the characteristics of this policy. Alternatively, insurance | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | companies may follow a selected policy over time, providing actual premiums charged and identifying modifications to the policy each year. | | |
| **New PPIs for Commercial Banking (NAICS 522110) and Savings Institutions (NAICS 522120)** | January 2005 (*PPIDR,* Jan-05, 7, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200501.pdf) | New indexes introduced as part of the BLS expansion of PPI coverage of the service sector. To measure prices in these industries, PPI implemented a user-cost methodology. The user cost for a financial service is the difference between the revenue it generates and the sum of its implicit and explicit costs. Interest is allocated between loans and deposits by means of a reference rate, which is the interest rate on risk-free assets held by banks (the same financial intermediation model used in the national accounts). For trust services and other banking services, the price is equal to the actual fee charged for performing the service. | | Not currently used as a deflator in BEA's expenditure-side GDP estimates. The measure for commercial banking in GDP is based on a BLS productivity index for banking services. |
| **New PPI for Construction, Mining and Forestry Machinery and** | January 2005 (*PPIDR,* Jan-05, 8, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200501.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. Measures changes in revenue received by companies that rent and lease construction, mining, | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **Equipment Rental and Leasing Industry (NAICS 532412).** | | and forestry machinery and equipment. The price-update methodology uses actual transaction prices for contracts when that information is available. But when no transactions for a sampled contract have taken place, respondents estimate what the net transaction price would have been based on prices for similar transactions. | | |
| **Import Price Index – the Inbound Ocean Liner Freight Indexes published monthly rather than quarterly.** | January 2005 (*USIEPI,* Dec-04, https://www.bls.gov/news.release/archives/ximpim_01132005.pdf). | The Inbound Ocean Linder Freight Indexes will be published on a monthly rather than a quarterly basis. | Improves accuracy of this component. | Small improvement in accuracy. |
| **New PPI for Nonresidential Building Construction (NAICS 236221) for new warehouse building construction.** | July 2005 (*PPIDR,* Jul-05, 6–8, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200507.pdf). | As part of PPI's Nonresidential Building Construction (NRBC) initiative, new output price index introduced that expands coverage of a sector previously not measured by the PPI. Building models are developed and specified to represent types of warehouse buildings constructed in the marketplace. Each month, survey respondents receive a | | Fills a gap in price deflators for GDP and reduces bias in structures deflators by an unknown amount. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | pricing form that includes the current quarter's estimated costs for materials and installation for which the firm has agreed to provide an overhead and profit percentage. | | |
| **New PPIs for the Wholesale Trade Sector (NAICS 423, 424, and 425120).** | July 2005 (*PPIDR,* Jul-05, 9–10, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200507.pdf). | New indexes introduced as part of the BLS expansion of PPI coverage of the service sector. The prices of services provided by merchant wholesalers are measured by margins. The gross margin is the difference between the selling price to the next-level buy and the acquisition price. | | None – Wholesale trade PPIs are not used for deflating expenditure components of GDP (though they are used for the GDP-by-industry estimates). |
| **New PPI for Internet Service Providers (NAICS 518111).** | July 2005 (*PPIDR,* Jul-05, 11, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200507.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. In most cases, the PPI measures Internet access transactions with an average-price methodology: the total revenue from a firm's transactions from a specific type of Internet access is divided by the firm's total number of connections for that type of Internet access. | | |
| **New PPI for Web Search Portals (NAICS 518112).** | July 2005 (*PPIDR,* Jul-05, 12, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200507.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. Industry output is measured indirectly, through the sale of | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | listings and advertisements to companies interested in reaching the audience of Web searchers who visit the portal site. | | |
| **New PPI for Security Guards and Patrol Services (NAICS 561612).** | July 2005 (*PPIDR,* Jul-05, 13, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200507.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. A sample of security contracts is selected and the services provided by that contract are held fixed. | | |
| **New PPI for Fitness and Recreational Sports Centers (NAICS 713940).** | July 2005 (*PPIDR,* Jul-05, 14, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200507.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. PPI measures changes in price for memberships, admissions, classes, and other fitness services. | | Small – in GDP, recreation services are mostly deflated using CPI. |
| **Import and Export Price Indexes to be published by the North American Industry Classification System (NAICS).** | January 2006 (*USIEPI,* Oct-05, https://www.bls.gov/news.release/archives/ximpim_11102005.pdf). | Beginning with the release of January 2006 data, the US Import and Export Price Indexes is published by the North American Industry Classification System (NAICS). Note that the main headline numbers are still based on the BEA end-use categories. | Improves quality of components by using a modern classification system. | Improves overall quality by use of more modern classification and by harmonizing with other NAICS-based data. Magnitude of improvement in accuracy not quantified. |
| **Import and Export Price Indexes – All** | January 2006 (*USIEPI,* Dec-05, https://www.bls.gov/news.rel | All the services indexes previously published on a quarterly basis are now published monthly. | Improves accuracy of these services indexes. | Small improvement in accuracy. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **services indexes to be published on a monthly basis.** | ease/archives/ximpim_01122006.pdf). | | | |
| **New PPI for Nonresidential Building Construction (NAICS 236222) for new school construction.** | July 2006 (*PPIDR*, Jul-06, 7, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200607.pdf). | As part of PPI's Nonresidential Building Construction (NRBC) initiative, new output price index introduced that expands coverage of a sector previously not measured by PPI. Building models are developed and specified to represent schools constructed in the marketplace. BLS combines detailed material and installation cost data with margin (overhead and profit) data collected monthly by BLS directly from building construction contractors. | | Fills a gap in price deflators for GDP and reduces bias in structures deflators by an unknown amount. |
| **New PPI for Amusement and Theme Parks (NAICS 713110).** | July 2006 (*PPIDR*, Jul-06, 8, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200607.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. Includes admission prices, prices for food and beverage sales, and prices for merchandise sales, games, and other services. | | Small – in GDP, recreation services are mostly deflated using CPI. |
| **New PPI for Golf Courses and Country Clubs (NAICS 713910).** | July 2006 (*PPIDR*, Jul-06, 9, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200607.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. Prices measured include membership dues and fees, greens and guest fees, food and beverage sales, and | | Small – in GDP, recreation services are mostly deflated using CPI. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | equipment rentals and all other golf services. | | |
| **Import and Export Prices Indexes to discontinue indexes classified on Standard International Classification System (SITC).** | July 2006 (*USIEPI,* Apr-06, https://www.bls.gov/news.release/archives/ximpim_05122006.pdf). | Due to budget constraints, the US Import and Export Price Indexes classified by the Standard International Classification System (SITC) will no longer be published. | | |
| **New PPI for Nonresidential Building Construction (NAICS 236223) for new office building construction.** | January 2007 (*PPIDR,* Jan-07, 9, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200701.pdf). | As part of PPI's Nonresidential Building Construction (NRBC) initiative, new output price index introduced that expands coverage of a sector previously not measured by PPI. Building models are developed and specified to represent office buildings constructed in the marketplace. BLS combines detailed material and installation cost data with margin (overhead and profit) data collected monthly by BLS directly from building construction contractors. | | Fills a gap in price deflators for GDP and reduces bias in structures deflators by an unknown amount. |
| **New PPI for Management Consulting** | January 2007 (*PPIDR,* Jan-07, 10–11, https://fraser.stlouisfed.org/fi | New index introduced as part of the BLS expansion of PPI coverage of the service sector. Specific contracts are | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **Services (NAICS 541610).** | les/docs/publications/ppi/ppi_bls_200701.pdf). | selected for re-pricing. Respondents provide the rates for each of the professionals who bill for their time on each of these projects, from which a total charge is calculated. The total price is adjusted for the *realization rate*—the amount actually received compared with the amount that would have been received if all consultants had billed at non-discounted rates. | | |
| **New PPI for Blood and Organ Banks (NAICS 621991).** | January 2007 (*PPIDR,* Jan-07, 12–13, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200701.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. Covers transaction prices received establishments (primarily non-profit organizations) engaged in collecting, storing, and distributing blood, blood products, and body organs. The types of establishments include blood banks, organ banks (also called Organ Procurement Organizations), and tissue banks, including eye and sperm banks. | | |
| **New PPI for Computer Training (NAICS 611420).** | July 2007 (*PPIDR,* Jul-07, 7, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200707.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. Covers establishments engaged in conducting training in areas such as computer programming, | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | software packages, computerized business systems, computer electronic technology, computer operations, and local area network management. | | |
| **New PPI for Commercial and Industrial Machinery and Equipment (except Automotive and Electronic) Repair and Maintenance (NAICS 811310).** | July 2007 (*PPIDR*, Jul-07, 8, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200707.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. Specific contracts are selected for the sample. In subsequent months, the respondent estimates the current price for providing the service described in the contract, including updating the hourly rate for each labor type and the estimated charge for replacement parts. | | |
| **New PPI for Nonresidential Building Construction (NAICS 236211) for new industrial building construction.** | January 2008 (*PPIDR*, Jan-08, 7, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200801.pdf). | As part of PPI's Nonresidential Building Construction (NRBC) initiative, new output price index introduced that expands coverage of a sector previously not measured by PPI. Building models are developed and specified to represent industrial buildings constructed in the marketplace. BLS combines detailed material and installation cost data with margin (overhead and profit) data collected | | Fills a gap in price deflators for GDP and reduces bias in structures deflators by an unknown amount. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | monthly by BLS directly from building construction contractors. | | |
| **Import and Export Prices Indexes to discontinue several services indexes.** | January 2008 (*USIEPI,* Dec-07, https://www.bls.gov/news.release/archives/ximpim_01112008.pdf). | Due to budget constraints, the US Import and Export Price Indexes for export postsecondary education services, export travel and tourism services, inbound ocean liner freight, and inbound tanker freight will no longer be published. | | Reduction in quality of the deflation of imports and exports of services for the services associated with the discontinued indexes. |
| **New PPIs for Nonresidential Building Construction Sector (NAICS 23811X, 23816X, 23821X, and 23822X) for contractors performing poured concrete, roofing, electrical, and plumbing/HVAC work on** | July 2008 (*PPIDR,* Jul-08, 6–7, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_200807.pdf). | As part of PPI's Nonresidential Building Construction (NRBC) initiative, new output price index introduced that expands coverage of a sector previously not measured by PPI. A survey form that includes the item description is sent out monthly to the respondent, who estimates an updated price using information on current costs and current overhead and profit percentage that would be applied if the identical job were performed in the current month. | | Fills a gap in price deflators for GDP and reduces bias in structures deflators by an unknown amount. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **nonresidential buildings.** | | | | |
| **General Hospitals and Nursing Care Facilities PPIs** | Approximately 2009. Bureau of Labor Statistics, Health Quality Valuation Team (2008) | Quality adjustments are introduced into the hospitals and nursing care PPIs. The adjustments are based on databases compiled by the Department of Health and Human Services called Hospital Compare and Nursing Home Compare. These data capture changes in inputs that are indicative of changes in health quality according to the panel of experts responsible for developing the database. Cost estimates created for each element in the measure are used to adjust for quality change. | Unknown. | Unknown, but hospitals and nursing homes carry a very large weight in GDP and productivity. |
| **New PPI for Internet Publishing and Web Search Portals (NAICS 519130).** | January 2010 (*PPIDR,* Jan-10, 7, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_201001.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. Price indexes cover three service categories: search and textual advertising sales, display and other advertising sales, and subscription, content access, and licensing sales. Represents a change introduced in the 2007 NAICS classification. | | |
| **Enhancement to the indexes for Prescription and** | January 2010 (*PPIDR,* Feb-10, 5–6, https://fraser.stlouisfed.org/fi | Now includes all the price quotations PPI collects for these products. Previously, the method employed most, | | Small – in GDP, pharmaceuticals are |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **Non-Prescription Pharmaceuticals.** | les/docs/publications/ppi/ppi_bls_201002.pdf). | but not all, of the price quotations collected from NAICS 325412, the Pharmaceutical Preparation Manufacturing industry. | | mostly deflated using CPI. |
| **New PPI for Offices of Dentists (NAICS 621210)** | January 2011 (*PPIDR*, Jan-11, 7, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_201101.pdf). | New index introduced as part of the BLS expansion of PPI coverage of the service sector. Covers prices for: dental visits and consultations, dental surgical intervention services, and dental non-surgical intervention services. | | Small – in GDP, dental services are mostly deflated using CPI. |
| **New PPI for Nonresidential Building Construction (NAICS 236224) for new health care building construction.** | January 2013 (*PPIDR*, Jan-13, 7, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_201301.pdf). | As part of PPI's Nonresidential Building Construction (NRBC) initiative, new output price index introduced that expands coverage of a sector previously not measured by PPI. Building models are selected from health care buildings constructed in the United States. BLS combines detailed material and installation cost data with margin (overhead and profit) data collected monthly by BLS directly from building construction contractors. | | Fills a gap in price deflators for GDP and reduces bias in structures deflators by an unknown amount. |
| **New Final Demand-Intermediate Demand** | January 2014 ("Producer Price Index Transitions from the Stage-of-Processing to the Final Demand-Intermediate | The new aggregation system is more consistent with GDP aggregation and includes services and construction coverage in the headline PPI numbers. | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **Aggregation System** | Demand Aggregation System, https://www.bls.gov/ppi/fdidtransition.htm) | | | |
| **New PPIs for health care services by payer type.** | July 2014 (*PPIDR,* Jul-14, 7–8, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_201407.pdf). | Publication structures for health care services expanded to provide detailed service line indexes based on payer type. For example, detailed indexes are provided for Medicare patients, Medicaid patients, private insurance patients, and all other patients. | | Small – in GDP, the PPIs used as deflators are mostly detailed industry or commodity PPIs. |
| **Revised methodology for the inputs-to-industries indexes.** | January 2015 (*PPIDR,* Oct-14, 9, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_201410.pdf). | Expands the scope of the inputs-to-industries indexes, which track average changes in prices for commodity inputs to several industries. | | |
| **PPI to update samples more frequently.** | June 2015 (*PPIDR,* Feb-15, 6, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_201502.pdf). | Sample will be updated three times a year, with data for February, June, and October. Previously samples had been updated biannually, with data for January and July. | This acceleration will result in indexes that better represent current industry production. | |
| **PPI introduces hedonic quality adjustment for Internet Access indexes.** | December 2016 (*PPIDR,* Jan-17, 7, https://fraser.stlouisfed.org/files/docs/publications/ppi/ppi_bls_201701.pdf). | BLS began using hedonic quality adjustment for broadband items within PPI data for Internet access services. The method accounts for rapid technological change because download | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | and upload speed typically increase over time. | | |
| **PPI introduces hedonic quality adjustment for integrated microcircuits.** | January 2018 ("PPI Introduces Hedonic Price Estimation for Integrated Microcircuits Indexes," https://www.bls.gov/ppi/microcircuitshedonics.htm) | *Quality adjustment* – PPI began using a hedonic model to measure quality-adjusted price change. | Quantitative impact not known. | |
| **Updated publication structure for Hospitals.** | January 2018 ("PPI Updates the Publication Structure for NAICS 622110, General Medical and Surgical Hospital," https://www.bls.gov/ppi/restructured-hospital-indexes.htm) | *New classification structure* – The new index structure is based on the International Classification of Diseases. | Quantitative impact not known. | |

*Sources: PPIDR: PPI Detailed Report (available from https://fraser.stlouisfed.org/title/63)*
*USIEPI: US Import and Export Price Indexes (available from https://www.bls.gov/bls/news-release/ximpim.htm)*

**Table B3. Changes in GDP statistical methods and impact on private nonfarm business output**

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **Exports and imports of semiconductors** | 1993. (*SCB*, Aug-97, 30, https://www.bea.gov/scb/pdf/national/nipa/1997/0897niw.pdf) | *Deflator* – Annual price estimates include prices of "dice and wafers." (Previous estimates had reflected only microprocessors and memory integrated circuits.) | Not available. | Not available. |
| **Investment in telephone switching and switchboard equipment** | Initially from 1993 (*SCB*, Aug-97, 30, https://www.bea.gov/scb/pdf/national/nipa/1997/0897niw.pdf), and later carried back to 1985 (*SCB,* Oct-99, 17, https://www.bea.gov/scb/pdf/NATIONAL/NIPA/1999/1099niw.pdf) | *Quality adjustment* –Introduced quality-adjusted annual price index based on hedonic regression from Federal Communications Commission (FCC) data. | Not available. | Not available. |
| **Nursing home services (for profit)** | 1995. (*SCB*, Aug-97, 30, https://www.bea.gov/scb/pdf/national/nipa/1997/0897niw.pdf) | *Deflator* – Newly available BLS PPI used for deflation. (Previous deflator was from Health Care Financing Administration.) | Not available. | Not available. |
| **Private and government investment, inventory investment, exports and** | 1993 (*SCB*, Aug-97, 30, https://www.bea.gov/scb/pdf/national/nipa/1997/0897niw.pdf) | *Quality adjustment* – BEA prepared Fisher chained-type price index that uses model shipments as quantity weights and prices from hedonic regressions. (Previous deflator was | The revised index "decreased at a much sharper rate" than the previous index. | Not available. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **imports of mainframe computers** | | BLS PPI for large-scale electronic computers.) | | |
| **Imports and domestic investment in computer terminals, storage devices, and peripheral equipment** | 1995. (*SCB*, Aug-97, 30, https://www.bea.gov/scb/pdf/national/nipa/1997/0897niw.pdf) | *Deflator* – Incorporated BLS Import Price Index for terminals, storage devices, and peripheral equipment for import and domestic investment and the BLS PPI for terminals into the deflator for domestic computers. | Not available. | Not available. |
| **PCE** | 1995 (*SCB,* Aug-98, 31, https://www.bea.gov/scb/pdf/NATIONAL/NIPA/1998/0898niw.pdf); Later back-cast to 1978 using CPI-U-RS. (*SCB,* Oct-99, 16–17, https://www.bea.gov/scb/pdf/NATIONAL/NIPA/1999/1099niw.pdf) | *Geometric mean CPIs* – Replaces fixed-weight BLS CPI components used for deflation with BLS geometric mean indexes. When first implemented in 1998, BLS was publishing geometric mean indexes as experimental series, but had announced it would incorporate them in the official CPI in January 1999. Back-cast series were from the CPI-U-RS. The CPI-U-RS | About 0.2 percentage point per year from the geometric mean. Additional effects from other changes reflected in the CPI-U-RS. | About 0.15 percentage point per year. Additional effects from other changes reflected in the CPI-U-RS. |
| **Cellular telephone service** | 1995–1997 (*SCB,* Aug-98, 31, https://www.bea.gov/scb/pdf/NATIONAL/NIPA/1998/0898niw.pdf), later carried back to 1987. (*SCB,* Oct-99, | *Deflation* – Cellular telephone service deflated using a price index developed by Jerry Hausman of MIT. After 1998, newly available CPI for cellular telephone is used for deflation. | Not available. | Not available. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | 17, https://www.bea.gov/scb/pdf/NATIONAL/NIPA/1999/1099niw.pdf) | | | |
| **PCE** | 1998 (*SCB,* Aug-98, 31, https://www.bea.gov/scb/pdf/NATIONAL/NIPA/1998/0898niw.pdf) | *Deflation* – New CPI item classification structure provides new, more appropriate deflators for many CPI components, including cellular telephone service, computers, online services, video cassette rental, auto and truck rental, parking fees and tolls, eyeglasses and eye care, commercial and vocational schools. | Not available. General improvement in accuracy of deflation. | Not available. |
| **Other professional (medical) services; Employment agency fees** | 1995 (*SCB,* Aug-98, 31, https://www.bea.gov/scb/pdf/NATIONAL/NIPA/1998/0898niw.pdf) | *Deflation* – Home health care services and medical laboratories deflated using newly available PPIs. Employment agency fees deflated using newly available PPI for employment agencies. | Not available. General improvement in accuracy of deflation. | Not available. |
| **Investment – Computers and peripheral equipment, Engineering services, Residential improvements,** | 1995 for computers and peripheral equipment, 1997 for engineering services, 1998 for residential improvements, 1996 for brokers' commissions (*SCB,* Aug-98, 31–32, https://www.bea.gov/scb/pd | *Deflation* – BLS PPIs for ink-jet printers and impact printers replace BEA printer price indexes. BLS Import Price Index for PC's replaces BEA price index for imported PC's. Capitalized engineering services (a component of many equipment investment categories) deflated using | Not available. | Not available. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **Residential brokers' commissions.** | f/NATIONAL/NIPA/1998/0898niw.pdf) | PPI for engineering services. Residential improvements deflated by a composite index of the PPI for construction materials and the Census Bureau index for new homes sold; previously, a recently discontinued CPI for maintenance and repairs was used. Brokers' commissions deflated using newly available PPI for real estate brokerage. | | |
| **Exports and imports – Freight services exports and imports, Printer exports and imports, Computer exports, Imports from US territories** | 1995, except for computer imports, which begin in 1997 (*SCB,* Aug-98, 32, https://www.bea.gov/scb/pdf/NATIONAL/NIPA/1998/0898niw.pdf) | *Deflation* – New import and export price indexes used to deflate imports of ocean liner freight services and air freight services, exports for air freight services. PPI for ink-jet printers replaces BEA price index for exports of ink-jet printers. Imports of personal computers deflated using newly available Import Price Index for personal computers, and imports of printers deflated using Import Price Index for printers. BLS Export Price Indexes used to deflate all five components of computer exports. PPI for pharmaceutical preparations used | Not available. | Not available. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | in deflator for imports from Puerto Rico. | | |
| **State and local – Other professional services** | 1997. (*SCB,* Aug-98, 32, https://www.bea.gov/scb/pdf/NATIONAL/NIPA/1998/0898niw.pdf) | *Deflation* – State & local government expenditures for other professional services deflated by a price index composed of newly available PPIs for advertising agencies; legal services; engineering, design, analysis, and consulting services; and accounting, auditing, and bookkeeping services. | Not available. | Not available. |
| **Investment – Software** | 1959. (*SCB,* Jul-99, 9–11, https://www.bea.gov/scb/pdf/INTERNAT/USINVEST/1999/0799mnc.pdf) | *Expanded scope of Investment* – Software was recognized as a type of fixed asset and expenditures on software were recognized as fixed investment. Previously, purchases of software had been treated as intermediate consumption. | Component was not included in GDP prior to the 1999 comprehensive revision. Software investment grew from zero before 1959 to 2.4% of private nonfarm business output in 1999 and 2.7% in 2015. | For 1987–2016, output growth was raised 0.12 percentage point per year (see Table 3 in the main text for more details). |
| **Services of regulated investment companies (mutual funds)** | 1959. (*SCB,* Jul-99, 14–15, https://www.bea.gov/scb/pdf/INTERNAT/USINVEST/1999/0799mnc.pdf) | *Measurement of output* – Value of imputed service redefined to equal operating expenses. Previously, the value had been based on net property income received. | Not available. | Not available. |
| **Banking services** | 1929. (*SCB,* Oct-99, 13, https://www.bea.gov/scb/pd | *Quantity extrapolation* – Uses BLS estimates of banking industry productivity, which are based on | Raised growth of real financial services furnished without | Raised growth rate of real private nonfarm business |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | f/NATIONAL/NIPA/1999/1099niw.pdf) | weighted average of various indexes of bank activity, including transactions, loans, and net income. | payment by 2.8 percentage points per year, based on revisions for 1987-1997. | sector output by 0.10 percentage point per year, based on revisions for 1987-1997. |
| **PCE - Nonprofit institutions** | 1988 for higher education, 1993 for other nonprofits. (*SCB,* Oct-99, 14, https://www.bea.gov/scb/pdf/NATIONAL/NIPA/1999/1099niw.pdf) | *Deflation* – For higher education, input-cost index based on integrated post-secondary education data system (IPEDS) finance survey. For other nonprofits, indexes of wages and salaries and price indexes associated with non-compensation expenditures. | Not available. | Not available. |
| **Investment – Nonresidential real estate brokers' commissions, Inventory investment in semiconductors** | 1996 for nonresidential real estate brokers' commissions, and 1983 for change in inventories for semiconductors. (*SCB,* Oct-99, 14, https://www.bea.gov/scb/pdf/NATIONAL/NIPA/1999/1099niw.pdf) | *Deflation* – Nonresidential real estate brokers' commissions deflated using newly available PPI. Semiconductor inventories deflated using BEA quality-adjusted price index. | Not available. | Not available. |
| **Exports and imports – Telephone switching equipment; Computers,** | 1985 for telephone switching equipment, 1992 for computers, peripherals, and parts (*SCB,* Oct-99, 14–15, https://www.bea.gov/scb/pd | *Deflation* – BEA quality-adjusted price index for telephone switching equipment replaces BLS international price indexes. For "parts and accessories" within "computers, peripherals, and parts," deflated using | Not available. | Not available. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **peripherals, and parts** | f/NATIONAL/NIPA/1999/1099niw.pdf) | BLS import and export price indexes for parts and accessories for computers and other office machines. | | |
| **Investment in computers and peripheral equipment, Investment in petroleum and gas well drilling and exploration, Imports of computers** | 1999 for computers, 2000 for petroleum and gas well drilling and exploration. (*SCB,* Aug-00, 29, https://www.bea.gov/scb/pdf/NATIONAL/NIPA/2000/0800nipr.pdf) | *Deflation* – For domestic investment in, and imports of computers, a BLS import price index for computers replaces average of PPIs for large-scale and mid-range computers and an unpublished BLS import price index for personal computers. PPI for oil and gas field services replaces PPIs for onshore field services and for offshore field services. | Not available. | Not available. |
| **Inventory investment** | 1997. (*SCB,* Aug-01, 25–26, https://www.bea.gov/scb/pdf/2001/08august/0801NIPAnnual.pdf) | *Classification* – Inventory investment estimates converted to the North American Industry Classification System (NAICS). | No impact on total current-dollar or real GDP. Accuracy of individual industries improved. | Minimal. |
| **Investment in Communication equipment, Custom software** | 1998. (*SCB,* Aug-01, 28, https://www.bea.gov/scb/pdf/2001/08august/0801NIPAnnual.pdf) | *Deflators* – Quality adjusted price index for local area network (LAN) equipment—routers, switches, and hubs—from the Federal Reserve Board used to deflate LAN portion of communication equipment. Custom software deflator based on a weighted average of BEA's own-account software price index and the PPI for | Not available. | Not available. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | prepackaged software applications sold separately (replacing the PPI for all prepackaged software applications). | | |
| **PCE – Brokerage and investment counseling, Airline passenger fares paid by US residents to US carriers on international flights,** | 1999. (*SCB,* Aug-02, 31, https://www.bea.gov/scb/pdf/2002/08August/0802AnnualRevision.pdf) | *Deflation* – BLS PPIs for brokerage services now used for deflation, replacing SEC data on volume and trade. BLS Import Price Index for fares paid to US carriers on international flights replaced broader Import Price Index for air passenger fares. | Not available. | Not available. |
| **Exports and imports of services – Brokerage services, Net insurance services** | 2000Q4 for brokerage services, 1999 for insurance services. (*SCB,* Aug-02, 31, https://www.bea.gov/scb/pdf/2002/08August/0802AnnualRevision.pdf) | *Deflation* – BLS PPI for security brokers, dealers, and investment banking companies replaces BEA implicit price deflator. PPIs for "life insurance carriers" and for "premiums for property and casualty insurance" replace BEA implicit price deflators. | Not available. | Not available. |
| **Property and casualty insurance services** | 1929. (*SCB,* Jun-03, 19–23, https://www.bea.gov/scb/pdf/2003/06June/0603NIPArevs.pdf) | *Redefine output to recognize implicit services* – Recognizes services funded by investment income; treats insured losses as an ex ante deduction from premiums (based on expected losses) rather than balancing losses against | Nominal GDP increased most years by 0.1–0.2%; time series smoothed by eliminating large swings associated with catastrophic losses. | Not available. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | premiums each period, thereby reducing large swings in measured output from catastrophic losses. | | |
| **Commercial bank services** | 1929. (*SCB,* Jun-03, 23–27, https://www.bea.gov/scb/pdf/2003/06June/0603NIPArevs.pdf) | *Redefine output to recognize services provided to borrowers* – Implicit services received by depositors to be based on the difference between the interest received on deposits and a "reference rate" representing the opportunity cost of borrowing or lending funds. Implicit services received by borrowers to be based on the difference between the interest paid on loans and the reference rate. | Nominal GDP reduced by about 0.9% because borrower services tend to be by businesses, and are thus treated as intermediate inputs. | Not available. |
| **PCE – Medical care and hospital insurance benefits,** | 1988 (*SCB,* Sep-03, 28, https://www.bea.gov/scb/pdf/2003/09September/0903NIPAPreview.pdf) | *Deflators* – Deflates medical care and hospital insurance benefits using weighted average of CPIs and PPIs for eight types of care that are more closely matched to the types of benefits. | Not available. | Not available. |
| **Investment – Nonresidential structures, Photocopying equipment, Own-account software** | 1997 for nonresidential structures, 1992 for photocopying equipment, 1959 for own-account software (*SCB,* Sep-03, 29–31, https://www.bea.gov/scb/pd | *Deflators* – New BEA hedonic price indexes for four building types—warehouses, factories, office buildings, and schools. Will be linked to new BLS PPIs when they become available. New BEA hedonic price index introduced for photocopying | Lowered price changes for these components. | Not available. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | f/2003/09September/0903NIPAPreview.pdf) | equipment. Price index for own-account software, which had been entirely based on input costs, now based 75% on input costs and 25% on prepackaged software price index (which reflects productivity changes). | | |
| **Investment – Nonresidential structures** | 2005 (*SCB,* Aug-06, 28, https://www.bea.gov/scb/pdf/2006/08August/NIPA_annualUPDATE.pdf) | *Deflation* – Investment in warehouses deflated by newly available PPI for warehouse construction. | Not available. | The use of a more appropriate deflator reduced bias in this component by an unknown amount. |
| **Investment – New light trucks, Nonresidential structures** | 2004 for new light trucks, 2006Q3 for nonresidential structures—educational and vocational structures and office buildings (*SCB,* Aug-07, 27, https://www.bea.gov/scb/pdf/2007/08%20August/0807_NIPA_rev.pdf). New light trucks deflator later (in 2013 comprehensive revision) carried back to 1987 (*SCB,* May-13, 14, https://www.bea.gov/scb/pd | *Deflation* – Investment by business in new light trucks now deflated by CPI, replacing a PPI. Most businesses purchase vehicles through motor vehicle dealers and therefore pay retail and wholesale margins, which are not included in the PPI. Investment in educational and vocational structures deflated by BLS PPI for schools, and investment in office buildings deflated by BLS PPI for office building construction. | Not available. | Not available. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | f/2013/05%20May/0513_nipa-preview.pdf) | | | |
| **PCE – Airline services** | 2005 (*SCB,* Aug-08, 18, https://www.bea.gov/scb/pdf/2008/08%20August/0808_nipa_annrev.pdf) | *Deflation* – Deflator for consumer purchases of domestic airline services changed to improved BLS PPI for domestic scheduled air transportation. Previous deflator was based on cents per revenue passenger mile for domestic carriers from the Air Transport Association of America. | Not available. | Not available. |
| **PCE – Goods bought at grocery stores** | Initially, 2005 (*SCB,* Aug-08, 18, https://www.bea.gov/scb/pdf/2008/08%20August/0808_nipa_annrev.pdf), then carried back to 2003 in 2009 comprehensive revision (*SCB,* May-09, 16, https://www.bea.gov/scb/pdf/2009/05%20May/0509_nipastats.pdf) | *Scanner data* – Estimates of the composition of goods bought at grocery stores are now based on point-of-sale retail scanner data from trade sources. | Not available. According to BEA article, "this method captures the variation in the composition of goods sold by grocery stores." | Not available. |
| **Investment – Nonresidential structures** | 2008. (*SCB,* Aug-08, 18, https://www.bea.gov/scb/pdf/2008/08%20August/0808_nipa_annrev.pdf) | *Deflation* - Investment in manufacturing structures deflated by BLS PPI for industrial building construction. | Not available. | The use of a more appropriate deflator reduced bias in this component by an unknown amount. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **PCE – all items** | 1929. (*SCB,* May-08, 6–17, https://www.bea.gov/scb/pdf/2008/05%20May/0508_nipa_pce.pdf; *SCB,* Mar-09, 18–19, https://www.bea.gov/scb/pdf/2009/03%20March/0309_nipa_preview.pdf) | *Item classification* – New classification system reflects modern expenditure patterns, improves linkages with source data on expenditures and prices, and improves international comparability. | Not available. Improves accuracy of individual components, but little net impact on total PCE. | Not available. (Probably small) |
| **Private investment in structures** | 1929. (*SCB,* Mar-09, 19, https://www.bea.gov/scb/pdf/2009/03%20March/0309_nipa_preview.pdf) | *Classification* – New classification of structures by function back-cast to 1929. | Not available. | Not available. |
| **PCE for goods** | 2003. (*SCB,* May-09, 9, https://www.bea.gov/scb/pdf/2009/05%20May/0509_nipastats.pdf) | *Scanner data* – Estimates of the composition of goods bought at electronics stores are now based on retail point-of-sale scanner data from a trade source. | Not available. | Not available. |
| **PCE for goods - Software** | 2007. (*SCB,* Aug-10, 22, https://www.bea.gov/scb/pdf/2010/08%20August/0810_nipa-revision.pdf) | *Scanner data* – Estimates of consumer spending for software bought at radio, television, and electronics stores and at computer and software stores are now based on retail point-of-sale scanner data from a trade source. | Not available. | Not available. |
| **Investment, Exports, and Imports -** | Initially, 2007 (*SCB,* Aug-10, 23, https://www.bea.gov/scb/pd | *Deflation* – Use quality-adjusted price indexes from the Federal Reserve Board to deflate: telephone switching | Not available. | Not available. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| **Communication equipment,** | f/2010/08%20August/0810_nipa-revision.pdf), carried back to 2003 in 2011 annual revision (*SCB,* Aug-11, 26, https://www.bea.gov/scb/pdf/2011/08%20August/0811_nipa_annual_article.pdf) | equipment, carrier line equipment, and wireless networking equipment. | | |
| **Investment – Research and development** | 1929. (*SCB,* Mar-13, 14–18, https://www.bea.gov/scb/pdf/2013/03%20March/0313_nipa_comprehensive_revision_preview.pdf) | *Expanded scope of Investment* – The intellectual property products produced by of research and development were recognized as a type of fixed asset and expenditures on R&D were recognized as fixed investment. Previously, purchases of R&D had been treated as intermediate consumption. | Component was not included in GDP prior to 2013 comprehensive revision. Nominal GDP was increased by 2.5% in 2012. | For 1987–2016, output growth was raised 0.01 percentage point per year. |
| **Investment – Entertainment, literary, and artistic originals** | 1929. (*SCB,* Mar-13, 18–20, https://www.bea.gov/scb/pdf/2013/03%20March/0313_nipa_comprehensive_revision_preview.pdf) | *Expanded scope of Investment* – The intellectual property products produced by of creation of entertainment, literary, and artistic originals were recognized as a type of fixed asset and expenditures on entertainment, literary, and artistic originals were recognized as fixed investment. Previously, expenditures on entertainment, literary, and | Component was not included in GDP prior to 2013 comprehensive revision. Nominal GDP was increased by 0.5% in 2012. | For 1987–2016, impact on output growth was less than 0.01 percentage point. |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | | artistic originals had been treated as intermediate consumption. | | |
| **Investment - Residential** | 1929 (*SCB,* Mar-13, 20–21, https://www.bea.gov/scb/pdf/2013/03%20March/0313_nipa_comprehensive_revision_preview.pdf) | *Scope of costs capitalized* – Broad set of expenses associated with the acquisition and disposal of residential housing are capitalized. Previously, only brokers' commissions were capitalized. | Estimate not available. Nominal GDP was increased by 0.3% in 2012. | Not available. |
| **Commercial bank services** | 1985 (*SCB,* Feb-13, 8–19, https://www.bea.gov/scb/pdf/2013/02%20February/0213_nipa-rev.pdf; *SCB,* May-13, 8–10, https://www.bea.gov/scb/pdf/2013/05%20May/0513_nipa-preview.pdf) | *Methods for computing implicit bank services* – 1) Modify set of assets and liabilities included in the calculations; 2) New treatment of losses from borrower defaults; and 3) Refine computation of reference rate to reduce volatility. | Estimate not available. Nominal GDP was decreased by 0.3% in 2012. | Not available. |
| **Investment – Nonresidential structures,** | 2011 for nonresidential brokers' commissions, 2012Q4 for health care structures. (*SCB,* Aug-14, 5, https://www.bea.gov/scb/pdf/2014/08%20August/0814_gdp_and_the_economy.pdf) | *Deflation* – Uses newly available PPI for real estate brokerage, nonresidential property sales and leases for deflation of nonresidential brokers' commissions. Uses newly available PPI for health care building construction for deflation of health care structures. | Not available. | The use of a more appropriate deflator reduced bias in these components by an unknown amount. |
| **PCE – Financial services** | 2012. (*SCB,* Aug-15, 4, https://www.bea.gov/scb/pdf/2015/08%20August/0815 | *Deflation* – Uses BLS PPIs for portfolio management and for investment advice to deflate portfolio | | |

| Component | Time Period (Sources) | Description of Change | Impact on Component | Impact on MFP Output Growth |
|---|---|---|---|---|
| | _gdp_and_the_economy.pdf) | management and investment advice services. Uses BLS PPI for commercial bank services to deflate trust, fiduciary, and custody activities. | | |

*Sources: SCB - Survey of Current Business (available at https://www.bea.gov/scb/issues.htm)*

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