Can Mismeasurement of the Digital Economy explain the U.S. Productivity Slowdown?

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* The views in the paper are those of the author and should be attributed to the IMF, its executive directors, or its management. Send comments or questions to: MReinsdorf@IMF.org. This paper draws heavily on joint research with David Byrne and John Fernald, as presented in Byrne, Fernald and Reinsdorf (2016).

The US entered its first major productivity slowdown in the post-war era in 1973. Strong productivity growth of producers and users of information and communication technology (ICT) products played key roles in bringing this slowdown to an end around 1995. Although the resumption of high productivity growth was widely interpreted as a return to normal, around 2004 or 2005, U.S. productivity growth entered a second period of slow growth. Within a few years most other advanced economies were also registering slowdowns in productivity growth that persist to this day. It is now the high productivity growth of 1995 through 2004 that looks to be exceptional. The productivity growth rates for the U.S. of Fernald (2014) show that the average labor productivity growth rate has been about 1¾ percentage points per year lower during the post-2004 productivity slowdown than in 1995-2004. A slowdown of 1¾ percentage points per year has dramatic long-run implications: if productivity growth had continued at its 1995–2004 pace then, holding hours growth unchanged, by 2015 business-sector output would have been $3 trillion larger in inflation-adjusted 2009 dollars.

The dismal productivity growth figures that advanced economies have continued to report long after the effects of the Financial Crisis should have dissipated seem inconsistent with the rapid pace of technological change reflected in the broad diffusion of digitalization into all types of processes and products. Also, in addition to discussing reasons to believe that digital products are being mismeasured, Hatzius (2015) has argued that the low inflation and good corporate profits reported during the current productivity slowdown are not what would be expected during a true productivity slowdown, as shown by the high inflation and poor corporate profits seen in past productivity slowdowns. (See also Hatzius and Dawsey, 2015, and Hatzius, 2016.) The search for explanations for the U.S. productivity slowdown has therefore led to a resurgence of interest in longstanding problems of measuring quality change in ICT products and a debate over whether the growth statistics are accounting for the benefits of new kinds of digital products.

To preview the main conclusions, although underestimation of quality improvements in ICT goods and software is indeed a source of downward bias in the U.S. productivity statistics, this was also true before productivity growth slowed down, and the size of this source of bias did not grow. However, some globalization-related sources of bias seem to have contributed modestly to the measured size of the productivity slowdown. Also, new digital products available through the Internet or smartphone apps, which grew rapidly in importance in the early 2000s, have created some gains that have not been captured in the growth statistics. However the major productivity impact of these products is on home production of non-market services that household produce for their own consumption. Though large, the welfare gains from productivity in non-market home production raises are not part of the production that is supposed to be measured by GDP or the statistics on productivity of market sector businesses. In sum, correcting for mismeasurement of the digital economy on a consistent basis over time would have only a small effect on the magnitude of the productivity slowdown.

Mismeasured Deflators for ICT Products

Alternative price indexes for ICT goods and software

Upward bias in the price indexes used for deflation of information and communication technology (ICT) products and downward bias in the associated output measures and have long been concerns in the economic measurement literature. In the case of the national income and product accounts (NIPAs) of the United States, attempts to measure ICT goods in ways that take account of these concerns date from the mid-1980s, when researchers using hedonic quality adjustment methods found large declines in the price indexes for computers and semiconductors not seen in official price indexes.[1] In 1985, the U.S. Bureau of Economic Analysis introduced hedonic methods for deflators for computers and peripherals into the national income and product accounts (NIPAs) , and the U.S. Bureau of Labor Statistics (BLS) did the same in the producer price index (PPI) in 1991 (Moulton, 2001). BEA extended the use of hedonic methods to the deflators for exports and imports of semiconductors in 1996 followed by telephone switches in 1997 (Grimm, 1996 and 1998). Shortly thereafter BLS began to use hedonic (or hedonic-like) methods in the consumer price index (CPI) for computers and its export and import price indexes for semiconductors. These improvements enabled the U.S. statistical system to measure the role of ICT in the productivity speedup that began in 1995.

Nevertheless, the problem of mismeasured deflators for ICT products was not entirely solved, and in the mid-2000s the amount of overestimation began to grow. Three factors that contributed to the growing mismeasurement are discussed below: changes in pricing practices, changes in technology, and the growing importance of product categories that are particularly hard to measure.

Suspicions that mismeasurement of ICT deflators was causing the official data to exaggerate the magnitude of the productivity slowdown were fueled by the sharp deceleration in the rate of decline of the official price indexes for computers in 2004, the year that the slowdown began (Figure 1 and Figure 2). In fact, since 2008, the implicit deflator for computers in the national accounts has tracked the average unadjusted price of a computer, implying that quality improvement came to a halt (Byrne, Fernald and Reinsdorf, 2016). No credit seems to have been given for performance-enhancing innovations such as multicore processors and more versatile GPUs, and features such as touch screens and longer battery life.

Byrne, Fernald and Reinsdorf (2016) calculate alternative deflators for ICT goods and software (the index for computers and peripherals is shown in Figure 3). For computers and peripherals, the implied upward bias in the NIPA deflator rose from 8 percent per year in the "productivity speedup" period of 1995-2004 to 12 percent per year in the productivity slowdown period of

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[1] The history of research on computer prices begins much earlier, however. For example, Chow (1967) documented the rapid decline of mainframe computer prices in the 1960s.

2004-2014 (table 1). For communication equipment, the implied upward bias in the NIPA deflator rose from 5.8 percent per year in the productivity speedup years to 7.6 percent per year in the productivity slowdown years.

Table 1. Growth Rate Difference between NIPA Deflator and Alternative Deflator[a]

	1995-2004	2004-2014
Computers and peripherals		
Average growth rate of NIPA deflator	–19.3	–6.6
Difference between NIPA deflator and alternative deflator	8.0	12.0
Communications equipment		
Average growth rate of NIPA deflator	–5.4	–2.7
Difference between NIPA deflator and alternative deflator	5.8	7.6
Other IT systems equipment		
Average growth rate of NIPA deflator	-0.6	0.5
Difference between NIPA deflator and alternative deflator	8.3	5.4
Software		
Average growth rate of NIPA deflator	-1.1	0.1
Difference between NIPA deflator and alternative deflator	1.4	0.9

a. Alternative deflator from Byrne, Fernald and Reinsdorf (2016, table 1).

Growing ICT measurement challenges: changing pricing practices

The evidence on the role of changing pricing practices comes from Byrne, Oliner and Sichel (2015). They find that in the mid-2000s Intel changed its pricing strategy for semiconductors, ending its practice of marking down the prices of older models at the time of introduction of a new model (though they may have been marked down later on). Some producers of smartphones and computers also adopted a strategy of not marking down old models when the new ones are released (reportedly because large price drops would create disappointment on the part of those who had just recently purchased the old model). However, standard price index techniques to handle the entry of new models or varieties assume that the "law of one price" holds. The law of one price implies that the difference in prices between the old and new models represents the value of the quality differences.

If the price of the old model falls by enough to be competitive with the new model when the new model is introduced, the price decline of the old model will be captured by the price index before the old model exits from the index basket.[2] Of course, even before the change in semiconductor

[2] In the simplest case of the "matched models" technique that is commonly used to compile a price index for a good, overlapping prices of the two models are collected in the link month. The price change of the old model is used in the calculation of the change in index up to the link month, and the price change of the new model is used in the

pricing policy, the price difference between the new and old model may have understated the quality difference if most buyers preferred the new model, but at least part of the quality difference would have been captured by the "matched models" price index. Furthermore, if the prices of the new model and old models are the same even though the new model has superior characteristics, a hedonic model will also underestimate the value of the quality improvements.

Growing ICT price measurement challenges: changing technology and product mix

Changes in technology that alter the set of physical characteristics that matter for a computer's performance may cause a return of upward bias in the computer deflator if the statistical agency does not update the specification of its hedonic model. In particular, multi-core processors and the reallocation of tasks formerly done by the CPU to GPUs or other specialized chips mean that CPU clock speed is no longer a good metric of computer performance. This has resulted in upward bias in the U.S. PPIs that continue to use clock speed for quality adjustment (Byrne and Corrado, 2016).

The third factor that has added to the difficulty of measuring price change for ITC goods and services is a change in the mix of ITC goods and services to include more specialized devices and services and more software.[3] Byrne, Fernald and Reinsdorf (2016) report that the share of ITC investment going to hard-to-measure software rose from 39.3 percent in 1995-2004 to 48.2 percent in 2004-2014. Software quality is particularly hard to measure, and in the cases of custom-software and own-account software, satisfactory quality adjustment procedures based on measurable, objective criteria may be impossible to identify. But even though we cannot estimate the size of the bias in the official deflator for software with much precision, there is reason to believe that the size of this bias is significant.

The U.S. PPI for application software publishing and the implicit deflator for software in the NIPAs have been close to flat in recent years. The implicit deflator for private business software has an average growth rate over 2004-2015 of about zero, and the average for software as a whole is 0.1 percent per year. This seems inconsistent with the likely productivity-enhancing effects of improvements in the hardware and software tools available to programmers (and price reductions may also have been possible because of open source software). What is more, the emergence of a large industry providing online digital services (such as Facebook and Google) and of a large "app economy" is suggestive of strong growth in software investment and software assets.[4] The average annual volume growth rate of investment in software in the NIPAs

calculation of the change in the index going forward from the link month. This procedure prevents the difference in two models' price levels, which is presumed to represent their quality difference, from influencing the price index.

[3] Furthermore, greater variety increases consumer welfare, but this downward effect on a cost of living index is not measured by commonly used price index formulas.

[4] Mandel, 2016, estimates that employment in the U.S. in writing smartphone apps in December 2015 was 550 thousand.

from 2002-2015 of 4.6 percent may therefore be low, particularly in light of the 6.2 percent growth rate for investment in computers over that same time period.

The alternative software deflator in Byrnes, Fernald and Reinsdorf (2016) implies an upward bias in the official deflator of just 0.9 percent per year in 2004-2014. In contrast, the alternative software index that was later calculated by Byrnes and Corrado (2016) falls 3.8 percent per year during those years, implying an upward bias in the growth rate of the NIPA deflator of 3.9 percentage points.

Another question that arises in measuring software and databases is the treatment of volunteer-created open-source software and wikis. National accounts generally use production expense to value non-market, and if volunteers are paid zero, the work product is not counted in GDP. Although the definition of GDP is appropriate for the key uses of this statistic, an alternative measure that valued the software and databases created by volunteers based on an estimate of the value of the volunteer's time might be useful for some purposes.

Communication Services

Services connected with digitization have also undergone quality changes that may not be well captured in official price and volume measures. The price index for communication services in the NIPAs has an average growth rate of -0.3 percent per year over 2004-2015. The amount of technological progress suggested by this figure seems low in light of the advances that occurred in mobile telephony technology and internet access services during those years.[5] The deflators of the components of communication services for mobile phone service and Internet access service do, however, fall a bit more rapidly, with growth rates of -1.6 percent and -2.1 percent, respectively.

Greenstein and McDevitt (2009) estimated that the switch from dial-up Internet service to broadband generated unmeasured increases in consumer surplus of $1 billion per year. Furthermore, quality adjustments to take into account of factors such as increased speed of Internet access, increased convenience of accessing the Internet via devices like smartphones and tablets, increased numbers of webpages that can be accessed would imply significantly faster volume growth for communication services than the official measures. Nevertheless, the volume growth rates for mobile phone service and Internet access service in the personal consumption expenditures component of the NIPAs are already fairly large, at 8.4 percent per year and 14.5 percent per year, respectively.

The weight on communication services in the output of the U.S. business sector is relatively small. Taking account of the small weight, Byrne, Fernald and Reinsdorf, 2016 find that a

[5] Under certain assumptions (detailed in Oulton 2012) the difference between the general inflation rate and the price index for a particular product will reflect the relative productivity growth in the production of that product.

plausible estimate for the effect of mismeasurement of communication services growth on labor productivity growth in 2004-2014 is just 0.04 percentage points.

Communications services also raise the question of the consumer surplus generated by smartphones appearing as a new good. A conceptual measure of the consumer surplus from a new good can be derived by assuming that the good was previously available at a high virtual price that caused demand to equal 0 and calculating the area under the demand curve from the virtual price down to the price at which the good first began to be purchased. The rapid take up of accessing the Internet via a smartphone suggests that the surplus from this new good is high. Incorporation of consumer surplus from being able to browse the web from a smartphone might therefore imply significantly higher volume growth and significantly lower price group for communications services as an aggregate. Nevertheless, it has long been recognized that the gains to consumers from new goods that are completely novel are not feasible to include in the CPI or GDP growth statistics.[6] Thus the omission from the growth statistics of the consumer surplus from the invention of a new good such as mobile phones that can be used for web browsing is just a recent example of a longstanding limitation in what is feasible to measure.

Implications for labor productivity

Even though the upward bias in the deflator for computers and peripherals was becoming larger as the productivity slowdown began, by that time, imports had displaced a considerable part of ICT production in the U.S. The drop in the weight makes the impact of mismeasurement of computers and peripherals on the estimates of labor productivity growth for the U.S. business sector smaller during the productivity slowdown period than in the period of strong productivity growth.

Figure 3 summarizes the adjustments to official measures of labor productivity growth calculated in Byrne, Fernald and Reinsdorf (2106) in three periods, 1978-1995, 1995-2004, and 2004-2014. The solid portions of the bars show the official data on average growth in U.S. business-sector labor productivity. As shown by the shaded portions of the bars, the adjustments have only a small effect on the size of the productivity slowdown, and that effect is in the wrong direction if the goal is to explain the slowdown.

The alternative deflators for computers and communication equipment of Byrne, Fernald and Reinsdorf (2016) raise the average growth rate of the value added of private business in 2004-2014 by just 0.13 percent per year, less than the effect of 0.27 percent per year in 1995-2004. These figures become 0.19 and 0.38 percent per year, respectively, when specialized computer equipment and software are also included. Using the alternative software index calculated by

[6] Indeed, Keynes wrote about the impossibility of quality adjusting the motor car and the cinema to allow price comparisons with older goods. For background on how consumption volume indexes reflect the changes in consumer surplus and an extension of this result to the appearance of a new good see the appendix.

Byrne and Corrado (2016) would raise the effect in 2004-2014 to around 0.24 percent per year. Finally, adding the small adjustments for Internet access services discussed above gives cumulative totals of 0.28 for the adjustments to measured productivity growth in 2004-2014 and 0.39 for the adjustments for 1995-2004.

The shaded regions of the bars in Figure 3 also contain some additional adjustments to productivity growth made by Byrne, Fernald and Reinsdorf (2106). Two of them have no direct relationship to problems in measuring the digital economy. First, broadening the definition of investment to include the intangible assets studied by Corrado, Hulten, and Sichel (2009) adds about 0.1 percentage point to growth in the 1995-2004 period, but has no effect thereafter because investment in these intangibles grows at the same rate as measured output after 2004. Second, correctly accounting for fracking (a technology for extracting gas or oil from "tight" formations) would plausibly add about 0.05 percentage points to U.S. productivity growth in the post-2004 period and an insignificant amount to the 1995-2004 period. Adding 0.05 percentage points to the adjustment in 2004-2014 bring the cumulative total up to 0.33 percent per year, while adding 0.1 percentage points to the adjustment for 1995-2004 brings it up to 0.49 percent per year.

Two additional effects included in the "other" category of Figure 3 are globalization, and free digital entertainment and information services such as Facebook. The discussion below will take a broader approach to these issues than was taken in Byrne, Fernald and Reinsdorf (2016).

Globalization

Reinsdorf and Yuskavage (forthcoming) find that offshoring of production from the U.S. to emerging market economies including China resulted in unmeasured price declines for intermediate inputs that artificially boosted U.S. productivity growth figures in the years before the Financial Crisis. This may have added 0.1 percentage points to the measured growth rate of labor productivity in those years, implying the negative adjustment in 1995-2004 in Figure 3 and returning the cumulative total of the adjustments for 1995-2004 to 0.39 percent per year.

Recently attention has shifted to a different kind of measurement problem connected to globalization. Global value chains, in which the production process for digital devices is fragmented into steps done in multiple countries, create opportunities for MNEs to shift income between jurisdictions for tax optimization purposes. But intellectual property assets such as patents, trademarks and R&D, which play large roles in the design, manufacturing and marketing of digital products, seem to create the most important opportunities for tax optimization. A multinational enterprise (MNE) may allow an offshore affiliate in a tax-advantaged location to purchase the intellectual property assets of the parent at a low price, or the affiliate may acquire the intellectual property assets by sharing in the cost of their development. The output associated with the use of the intellectual property assets is then recorded in the low tax jurisdiction, not the country where the intellectual property was originally created.

Ireland may have furnished an illustration of this sort of problem from the side of the host country for the intellectual property last July, when it released its GDP figures for 2015. Irish GDP grew by an astounding 26.3 percent. Burke-Kennedy (2016) attributes this jump largely to the movement (on paper, at least) of intellectual property or other operations into Ireland by Apple.[7] Ireland also recorded a 46.6 billion euros increase in current price net exports, some of which appears to represent contract manufacturing arrangements treated as "factoryless goods production". In a tax case against Ireland, the European Commission has alleged that up to 2014, at least for tax purposes, most of Apple's profits from sales of its products in a Europe, the Middle East, Africa and India were attributed to a "head office" that was not located in any country (European Commission press release 30 August, 2016). In 2011 the income allegedly attributed to this "head office" was about $22 billion.

MNEs involved in digital, pharmaceutical and other kinds of industries may be attributing production to special purpose entities in low tax jurisdictions that actually occurs in the US and other advanced economies. Rassier (2014) finds that an alternative way of measuring the geographic distribution of the output of MNEs based on where their assets and employees are located raises the estimate of U.S. GDP by an average of 0.9 percent in 2005-2009.

The size of this distortion appears to have grown during the period of the productivity slowdown. Suppose that the average growth of the amount of missed output is equal to a twelfth of the level that had accumulated by the time period analyzed by Rassier (2014) and that all of this growth can be assigned to the business sector for which productivity is measured, which amounts to a bit less than 75 percent of GDP. The growing amount of U.S. output misreported as produced in offshore locations would then cause a drag on the measured growth rate of labor productivity of around 0.1 percent per year (calculated as (0.9/12)/0.75). This effect may have slowed after 2009, so a more conservative estimate seems appropriate. A downward bias of 0.05 percentage points in the measured growth rate of labor productivity from the growing misreporting of the location of production seems plausible.

A distortion in the reported location of ITC production also has implications for the weights on the alternative deflators for ITC goods. This effect depends on the level, rather than the growth, of the U.S. production attributed to offshore locations. The finding in Byrne, Fernald and Reinsdorf (2016) of a tiny effect mismeasurement of the deflator for computers and peripherals on estimates of U.S. productivity growth in 2004-2014 hinges on the declining weight. (The weight on computers and peripherals was 0.5 percent in the 2004-2014 period, compared with 2.9 percent in 1995-2004.)

Rassier's estimate of 0.9 percent of U.S. GDP that is reported as occurring in other locations included non-ICT industries, so only a portion of it involves products with mismeasured

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[7] Airplane leasing and corporate inversions by U.S. pharmaceutical companies are also thought to play a role in the jump in Irish GDP.

deflators. The U.S. production of computers and peripherals that is reported as occurring in offshore locations may be large enough to raise the weight on output of private business during the slowdown period by 0.4 percentage points. The corrected deflator for computers and peripherals of BFR (2016) has a growth rate that is 12 percentage points lower than the official deflator in 2004-2014, so a correction to their weight of 0.4 percentage points would amplify the effect of correcting the deflator by enough to add about 0.05 percent points to downward bias in productivity growth during the slowdown period. Adding this to the estimate of 0.05 percentage points for the direct effect of the growth in the amount of U.S. output attributed to offshore locations, the total effect of this globalization-related distortion on productivity growth could therefore be 0.1 percentage points during the slowdown period. The cumulative total of the adjustments to productivity growth for the 2004-2014 period therefore rises from 0.33 to 0.43 percent per year.

Of course, similar effects also occurred before 2004, but they were smaller. If in 1995-2004 the effects of shifting income between jurisdictions caused a downward bias of 0.04 percent per year in the measured productivity growth rate, the cumulative total of the adjustments for measurement problems in that period would also equal 0.43 percent per year. The effect on the magnitude of the productivity slowdown of adjustments for mismeasurement would then be exactly zero.

Internet-based Digital Services

The ICT goods and software with potentially biased deflators are not the only digital products that figure in the debate over the role of mismeasurement in the productivity slowdown. Digital products made possible by the Internet and smartphones have also been suggested as overlooked sources of growth whose importance grew rapidly in the early and mid-2000s. These new digital services include digital intermediation of peer-to-peer services, e-commerce, free digital entertainment and information services supported by advertising, and low-cost or free smartphone apps (also frequently supported by advertising) that have replaced more expensive products such as navigation systems and cameras.

These products have clearly brought about important improvements in consumer welfare. However, this does not necessarily imply that GDP growth has been underestimated. Ahmad and Schreyer (2016) point out that GDP is not supposed to measure total welfare, and conclude that the existing accounting framework of the *System of National Accounts 2008* (SNA) remains adequate to handle these new digital products. The sources of underestimation in GDP therefore come from gaps in the practical estimation techniques that capture the values, prices and volumes of the existing conceptual framework.

Furthermore, Byrne, Fernald and Reinsdorf (2016) argue that digital entertainment and information services and smartphone apps have raised households’ productivity in home production, but productivity gains in home production do not belong in the measures of market output covered by our GDP and productivity statistics. Home production of non-market services for a household's own consumption is outside of the production boundary measured by GDP

Peer-to-peer services

As an example of the practical estimation challenges, consider the platforms that intermediate peer-to-peer services. These platforms have created low cost alternatives for local passenger transportation (e.g. Uber), and lodging away from home (e.g. Airbnb) and created new markets for a variety of tasks in the "gig economy" (e.g. Task Rabbit), and for financial services. Issues arise both in measuring the value and in measuring the price and volume of peer-to-peer services. For values, although the intermediation services of the platforms themselves are thought to be well-captured, the household businesses that provide the peer-to-peer services themselves may be missing from the source data used to compile the national accounts. However, in the case of the U.S., the nominal value of the peer-to-peer services generally is counted in GDP because the platforms report to the tax authority the amounts that the households providing the service have earned. Ironically, it may be the intermediation service itself that is under-estimated if the platforms report that their production occurred offshore. Globalization means that we can no longer automatically assume that large enterprises are better measured than the small ones.

A more difficult question in measuring peer-to-peer services is how to incorporate these services into price and volume measures. When the new peer-to-peer services are brought into the CPI it will be likely be by linking them into the index, which is the standard way to handle a new good. The cost savings to consumers from substituting peer-to-peer service providers for traditional service providers will not be reflected in the CPI or in the deflators in the national accounts. Although the size of the bias in the price index may be impossible to estimate, its sign can be presumed to be positive. As a general rule, if a new type of good or service appears in the marketplace and is chosen by large numbers of consumers, we can infer that those consumers who voluntarily switch to it perceive its quality-adjusted price as lower.[8] Nevertheless, failure to capture the consumer surplus from new goods that are quite different from any existing good is not a new problem, nor one that is limited to the digital products. Thus, the overstatement of price growth and the understatement of volume growth associated with the appearance of widely used peer-to-peer services that cannot be compared with a pre-existing service are just recent examples of a problem that has existed since the earliest days of price and volume statistics.

Peer-to-peer local passenger transportation seems to be one case where a price comparison is possible. An Uber ride seems to be sufficiently similar to a taxi ride to compare their prices directly, or perhaps with a quality adjustment for waiting time. (For example, if Uber surge pricing is in effect, and the wait for the taxi is longer Thant the wait for an Uber driver, the wait time difference might need to be taken into account.) Treating peer-to-peer local transportation

[8] In addition, increases in the availability of variety from the emergence of these new services tend to reduce a cost of living index.

services as a perfect substitute for taxi services would probably lower the growth rate of the CPI and raise the growth rate of GDP, albeit by small amounts. For other kinds of new peer-to-peer services, such as Airbnb, estimating the value of the quality differences from a similar service that is already in the CPI or GDP deflator in order to make a quality-adjusted price comparison may be quite challenging.

The weight on local passenger transportation in U.S. GDP is quite small, and the revenue earned by Uber drivers worldwide in 2014 was reportedly around $2.2 billion. Lyft and other competitors in the U.S. are much smaller. If the weight of peer-to-peer local transportation services in household consumption of market goods and services was on the order of 0.03 percent in 2014, it is clear that correcting the deflator for local passenger transport services would have a very tiny effect on estimated productivity growth. Corrections to the GDP volume measures from other kinds of peer-to-peer services are impossible to quantify, but it is safe to presume that they would be small.

E-commerce

E-commerce has grown rapidly in importance, both for business-to-business and business-to-consumer transactions. According to the U.S. Census Bureau's *Monthly Retail Trade Report*, the share of e-commerce in retail sales has risen about 0.5 percentage point a year since 2000—from 0.9 percent in 2000 to 2.1 percent in 2004, 5.3 percent in 2012, and 7.3 percent in 2015.[9] This steady shift in purchasing patterns reflects the gains to consumers in savings of time and transportation costs, as well as their ability to search over a much broader range of varieties. The time savings may be particularly important: recently Wal-Mart in the U.S. has had success with a hybrid form of e-commerce in which customers use an app to place their grocery order and the items are packed and ready to take home when the customer arrives at the store.

Byrne, Fernald and Reinsdorf (2016) estimate an adjustment for the gains to consumers from e-commerce by treating e-commerce as a new variety in Feenstra's (1994) formula for the unmeasured gains from net variety growth. The formula is based on a constant elasticity of substitution model with $\sigma > 1$. Using the Census shares for e-commerce and treating e-commerce as a different variety with $\sigma = 4$, the correction factor for the price index for retail goods falls 0.015 percent per year from 2004 to 2014, compared with 0.008 percent per year from 1995 to 2004. Personal consumption expenditures on goods amount to about 25 percent of the gross value added of business, excluding housing. Using this as a weight on the bias in the retail sales price index implies an upward correction of about 0.04 percentage points to the growth rate of business-sector productivity after 2004 and about 0.02 percentage points to the

[9] The Census Bureau defines e-commerce as purchases made over the Internet or other electronic network or via email. The e-commerce shares for products that are easy to order online (such as books) are even larger, because some products (such as gasoline and building supplies) presumably involve little e-commerce (https://www.census.gov/retail/mrts/www/data/excel/tsnotadjustedsales.xls).

growth rate from 1995 to 2004. Accounting for variety growth from e-commerce would reduce the productivity slowdown by about 0.02 percentage points.

Of course, it is possible that this formula calibrated with the assumption that σ =4 underestimates the gains from e-commerce, but it gives an indication of the likely magnitude of the effect on productivity growth estimates. If the Census Bureau data on e-commerce are accurate, so far the shifts in buying channel have not been large enough to produce a large effect.

Free digital services supported by advertising

The popularity of free digital entertainment and information services supported by advertising, and the high market value of digital platforms such as Facebook and Google have led to renewed interest in a question that was debated in the national accounts literature long ago, when free entertainment from broadcast television had become important (Cremeans, 1980). In the SNA, a media business that gets its revenue from selling advertising is treated as a producer of intermediate inputs consumed by the industries that place the ads.[10] The feeling that this treatment does not fully account for the value of the free entertainment or information provided to households in order to attract an audience has led to proposals for alternative treatments.

In principle, free entertainment or information services that are provided to households by advertising-supported media companies are included in the measures of GPD and household consumption because the cost of the advertisements is included in the price of the advertised product. Households pay for the media services that they consume when they buy the products that are advertised.[11] Nevertheless, the continued interest in alternative approaches shows that many users and compilers of national accounts have doubts about whether the output of advertising-supported media services is being fully captured.

Nakamura and Soloveichik (2015) and Nakamura, Samuels and Soloveichik (2016) argue that the value of the entertainment and information services consumed by households should also be directly included in GDP. To do this, they propose a treatment for media companies in which households implicitly pay for the "free" media services by supplying ad watching services in a kind of barter transaction.

Ravets (2016) discusses two other alternatives for including media services supported by advertising in household final consumption. The first of these is simply to add an estimate of the value of the ad-supported services consumed by households to household consumption and also to the output of media industry. This estimate is obtained by subtracting the cost of producing the

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[10] In 2014 Facebook got over 90 percent of its revenue from advertisers, and Google's parent Alphabet got about 90 percent.

[11] Nakamura, Samuels and Soloveichik (2016) note that some free information services are consumed by other businesses, and some advertising targets businesses, not households. As a simplification, here we assume all the free media services are consumed by households.

services directly used by the ad buyers (selling the ad space, interacting with the ad buyers, and creating and displaying the ad) and an overhead from the ad revenue, leaving the amount that is available to pay for producing the media services. In Ravet's example, this amount exactly equals the cost of producing the media services. The measure of GDP is higher than under the current approach by an amount equal to the extra output of the media services industry. The operating surplus of the media services industry also rises by this amount. The industry's saving does not change, however, because it makes imputed transfers to households, which households use to purchase the media services that they consume.

Nevertheless, Ravet discusses a second alternative that instead treats the cost of producing the media services as a kind of social transfer in kind. In the SNA social transfers in kind consist of goods and services purchased by a government or nonprofit institution serving households and provided to households for free or at an economically insignificant price. An analogous treatment for ad buyers would treat them as purchasing media services for consumption by households. Under this treatment, measured GDP would rise by the same amount as under the first alternative, but the rise in GDP would be due to a reclassification of some of the output currently used for intermediate consumption by the ad buyers as final consumption of households.

Each of these approaches has its weaknesses. Treating households as producers of ad-watching services consumed by the advertisers would open the door to other imputations of household production of services, and usually the consumers of the media services are not obligated to watch the ads as a condition for viewing the content, as would be the case in a true barter transaction.

In the first alternative presented in Ravets (2016), the operating surplus of the media services industry may be viewed as overstated, as the cost of producing the media services is included in the price of the ads and also in household consumption. Nevertheless, if we truly believe that output is understated by the current approach, measuring the value of the services given to consumers by the cost of producing them and adding them to household final consumption would be the most straightforward solution.

The second alternative in Ravets (2016) is subject to a similar objection to the first one, except in this case it is the ad buyers whose operating surplus would be viewed as overstated. An additional problem with the second approach is that raising the consumption of households—which is the motive for a social transfer in kind—is not the objective of the ad buyers.

Nakamura, Samuels and Soloveichik (2016) estimate the impact of their approach on measures of U.S. GDP growth and productivity growth and find that they are tiny. The impact on GDP growth in volume terms between 1998 and 2012 is 0.009 percent per year. (Note that all three approaches have the same impact on GDP growth.) This suggests an effect on estimated labor productivity of private business of slightly more than 0.01 percent per year.

A fourth approach to media services supplied by digital platforms such as Facebook and Google avoids these disadvantages and is consistent with the approach that seeks to recognize the complete set of intangible assets, as discussed in Corrado, Hulten and Sichel (2009). Because of network externalities, familiarity and habit, the user base of digital platforms is often quite sticky. Nakamura, Samuels and Soloveichik (2016) discuss how his has led to the “ubiquity now, revenue later (URL)” model in Silicon Valley. Although business accounting standards generally do not allow customer relationships to be treated as a capital asset, for an economic point of view, an approach to digital platforms with network externalities in which the platform’s user base is a kind of intangible asset would be reasonable.

Nakamura, Samuels and Soloveichik (2016) report that that the combined market value of five leading US social network platforms (Google, Facebook, Yahoo, LinkedIn and Twitter) grew by $600 billion over the ten years ending in 2015. Allowed for the fact that some of this increase in value reflects expenditures already counted as investment in the NIPAs, adding $50 billion per year to investment would, on average, raise the level of gross value added of private business in 2005-2015 by slightly more than 0.4 percent. However, stock market valuations reflect expected future profits from existing products and potential new products than may be launched as ways of leveraging the value of the digital platform. These future profits may include contributions from productivity gains. For productivity analysis, actual amounts invested would, if feasible, be a more suitable basis for measuring investment than changes in enterprise value implied by equity markets. Measured in this way, the effect on output growth of counting investment in the growing the user base as an intangible asset would be smaller than using changes in stock market valuations. But the upward effect would be greater in the period after 2004 than in the productivity speedup period, perhaps reducing the size of the productivity slowdown by as much as 0.1 percentage point.

Another kind of service that is often free because it is supported by advertising is smartphone apps. An estimate of how much money consumers are saving by not having to buy the things that smartphone apps replace would be a useful starting point for estimating their effects on the cost of living and on the measured rate of household consumption volume growth. Of course, consumers would likely consume smaller quantities of these items if they had to pay for them, so the money saved would represent a kind of Paasche bound on the cost of living index and hence would overstate the price decline. Similary, valuing households’ consumption of free services of smartphone apps at the prices that they would have had to pay using the old technology would give a kind of Laspeyres upper bound that would overstate the growth of the volume of consumption. But bounds would at least be a good starting point for understanding these effects.

Conclusion

Mismeasurement has been suggested as the explanation for a significant part of the productivity slowdown reported for the U.S. economy in the years after 2004. Upon investigation, however, the contribution of mismeasurement to the slowdown in labor productivity growth in the US economy turns out to be tiny. The combined effects of mismeasured deflators for ICT products, underestimation of volume growth of communication services and globalization-related distortions caused the same amount of downward bias in the estimated growth rate of labor productivity during the high growth years of 1995-2004 as during the slow growth years of 2004-2014.

The gains from Internet-based digital services that increased rapidly in importance in the early and mid-200s tip the scales towards a small contribution to the productivity slowdown from measurement problems. The effects are much smaller than many have supposed, however. The productivity gains in home production of services for the household's own consumption free digital services have undoubtedly been large. But these productivity gains fall outside the boundary of the market and near-market production measured by GDP, and also outside the boundary of the market output that is the focus of the productivity statistics. Attempts to gauge the plausible size of the gains from the Internet-based services that are relevant for market sector productivity suggest that they are not large. More research would, however, be useful, as would research on measuring the welfare gains from digitization that fall outside the scope of GDP.

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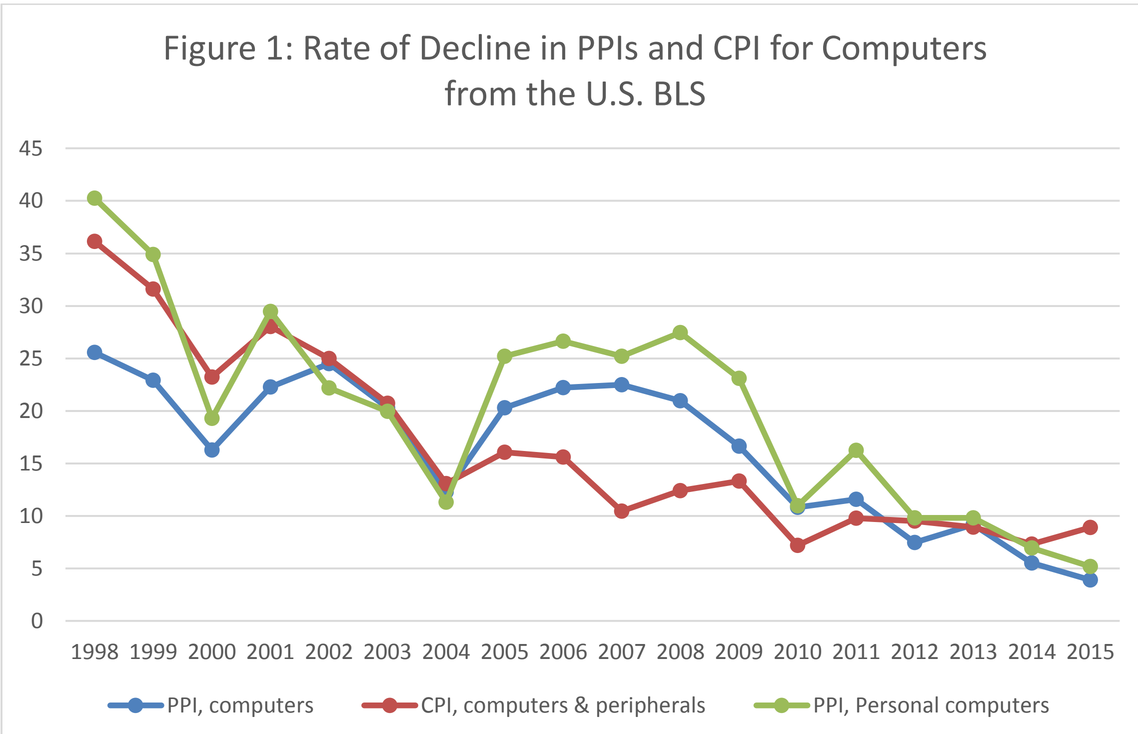


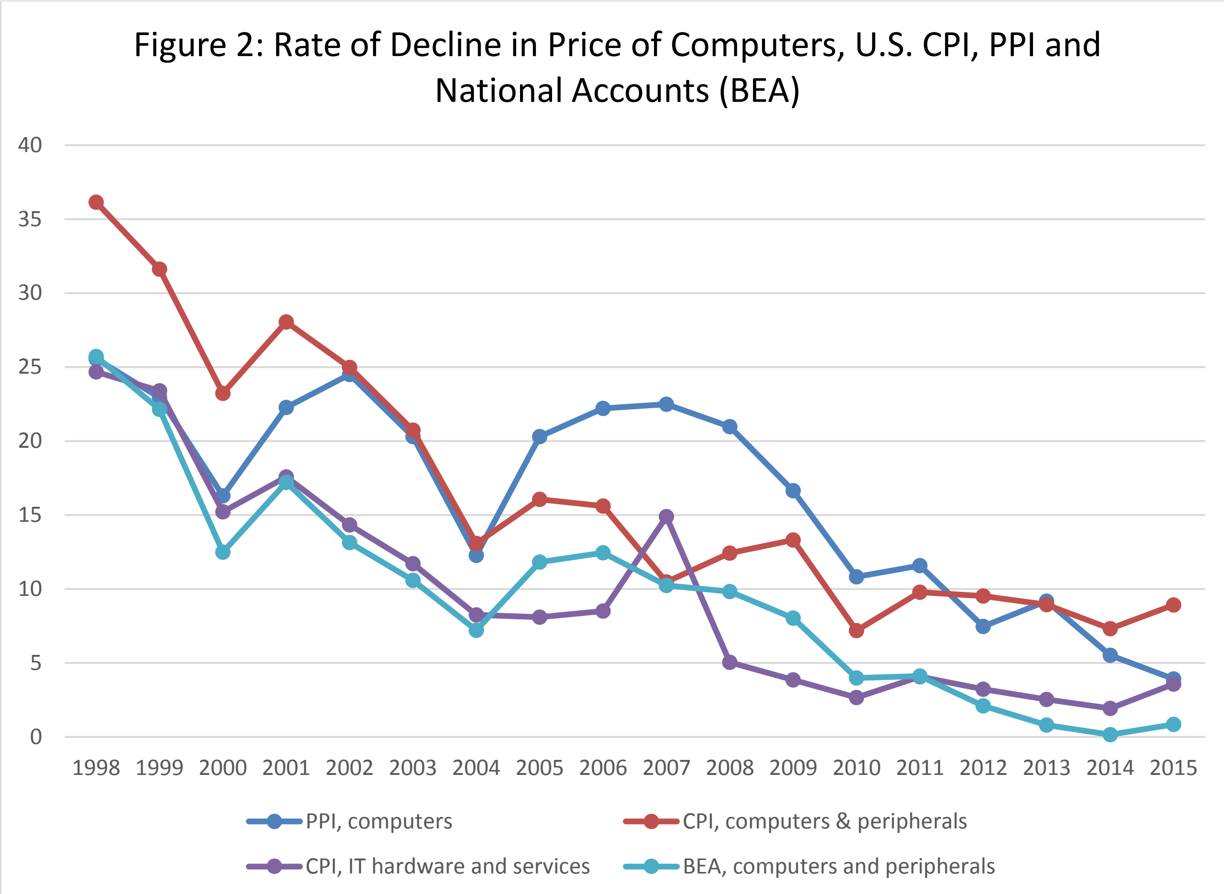
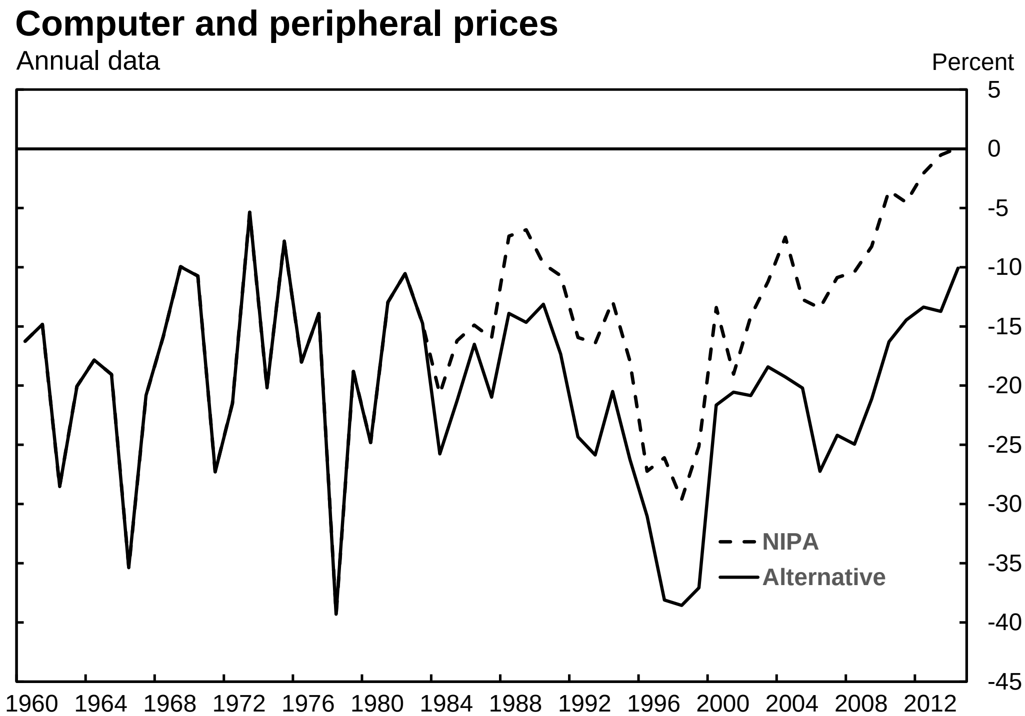


Figure 2: Rate of Decline in Price of Computers, U.S. CPI, PPI and National Accounts (BEA)

Figure 3: Official and Alternative Deflators for Computers and Periphals

(Growth Rates)



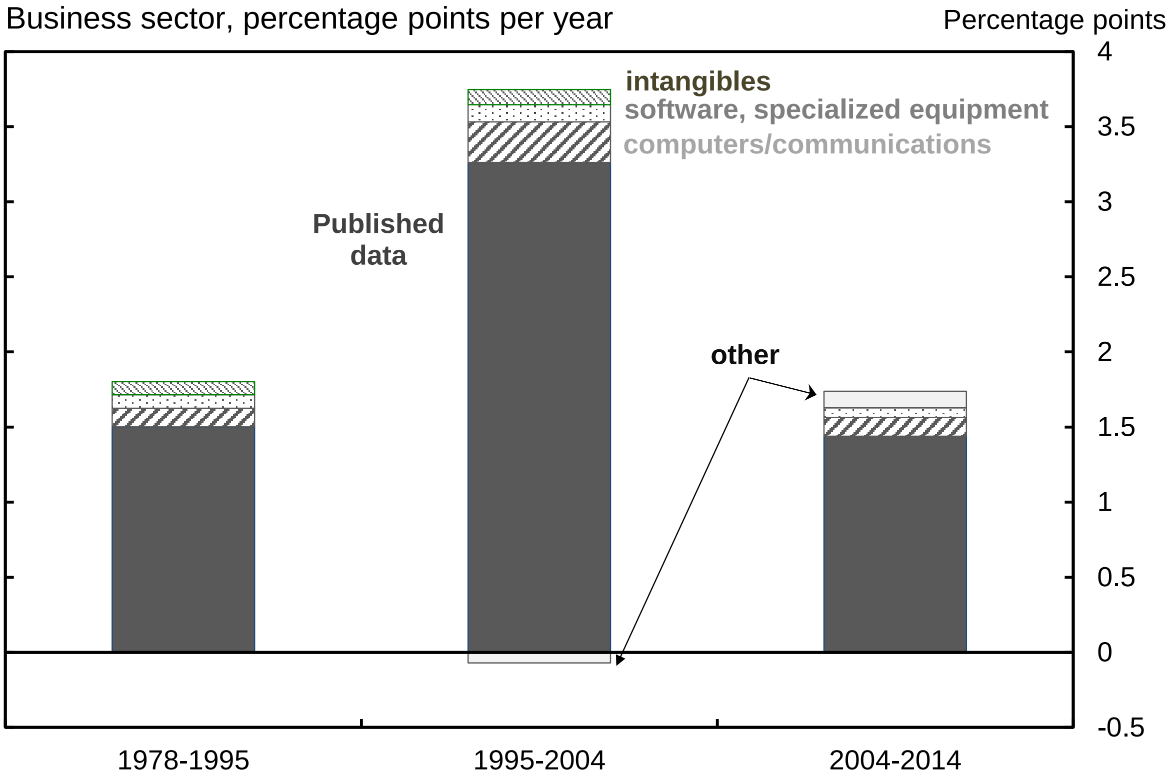
Source: Byrne, Fernald and Reinsdorf (2016)

Figure 4: Official Measures of Labor Productivity and Adjustments to Them[a]

(average annual growth rates)

Adjustments to growth in output per hour

Business sector, percentage points per year



Source: BLS, Fernald (2014a), and authors' calculations. Other comprises Internet, free digital services, globalization, and fracking.

a. Adjusted measures are from Byrne, Fernald and Reinsdorf (2016)

Appendix: Background on the New Goods Problem

As background on the new goods problem, consider first the standard problem of measuring the change in real consumption when prices and income change but the set of available products stays the same. In this case, the Fisher quantity index used by BEA to measure the change in real personal consumption expenditures (PCE) is an average of upper bound and lower bound measures of the relative change in consumer surplus. A Fisher index is a geometric average of a Laspeyres index and a Paasche index. Letting the $e(\mathbf{p},u)$ be the expenditure function, the equivalent variation measure of consumer surpus is $EV = e(\mathbf{p}_0,u_t) - e(\mathbf{p}_0,u_0)$ and the compensating variation CV measure is $e(\mathbf{p}_t,u_t) - e(\mathbf{p}_t,u_0)$. If $Y_0 = \mathbf{p}_0\,\mathbf{q}_0$ is total expenditures in period 0, the change in the Laspeyres quantity index is an upper bound on EV/Y_0:

$$\frac{\mathbf{p}_0\mathbf{q}_t}{\mathbf{p}_0\mathbf{q}_0} \geq \frac{e(\mathbf{p}_0,u_t)}{e(\mathbf{p}_0,u_0)}$$

$$= 1 + \frac{EV}{Y_0}$$

Similarly, the change in the Paasche quantity index is a lower bound to $CV/(Y_t - CV)$:

$$\frac{Y_t}{Y_t - CV} = \frac{e(\mathbf{p}_t,u_t)}{e(\mathbf{p}_t,u_0)}$$

$$\geq \frac{\mathbf{p}_t\mathbf{q}_t}{\mathbf{p}_t\mathbf{q}_0}$$

Although real PCE generally does not measure the total consumer surplus from consumption of a good, when a new good first becomes available the change in consumer surplus is relevant for measuring the change in real consumption.[12] The theoretical measure of the change in the real consumption imagines that just before the new good entered, it was offered for sale at the "virtual price" that just drove demand to zero. The area under the demand curve from the virtual price down to the actual price of the good after it entered then defines the consumer surplus that is used to measure the gains from the entry of the new good. The gains to later adopters, whose willingness to pay is bounded by a previous actual price that they chose not to pay, can be measured by a chained superlative price index such as the Fisher index. For example, using this sort of approach to analyze growth of broadband access services, Greenstein and McDevitt (2009) estimate that the uptake of broadband between 1999 and 2006 generated $4.7 to $6.8

[12] Measuring gains in consumer surplus when new goods appear (and also of losses when existing goods vanish, as the approach would have to be applied in a consistent way) would probably not be feasible for a statistical agency to do in real time, and the estimates might also be unacceptably sensitive to choices of approach and assumptions.

billion in consumer surplus, an amount equal to about 0.07 percent of the value added of business.

If information is costless, so that consumers learn about the advantages of the new good quickly, the gains that need to be measured based on the fall from a virtual price to an actual price will be confined to the first year or two after the good becomes available. On the other hand, if costly information slows the adoption of the new good, bringing the new good into the chained superlative index quickly may be insufficient to capture all of the gains. Nevertheless, it is often reasonable to presume that for most new goods, the unmeasured consumer surplus related to market production are confined to the first few years.