COMMENT BY

ROBERT J. GORDON  The slow productivity growth since 2004, particularly since 2010, represents one of the outstanding economic puzzles of our time. It implies slow current growth of potential real GDP. If it continues, it implies slow future growth of potential GDP and fewer resources to address the nation’s problems, including education, infrastructure, and the looming shortfalls in funding for Social Security and Medicare. It would be reassuring for puzzle solving, although disconcerting for the integrity of the nation’s statistical system, to learn that the entire post-2004 or post-2010 slowdown in productivity growth was due to well-identified errors in measurement, and that the underlying “true” rate of productivity growth has not decelerated at all.

THE QUESTIONS TO BE ADDRESSED  This paper by David Byrne, John Fernald, and Marshall Reinsdorf places its main emphasis on the post-2004 productivity growth slowdown and highlights the $3 trillion in additional business sector real GDP that would have been produced in 2015 if the productivity growth rate of 1995–2004 had continued after 2004. But the post-2004 slowdown is not the only productivity puzzle to be explained. My figure 1 displays the five-year moving average growth rate of quarterly utilization-adjusted total factor productivity (TFP) growth going back to 1952. This data plot identifies four separate eras of TFP growth—consistently rapid, at about 2.0 percent a year, through 1973; then slower and erratic, in the range of 0 to 1.5 percent, from the early 1970s through the mid-1990s; then healthy again for a decade between 1995 and 2004; and finally a sharp slowdown, to about 0.5 percent a year, during most of the past decade.

Average TFP growth rates over selected periods are listed in my table 1. The first two rows contrast the 26 years from 1947 to 1973 with the 42 years since 1973. When the postwar era is divided at 1973, the TFP growth rate slows by more than half, from 2.10 to 0.82 percent a year. This sharp contrast poses the first productivity puzzle: What caused the post-
1973 slowdown? The next three rows divide up the post-1973 interval at 1995 and 2004. The TFP growth rates for 1973–95 and for 2004–15 are almost identical, at about 0.5 percent, in sharp contrast to the growth rate of almost 2.0 percent achieved between 1995 and 2004. This leads to the second puzzle: What caused TFP growth to revive? And to the third puzzle: Why was that revival only temporary? The final two rows of my table 1

<table>
<thead>
<tr>
<th>Period</th>
<th>TFP growth (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1947:Q2–1973:Q1</td>
<td>2.10</td>
</tr>
<tr>
<td>1973:Q1–2015:Q4</td>
<td>0.82</td>
</tr>
<tr>
<td>1973:Q1–1995:Q1</td>
<td>0.52</td>
</tr>
<tr>
<td>2004:Q1–2015:Q4</td>
<td>0.48</td>
</tr>
<tr>
<td>2004:Q1–2010:Q1</td>
<td>0.73</td>
</tr>
<tr>
<td>2010:Q1–2015:Q4</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Source: Federal Reserve Bank of San Francisco (http://www.frbsf.org/economic-research/indicators-data/total-factor-productivity-tpf/).
divide the 2004–15 era in early 2010 and show that TFP growth during the 2004–10 period was slightly faster than from 1973 to 1995, but during the 2010–15 period was somewhat slower.

This alternation between relatively fast and relatively slow TFP growth over the four eras of the postwar epoch places a broader perspective on Byrne, Fernald, and Reinsdorf’s topic of mismeasurement. Techniques of measurement have been relatively constant since 1947, and thus it is implausible to argue that the slowdown from the first era (1947–73) to the second era (1973–95) happened because measurement became worse by an average of 1.5 percentage points a year. In the same way, it is implausible to argue that the revival to the third era (1995–2004) occurred because measurement became better, at a rate of 1.5 percent a year. Likewise, it is implausible to argue that the slowdown to the fourth era (2004–15) occurred because measurement once again became worse, at a rate of 1.5 percent a year, as had occurred previously, after 1973. These alleged appearances and disappearances of measurement errors of 1.5 percent a year in both directions are implausible, because measurement techniques were relatively constant across the four postwar eras.

MEASUREMENT ERRORS HAVE DIMINISHED IN IMPORTANCE IN THE MARKET ECONOMY Byrne, Fernald, and Reinsdorf place their primary emphasis on the measurement of the private business economy. Their main focus is on mismeasurement in the form of biased deflators for information and communication technology (ICT) equipment in the National Income and Product Accounts (NIPA). They survey recent research on the prices of ICT equipment and conclude that the NIPA deflators systematically understate the rate of decline in the quality-adjusted prices of ICT equipment and thus understate the rate of growth of real ICT investment as well as real GDP and labor productivity. TFP is affected less, because the use of improved deflators not only raises real GDP growth but also raises the growth rate of capital input that is subtracted from output in the calculation of TFP.

However, this price index bias does not help at all in understanding the post-2004 productivity growth slowdown, because the price index bias is roughly constant both before and after 2004. The difference between the rate of change of the authors’ liberal ICT price index and the corresponding NIPA index is −5.1 percent a year during the period 1995–2004 and an almost identical −4.5 percent in 2004–14. Both the liberal index and the NIPA index exhibit a sharp deceleration in the rate of the price decline after 2004, which points to a declining rate of technological improvement in ICT equipment as a substantive reason for the productivity growth slowdown.
The constant post-2004 price index bias is not the end of the story, however, because the relative importance of ICT equipment in the economy has changed in two ways. First, ICT investment is a smaller share of GDP. Comparing the two years 1999–2000 with 2014–15, the GDP share of information processing equipment declined from 2.77 to 1.79 percent, and that of computers and peripherals fell fully by half, from 1.00 to 0.45 percent. When combined with the relatively constant pre- and post-2004 price index corrections, the shrinking ICT shares imply that the price index bias for GDP and labor productivity became smaller after 2004.

The second reason why the price index bias has become less important stems from a sharp shift of ICT investment from domestic production to imports. My figure 2 exhibits the startling shift in computer purchases—from 17.8 percent imported in 2002 to an average of 87.9 percent imported in 2011–13. Consider the implications of the extreme case in which all ICT equipment is imported. An upward price index bias for imported computers would lead to an understatement of the growth rate of both computer investment and computer imports, netting out to zero impact on GDP and labor productivity. The understatement of growth in capital input, however, would lead to an overstatement of TFP growth. Thus the shift to computer imports in the last decade has caused true TFP growth to slow down more since 2004 than in the official NIPA data. This tendency has been exacer-

Figure 2. Import Penetration of Computer Equipment Investment, 2002–13

![Graph showing the import penetration of computer equipment investment from 2002 to 2013.](source: Byrne and Pinto (2015).)
bated by the fact that the price indexes for imported computers used in the NIPA decline at a substantially slower rate than the deflators for domestically produced computers, whereas the observed shift of computer purchases to imports suggest the opposite—that the true prices of imported computers have declined faster than prices of domestic production.

These two factors, the declining share of ICT investment in GDP and the shift to imports, together with the substantial upward bias in the price index for imported computers, suggest that since 2004 measurement issues have caused the poor performance of TFP growth to be even worse in reality than in the government’s statistics. Byrne, Fernald, and Reinsdorf’s treatment concludes, in the third column of their table 2, that measurement errors cause labor productivity growth to be understated by 0.49 percentage point for the period 1995–2004 and by 0.18 point for 2004–14, for a net measurement improvement of 0.31 percentage point. Because of offsetting adjustments to output and capital input, the effect on TFP growth is much smaller and goes in the opposite direction, with measurement errors causing TFP growth to be overstated by 0.08 percentage point during 1995–2004 and by a slightly greater 0.12 percentage point during 2004–14. The conclusion is that improved measurement causes the post-2004 slowdown in both labor productivity and TFP growth to become even worse than in the official data.

These important conclusions of Byrne, Fernald, and Reinsdorf’s analysis combine an upward bias in the price indexes of computers with a shrinking share of computer investment and of the domestic production share of computer equipment. If this upward price index bias were larger, their conclusions would be magnified. In his important historical study of the price indexes of computers, William Nordhaus (2007, table 10, p. 153) concludes that the price of computer power during the 1990–2002 period decreased at an annual rate of −57.5 percent, as compared with Byrne, Fernald, and Reinsdorf’s alternative price index for computers and peripherals in their table 1, which declines at a much slower annual rate of −27.3 percent during the 1995–2004 period. Though there are conceptual differences between Nordhaus’s performance-based measure and Byrne, Fernald, and Reinsdorf’s hedonic price indexes, Nordhaus’s index has the advantage that it includes data for both mainframe and personal computers, whereas Byrne, Fernald, and Reinsdorf’s indexes for the 1990s are based only on personal computers. Compared with mainframes, personal computers achieve a much lower price per calculation, and thus the transition from mainframes to personal computers that took place in the 1980s and 1990s reduced the average price per calculation more rapidly than the
price decline for personal computers alone.\textsuperscript{1} To the extent that Nordhaus’s (2007) approach is a better guide to the overall price behavior of computer investment in the 1990s, there has been an even greater tendency for official data to understate that rapid growth of labor productivity during the 1995–2004 period and to understate the true decline in its growth rate since 2004.

**THE WELFARE EFFECTS OF FREE INTERNET CONTENT** Free Internet information was available both before and after the 2004 transition from fast to slow productivity growth. The proportion of American households connected to the Internet rose from 5 percent in 1995 to 56 percent in 2004, followed by a more gradual increase to 75 percent by 2013 (Gordon 2016, figure 13-4, p. 455). The mismeasurement hypothesis refers to the difference in the welfare benefits from free Internet content available after 2004, as compared with before 2004. An aspect of the post-2004 improvement is the transition from dial-up to broadband access; the proportion of households with broadband increased from 3 percent in 2000 to 29 percent in 2004 and to 65 percent after 2009 (Gordon 2016, figure 13-5, p. 455). Thus, even if the same amount of time were spent on Internet access before and after 2004, there was a quality change in the form of much faster response times made possible by the spread of broadband. Byrne, Fernald, and Reinsdorf recognize that download speed is not considered a quality change in current deflators for Internet access, but they assert that “only a small amount of extra digital service output is missed.”

Most of Byrne, Fernald, and Reinsdorf’s treatment of free digital services refers to their role in the market economy. The authors consider alternatives to the current national accounts treatment of advertising-supported media as an intermediate good. Even when free Internet services and other forms of entertainment are treated as final consumption, their role in the market economy can be no larger than their advertising revenue. Because total advertising revenue from all sources, including television and print media, amounts to only 1.3 percent of GDP, and because real advertising revenue has grown faster than business sector GDP by only a small margin, the authors find the impact of free Internet services on market GDP to be close to zero. Intuitively, the growing advertising revenue of Google and Facebook is largely canceled out by the decline in advertising revenue from older forms of media, particularly print publications.

\textsuperscript{1} Nordhaus (2007, p. 155) provides an example of a 2002 IBM supercomputer that had a price-per-performance ratio roughly 34 times higher than a typical Dell personal computer in 2004.
Advocates of the mismeasurement hypothesis have in mind the broader scope of free Internet services as a source of increased consumer welfare, going well beyond market GDP. They point to the rapid increase in Internet usage, particularly of mobile services accessed on smartphones and tablets, as a focus of consumers’ leisure-time activity. How important is the increase in consumer welfare resulting from increased Internet use? More than one-third of the U.S. population uses Facebook, and the time each day that its users devote to Facebook reached 50 minutes in 2015 (Stewart 2016). Taken together with other Internet services, most notably YouTube and Google, total daily time devoted to the Internet has been estimated at two hours (Karaian 2015). By comparison, the American Time Use Survey (ATUS) reports that in 2014 Americans on average spent 2.8 hours a day watching television. A problem with the estimation of consumer surplus is that the ATUS does not report on Internet usage as a separate category, with the exception of “household and personal e-mail and messages,” which accounted for a trivial 0.03 hour per day. Some mobile phone usage may occur during the ATUS category of time devoted to “socializing and communicating” (0.71 hour per day). Otherwise, the omission of Internet usage could imply that multitasking is the standard mode of behavior, with mobile phones accessed while watching television, eating meals, riding public transit, or standing in line.

To assess the consumer welfare aspects of free Internet services, Byrne, Fernald, and Reinsdorf develop an explicit model based on Gary Becker’s (1965) theory of the economics of time, in which total consumption is subject to both a monetary and time budget constraint. However, they do not provide their own estimates of the time value of free Internet services, relying instead on a paper by Erik Brynjolfsson and Joo Hee Oh (2014) that values the incremental consumer surplus from free digital services as “equivalent of adding about 0.3 percentage point per year to business sector output.” Note that this addition of 0.3 percentage point exactly cancels out the authors’ estimate in their table 2 that the post-2004 decline in business sector labor productivity has been understated by the same 0.3 percentage point a year.

Is this estimate too large or too small? Chad Syverson (2016) provides a survey of different approaches to measuring the consumer surplus of the Internet and compares the resulting surplus estimates to the total missing annual output from the post-2004 productivity slowdown, which he

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estimates, like Byrne, Fernald, and Reinsdorf, to be about $3 trillion in 2015. Most of the literature surveyed by Syverson provides surplus estimates of about $100 billion a year, a trivial fraction of the missing $3 trillion. But one approach developed by Austan Goolsbee and Peter Klenow (2006), when updated by Syverson’s numbers, yields a post-2004 incremental surplus estimate of $842 billion, almost one-third of the missing $3 trillion. This one-third translates into 0.6 percentage point of the total post-2004 slowdown of 1.8 percentage points in the growth rate of business sector productivity. How reasonable is this estimate?

Applying $842 billion to the 80 percent of the population with broadband access yields an annual per capita sum of $3,300. If incremental post-2004 Internet usage, compared with the use of the Internet before 2004, is one hour per day, this would imply an Internet value of $9 per hour. This compares with Syverson’s (2016) estimate of the average 2015 after-tax wage of $22. The difference between $9 and $22 makes sense, because it reflects the fact that only half the population is employed, and the leisure time spent on the Internet is inframarginal. The use of one hour per day in this calculation, rather than the two hours reported as average daily Internet use, reflects not only the fact that some time was allocated to the Internet before 2004 but also the multitasking implied by the ATUS time allocation. Much if not most Internet use, according to the ATUS, is not occurring during hours of leisure that previously had zero value, but rather as multitasking during hours that previously had value obtained from socializing or watching television.

Therefore, Byrne, Fernald, and Reinsdorf appear to be too dismissive of the consumer surplus contributed by free Internet services. Their estimate, taken from Brynjolfsson and Oh’s (2014) findings, values incremental post-2004 Internet services as worth 0.3 percent of business sector output per year, just enough to offset the authors’ table 2 estimate that the decline in the growth rate of business sector productivity has been understated by the same 0.3 percent per year. In contrast, Syverson’s (2016) approach values the consumer surplus at 0.6 percent per year, twice as much. This is enough to offset the 0.3 percentage point measurement understatement from the authors’ table 2, as well as contributing an additional 0.3 percentage point consumer surplus bonus that provides a partial counterweight to the overall 1.8 percentage point productivity growth slowdown. The relatively large size of this Internet valuation naturally leads to the question of how much consumer surplus was contributed by inventions in the past, including the value of free Internet services introduced in the 1995–2004 decade, such as e-mail, search engines, Wikipedia, and the early phase of e-commerce
provided by Amazon, iTunes, and airline websites. The technique of multiplying hours of leisure by an hourly value based on the wage rate would yield a particularly large value of incremental consumer surplus in the early 1950s, as free television broadcasts reached almost every home between 1950 and 1955.

History is full of examples of added consumer surplus that was not included as an increase in GDP. During the period from 1900 to 1940, as motor vehicles replaced horses, real GDP did not value the removal of horse droppings and urine from city streets and rural highways. And real GDP did not value the increase in speed and load-carrying capacity made possible by automobiles, nor their flexibility, which gave birth to a new industry called “personal travel.” Moreover, real GDP did not value the increase in consumer surplus as clean running water arrived at the in-home tap and replaced the previous need to carry pails of water into the house from nearby wells or streams. Finally, real GDP did not value the replacement of the outhouse and the need to physically dispose of human waste with the silent efficiency of public sewers. Running water, the electric washing machine and refrigerator, the automobile, and all the other inventions of the late 19th and early 20th centuries are linked into the GDP statistics, which means that zero value is placed on their invention. Real GDP did not value the reduction of infant mortality from 22 percent of new births in 1890 to about 1 percent in 1950. By some estimates, this change created more welfare value than all the other sources of increased consumer welfare taken together.

CONCLUSION Because newly invented products and services have always provided consumer surplus that supplements growth in real GDP by unknown amounts, the authors of this paper are correct to focus their main attention on the measurement issues that arise in the private business sector of the market economy. They convincingly demonstrate that the post-2004 slowdown in the growth rate of labor productivity and TFP has not been due to measurement errors. On the contrary, because the most evident source of measurement bias is in the price indexes for ICT equipment, the understatment of business sector output and productivity was greater in the 1995–2004 period than in the 2004–15 period, both because ICT investment was a greater share of GDP and because a much greater share of ICT equipment was manufactured in the domestic economy, whereas after 2004 there was a sharp increase in the share of such equipment that was imported. The authors thus conclude that the post-2004 slowdown is real. I agree with their interpretation that after 2004, productivity growth returned “back to normal,” to a rate roughly the same as that achieved between 1973
and 1995, and that the burst of faster productivity growth between 1995 and 2004 reflected a one-time-only conversion of the economy to a modern world whose ICT equipment and software replaced the previous world’s typewriters, calculating machines, and file cabinets.

REFERENCES FOR THE GORDON COMMENT


Karaian, Jason. 2015. “We Now Spend More Than Eight Hours a Day Consuming Media.” *Quartz*, June 1.


GENERAL DISCUSSION Dan Sichel commended the paper for making a good case that mismeasurement in the technology sector is not the right way to understand the productivity slowdown, as the paper convincingly shows that there has not been either (i) a big shift in shares toward the unmeasured or quality-measured sectors, or (ii) a really big step up in the amount of mismeasurement, what he called the “ingredients” of the mismeasurement story. However, he expressed concern that a casual reader might come away with the wrong impression. In particular, while mismeasurement is not a good explanation for the productivity slowdown,