

Productivity, Prices, and Measurement

**Robert J. Gordon
Northwestern University and NBER**

**For Presentation at Boskinfest,
Stanford University,
October 2, 2015**

1. Introduction

The slow pace of the post-2009 economic recovery has continued to frustrate the Fed and other makers of economic policy. In the six years between the business-cycle trough in 2009:Q2 and 2015:Q2, GDP growth averaged only 2.1 percent per year. Despite this slow growth of output, the unemployment rate has declined steadily from its peak of 10.0 percent in October, 2009, to its recent 5.1 percent rate in August, 2015. The mediocre growth of actual output together with steadily declining unemployment implies that growth in potential output must have been much slower than the actual growth rate, and this in turn is explained by a combination of declining labor-force participation and slow productivity growth. In the five years ending in 2015:Q2, growth in output per hour for the total economy was only 0.5 percent per year.¹

The frenetic current pace of innovation, as evidenced by the continuing creation of billion-dollar “unicorn” companies, contrasts with this dismal record of productivity growth. This contrast evokes at least two possible interpretations. The first, recently put forth by Jan Hatzius and Kris Dawsey (2015) of Goldman Sachs, is that the slowdown is a measurement illusion, due to price index bias that has caused a much larger share of true productivity growth to be missed by the statistical agencies than was true in the past. The second interpretation, which I tend to favor, interprets the recent slowdown in productivity growth as a substantive reality, part of a longer-term process that has been underway since the 1970s. Understatement of growth in productivity and output growth is nothing new. Growth in “true” productivity growth has always been faster than that of measured productivity growth, primarily because the Consumer Price Index (CPI) has always suffered from an upward bias due to substitution, outlet, new product, and quality change bias. The question is whether these sources of bias are now greater or less than in the past.

This paper takes a long-run perspective to the issue of price-index bias and its effects on measured productivity growth. It begins with the official record of postwar productivity growth, with its distinct episodes of rapid and slow growth. It then proceeds in reverse chronological order, contrasting improvements in the CPI that have taken place before and after the Boskin Commission report with the recent accusations that price index bias has greatly increased in magnitude over the past 15 years. It then moves backwards to consider earlier sources of price index bias in the 1990s, in the earlier postwar years, and finally over the long period between 1870 and 1940.

2. The Productivity Record, 1951-2015

¹ Total economy productivity is calculated as the average of GDP and Gross Domestic Income (GDI), divided by total economy hours of work, an unpublished series provided by the Bureau of Labor Statistics.

Productivity growth is quite volatile from quarter to quarter and even from year to year. When smoothed to a 12-quarter moving average growth rate, as in Figure 1, the basic outlines can be seen of the record of measured productivity growth in the total economy. Nevertheless there are still erratic movements connected to the business cycles, particularly those associated with the back-to-back recessions of 1980 and 1981-82. To purge the data of business cycle effects, Figure 2 presents a smoothed version of the total-economy productivity growth rate, using the Kalman filter which extracts from the historical record any changes in productivity growth explained by changes in the unemployment gap.² .

The postwar record as depicted in Figure 2 divides up productivity growth into four eras. First came rapid growth at a rate of about 2.7 percent per year in the 1950s peaking in 1961, and then there was a steady decline in growth between 1963 and 1979. Productivity growth was relatively slow in the range of 1.4 to 1.5 percent until 1996, when a hump-shaped revival brought growth up to a peak of about 2.3 percent through 2006. The final stage has been a sharp slowdown from about 1.6 percent in 2009 to a mere 0.5 percent in 2015. For convenience I refer to the four eras as “fast mid-century growth,” “the first slowdown,” “the dot.com temporary revival,” and “the recent slowdown.”

In recent working papers and in my forthcoming book, I highlight the early growth period of the 1950s and early 1960s as a continuation of rapid productivity growth that characterizes the entire half-century between 1920 and 1970. These 50 years were the period when the inventions of the Second Industrial Revolution (IR #2), particularly electricity and the internal combustion engine, revolutionized production methods throughout the economy. The 1950s and 1960s benefitted from the last stages of the effects of IR #2, in the form of air conditioning, the interstate highway system, and the development of commercial jet air travel. The post-1970 slowdown in productivity growth is interpreted as representing a hiatus after the main effects of IR #2 were in place and the benefits of the digital Third Industrial revolution (IR #3) which became visible in the data after 1996. The impact of IR #3 on productivity growth can be called the “dot.com” revival and was temporary, with the rate of productivity growth falling back in 2007-09 close to the slow pace of 1980-95. Since 2009 the productivity growth trend has steadily slowed. The actual rate of growth of economy-wide labor productivity in the five years ending in 2015:Q2 was just 0.5 percent per year.

A primary focus of this paper is on the slowdown of the last five years as compared to the years of the dot.com revival. If the accuracy of price indexes has improved in the direction of less upward bias, then productivity growth is understated by less in recent years relative to the late 1990s, and the post-2009 slowdown is greater than in the measured data. In contrast if the price indexes have become subject to a greater upward bias, as claimed by Hatzius and Dawsey, then part (or even all) of the post-2009 slowdown in measured productivity growth is

² The unemployment gap is the difference between the actual and natural unemployment rates, where the later is derived in my ongoing research on the U. S. inflation process. This is an updated version of Gordon (2013).

explained by price index error. In the next section we examine the case for improvements in the CPI and subsequently turn to the Hatzius-Dawsey claim that upward bias has increased.

3. Post-Boskin Improvements in the CPI

A detailed evaluation of changes in the CPI is provided in the companion conference paper by Diewert, so here only a few comments are appropriate. Johnson, Reed, and Stewart (2006) reviewed changes in the CPI made in the first decade after the Boskin report. They begin with substitution bias, which had been estimated at 0.4 percent per year in the report, dividing their evaluation into lower-level and upper-level substitution bias. In 1999 the CPI began to use geometric rather than Laspeyres weights to aggregate at the lower level but maintained an experimental Laspeyres index for purposes of comparison. The authors show that the reformed CPI-U with geometric weights increased during 1999-2004 by 0.28 percentage points slower than the experimental index. For upper-level bias the BLS in 2002 introduced a separate chained-weighted CPI after keeping track of its movements in experimental indexes prior to 2002. The chain-weighted index during 1999-2004 increased 0.40 points slower than the CPI-U that continued to maintain fixed weights at the upper level.

However for productivity measurement the introduction of the chained CPI is not relevant, since the productivity data are based on GDP which since 1999 has used chain weights as its method of aggregation and has revised the GDP data to use chain weights all the way back to 1929. In addition to using chain weights, the deflators for personal consumption expenditures (PCE) and for GDP are aggregated using a different set of weights than in the CPI, so that differences between the CPI and PCE deflators reflect more than the effect of chaining. Table 1 exhibits the annual rates of change in the CPI and PCE deflator for time intervals going back to 1982 and also the change for the chained CPI since 2000. The CPI always rises faster than the PCE deflator but by varying amounts – by 0.16 percent in 1982-1990, by 0.69 percent in 1990-2000, and by 0.35 percent between 2000 and 2014. In the final period the PCE deflator rose by 0.10 points less than the chained CPI.

An additional set of CPI improvements updates expenditure weights from consumer expenditure surveys every two years as contrasted with every ten years in the past. Further, the lag time from survey to implementation is shorter. As a result the lag of the CPI behind changes in consumer behavior is much shorter than in the past. Johnson *et al.* report that the updated weights reduced the annual rate of increase of the CPI by 0.06 points relative to the increase that would have occurred with the old weights in place.

Johnson *et al.* also provide information on the attempt by the CPI to deal with the issue of quality-change bias by introducing in the late 1990s hedonic price indexes for selected products. They conclude that the effect has been negligible, not only because the weight on the items using hedonics, e.g., TV sets and audio equipment, was quite small (less than one

percent), but also because of mixed signs in the effects of hedonics on particular items when compared to previous methods. This conclusion contrasts with the view that the introduction of hedonic indexes should have had a substantial effect in reducing quality-change bias in the CPI. In fact prior to 1999 the BLS had used hedonic methods for many apparel categories (since 1991), resulting in an estimated +0.39 percent rate of growth, i.e., downward bias, for the included categories, indicating a decline in the average quality of clothing. Starting in 1988 a hedonic approach was taken to adjust the quality of housing for one attribute, aging, and this resulted in an effect of +0.31 percent per year for the housing component.³

In my book on durable goods price measurement (1990), I evaluated quality change bias for numerous types of products. To provide perspective on recent changes in CPI methodology, I provide here an updated comparison of the CPI for television sets with my own price index developed from price and quality data in periodic product reports that appear in *Consumer Reports*, hereafter *CR*. My method is a variant of the matched model method that I call comparison of “closely similar” models. In the 1990 book comparisons were made across *CR* product reports that record price changes for models that are similar in picture size, black and white vs. color, and cabinet type (console, table model, or portable). A total of 40 such comparisons were made spanning 1947 to 1986. Some of the comparisons measured price change for a particular picture size in adjacent years, while in other cases several years elapsed between product evaluations of a given picture size. For instance one comparison was for 13” color portables spanning 1979 to 1985, while another was for 12” black and white portables spanning 1980 to 1982.

Commentary in the *CR* product reports revealed two additional quality dimensions that were subject to substantial improvement over the years of the study – repair costs and energy usage. Using data provided in the *CR* commentaries, separate adjustments were made to the basic price indexes to account for the value to consumers of the repair and energy savings. Table 2 displays annual rates of change over selected intervals for the CPI and the two *CR* indexes, those unadjusted and adjusted for repair costs and energy use. For 1950-72 the unadjusted *CR* index declined at an annual rate 2.14 percent faster than the CPI, whereas the difference between the adjusted *CR* index and the CPI was -4.22 percent per year. In contrast during 1972-83 both the CPI and unadjusted *CR* indexes registered close to zero price change, while the adjusted *CR* index declined at a rate -3.20 percent faster than the CPI.

Note that the unadjusted *CR* indexes by construction provide an underestimate of the rate of price decline, because they contain no corrections for the improvement in picture quality which occurred steadily during the years of the study, particularly for color sets where picture quality in the early 1980s was sharply improved from the color sets of the early 1960s with their faded colors and hard-to-adjust “fine tuning” knobs.

³ The source paper by Johnson *et al.* (2006) does not indicate the time period over which the apparel and housing differences were calculated.

To provide an updated perspective on the CPI, I collected TV prices for a small subset of years between 1983 and 2014 (1983, 1992, 1999, 2004, 2010, and 2014). Only the unadjusted CR index is shown, as after the 1980s CR makes no further mention of repair costs or energy use. The only quality dimensions controlled for were picture size and presence or absence of a high-definition picture tube (plasma or LCD). The growth rates in Table 1 are shown for 1983-99 and 1999-2014, breaking the intervals at 1999 because that was the year that the CPI began to use the hedonic method. The unadjusted CR index for 1983-99 declined at a rate 4.03 percent per year faster than the CPI, an even greater difference than during 1950-72. After 1999 the pace of price decline picked up both for the CPI and the CR index, and both recorded similarly rapid rates of price decline, particularly during 2004 and 2014. No significance should be placed on the relatively small difference between the two indexes over the 1999-2014 time span, because different groups of CR comparisons registered quite different rates of price decline, indicating that the CR index could have turned out quite differently if different years or sets of models had been used.⁴

Our study of TV set prices suggests that since 1999 the CPI has done a substantially better job in tracking the pace of price decline in the dynamic TV set market. In addition the changes implemented in the 1999-2002 period removed lower-level substitution bias and updated the market basket more frequently. The two changes, according to Johnson *et al.*, caused the CPI to increase 0.34 percentage points slower per year than would have occurred without these changes (0.28 for substitution bias and 0.06 for market basket updating). In the context of explaining the productivity growth slowdown of the past half-decade, we conclude that worsening CPI bias does not contribute to the slowdown, because CPI bias appears to be less than before.

4. Computer Prices

Considerable recent attention has been attracted by a new paper by David Byrne, Stephen Oliner, and Daniel Sichel (hereafter B-O-S) that provides considerable evidence that the rate of decline of semiconductor prices has been significantly understated by the Producer Price Index (PPI). They attribute this error in the PPI matched-model index for microprocessor units (MPUs) to a change in the price-setting policies of Intel, the largest producer. Prior to 2003 the price of a particular Intel MPU model tended to drop rapidly in the year or two following its introduction, in order to compete with the availability of newer and faster models. But by 2006 the posted price of a specific model was held fixed even after faster new models became available. The matched-model approach thus misses the price decline that now is limited to the arrival of new models that by definition are omitted from the matched-model PPI. The B-O-S

⁴ For instance, plasma 42" HD sets registered an annual rate of price decline of -32 percent per year during 2004-2010, while 42" LCD sets recorded a price decline of -11 percent during 2010-14.

alternative uses a hedonic price index based on a performance measure that controls for quality changes. Between 2008 and 2013 the B-O-S hedonic index declines at an average annual rate of 43 percent, while the PPI rate of decrease was only 8 percent per year.

Hatzius and Dawsey extrapolate the B-O-S finding for semiconductors to all general-purpose IT hardware and assume that the true rate of price decline has slowed only one-quarter as much as officially measured. However this is sheer conjecture, since the change in pricing strategy by Intel does not imply changes in the pricing strategy of firms selling computers and peripheral equipment. The PPI for computer equipment uses hedonic indexes to value changes in quality when new models are introduced.

The main issue in assessing the validity of computer price deflators and any existing price index bias is the increasing role of imports of computer equipment, a basic change in the computer marketplace that is emphasized by Byrne and Pinto (2015) but ignored by Hatzius and Dawsey. Figure 3 shows the sharp jump from 35 to 88 percent between 2008 and 2011 in the percentage of computer investment obtained from imports. The topic of imported computers raises two issues, the validity of the import deflators and the impact of high import penetration on the interpretation of price index bias.

Figure 4 displays the computer price indexes for imports (the blue line) and for domestic production (the red line). The BEA price index used to deflate nominal expenditures on computers is the black line, which is close to the red domestic line in the early years 2003-05, reflecting the dominant share of domestic production. Then the BEA price index shifts up and is almost identical to the blue import line after 2011. It seems highly implausible that import prices would be declining so much more slowly than domestic prices, and the shift from domestic production to reliance on imports would suggest the opposite – that true import prices are declining, if anything, faster than domestic prices. Let us assume that the “true” import price index changes at an identical rate to the domestic price index. This means that the deflator used by the BEA would look like the red line in Figure 4, not the black line. The BEA price index used to deflate computer investment would decline at a 6.7 percent faster rate during 2006-10 and at a 4.4 percent faster rate during 2011-13.

The result would be faster growth in fixed investment and in the capital stock, but not in real GDP or labor productivity. This occurs because the more rapid growth of investment is exactly offset by more rapid growth of imports, which are subtracted out in the calculation of real GDP. With unchanged growth in labor productivity, there would be a shift in the division of labor productivity growth into more capital deepening and less growth in total factor productivity (TFP). Thus the plausible conjecture that the import price index for computers declines too slowly does not resolve the puzzle of slow productivity growth during 2010-14 and deepens the puzzle of slow TFP growth in recent years.

The sharp rise of import penetration in U.S. computer investment has an important side effect which has thus far escaped comment, as far as I know. During 2011-13 the average import share was 88 percent. For ease of discussion let us assume that the import share is 100 percent, so that no computer equipment is produced in the U.S., and GDP growth is independent of the rate of change of computer investment because any change of investment is exactly offset by an equal change of imports. The deflator for computer investment would be identical to the deflator for computer imports. Any factor that creates an upward bias in the import deflator would have no effect on GDP or labor productivity. The conjecture of Hatzius and Dawsey that the BEA computer deflator greatly understates the rate of price decline would be irrelevant to the current debate about the sources of the labor productivity slowdown. And the greater the extent of price index bias for computer equipment, the larger is the share of labor productivity growth explained by capital deepening and the smaller is the share explained by TFP growth.

The same point applies to the upward bias in prices for communications equipment, including smart phones, revealed in a new paper by Bryne and Corrado (2015). They find that the average difference between the rate of change of the BEA deflator for communications equipment and their new index widened from -6.1 percent for 1985-2010 to -10.9 percent for 2010-2014. Even if all communications equipment were produced domestically, this difference would boost real GDP growth by only 0.025 percent per annum in the later period relative to the earlier period.⁵ This is an overstatement because a substantial share of communications equipment is imported, and we concluded above that any price index bias for imported equipment has no impact on real GDP growth.

If we now shift our attention from the recent past to the earlier decades of the computer revolution, we return to an era in which domestic computer production dominated, so that the correction of any upward bias in computer price indexes translates directly into faster growth in output and labor productivity. The greatest challenge to the accuracy of the BEA computer price index comes from Nordhaus (2007), whose indexes of price relative to performance extend back long before electronic computers to primitive calculating machines, the abacus, and hand calculations. His basic computer price index is based only on one attribute, a chained set of performance benchmarks, and thus amounts to a price index for computer processors rather than for computers themselves. It thus differs from hedonic indexes that use as quality characteristics inputs to the computation process, e.g., speed, memory, hard drives, ports, CD drives, and others. Assuming that the price of items ancillary to the computation process have declined much less rapidly than computation performance itself, then we would expect hedonic price indexes for computers to decline at a slower rate than Nordhaus' performance-based measures.

⁵ The share of communications equipment in GDP in 2015:Q2 was 0.51 percent (NIPA table 5.5.5 divided by NIPA table 1.1.5). Multiplying this by the 4.8 percent between the average 1985-2010 and 2010-2014 growth rates yields an adjustment to real GDP growth of 0.025 percent.

Indeed, this is the outcome when Nordhaus compares his price-to-performance measure, which decreases at an annual rate of 50.7 percent during 1969-2005, with the BEA price index for computers, which declines during 1969-2004 at an annual rate of 18.7 percent.⁶ Nordhaus attributes a small part of the difference, three percentage points a year in his example, to the fact that the ancillary components of the computer other than the processor have had much slower declines in price than processor performance. He does not mention a more important cause, that his index combines price-performance ratios for mainframes with those for personal computers and thus treats the transition from mainframes to PCs as a price reduction, whereas the BEA links together separate price indexes for mainframes and PCs without allowing for the large price-performance difference between them. In another context he shows that a 2004 supercomputer had a price per unit of performance (clock speed) 34 times higher than a Dell personal computer in the same year. If we treat the computer industry as transitioning between mainframes in 1980 to mainly PCs in 2000, that 34 times difference in the price-to-performance ratio would translate into an annual rate of price decline of -17.6 percent, accounting for a large part of the remaining difference between the BEA and Nordhaus indexes.

The question for this paper is not the size of bias in price indexes for computers, but how much difference it makes for growth in real GDP and hence in labor productivity. Allowing for the methodological difference between the BEA hedonic price index that takes into account ancillary data storage and input-output characteristics and the Nordhaus indexes that ignore ancillary characteristics, we can examine the impact of a potential upward bias of 25 percent per year in the BEA price index for computers and peripherals. The effect on GDP growth is determined through multiplying by the share of computer and peripheral investment in GDP, which amounted to 0.43 percent in 1980, rising to 1.19 percent in 2000, and then declining to 0.40 percent in 2015:Q2. Multiplication yields an increase of real GDP growth by 0.1 percent in 1980, 0.3 percent in 2000, and 0.1 percent in 2015. As we have seen, the effect on real GDP would be further reduced for 2015 from 0.1 percent to zero, due to the shift from domestically produced to imported computer equipment.

5. Internet Services

The largest revision made by Hatzius and Dawsey is to place a value on free internet services. Citing Brynjolfsson and Oh (hereafter B-O, 2012), they credit free internet services for adding $\frac{3}{4}$ of one percent to real GDP growth each year during the time span 2007-2011. The B-O source study uses time survey data to establish that time spent on the internet for consumption (leisure) purposes, as opposed to internet for work purposes, rose from 4.8 to 5.8 hours per week during 2007-2011. They value the consumer surplus created as \$562 billion in

⁶ See Nordhaus (2007, Table 10, p. 153). Price indexes are expressed in real terms relative to the GDP deflator.

2007, rising to \$1,196 billion in 2011. They do not translate this into a value per person-hour, but we can do so using some simple assumptions.

Since the B-O method uses the market wage rate to value leisure time, it applies only to the employed population of about 150 million, not the entire population of 300+ million. That is, the value of leisure time is considerably lower for those who are not employed, including the unemployed and those who choose not to be in the labor force, including children, teenagers, non-working parents, and retirees. The consumer surplus value for 2011 of \$1,196 billion comes out at about \$8,000 per employee per year. Since internet use was 5.8 hours per week or 290 hours per year, the implicit value of an hour of leisure is $\$8,000 / 290$ or \$27.58.⁷ They also provide an estimated total consumer surplus from television viewing of 19.6 hours per week of \$1,399 billion for 2011, which translates into \$9.52 per hour. The consumer surplus values of \$27.58 and \$9.52 can be compared to average hourly earnings of \$19.44 for 2011.⁸

These calculations invite several comments. First, the much higher valuation of free internet use (\$27.58 per hour) compared to free television use (\$9.52 per hour) emerges from the theoretical specification with no attempt at justification. Second, no value appears to be placed on the leisure-time activities that are displaced by free internet use. Third, to value all internet time at the level of the wage or above ignores the diminishing marginal utility of leisure. In labor-market equilibrium only the marginal hour of work is equated to the marginal value of leisure, and the infra-marginal hours of leisure are valued at less than the wage. Fourth, the growth rate of internet use and its effect on GDP should be computed not just for 2007-11 but rather for the entire transition from the first year of the internet, which we can date at 1995.

As an alternative calculation, we can use an hourly valuation of \$10 per hour, times 5.8 hours of weekly internet use, to arrive at a 2011 internet consumer surplus valuation of \$434 billion. Starting with a value of zero in 1995, the increase from zero to \$434 billion in 2011 comes out at \$27 billion per year or 0.22 percent of GDP.⁹ A similar exercise carried out for the first 16 years of television between 1948 and 1964 would presumably yield a roughly equivalent value of unmeasured consumer surplus.

6. The Earlier History of Lost Consumer Surplus

The emergence of free internet use as a major use of leisure time follows a long history in which the value of leisure hours were made gradually more valuable through the successive inventions of the phonograph, radio, motion pictures, and television. In a unique study, Bakker

⁷ I assume that internet use is spread over 50 rather than 52 hours per week, allowing for internet-free vacations.

⁸ Average hourly earnings is for production and nonsupervisory workers in private nonagricultural industries, from *Economic Report of the President*, Table B-15, p. 402.

⁹ The 0.22 percent is the ratio of \$27 billion to average nominal GDP during 1995-2011, which is \$11,755 billion.

(2012) has calculated that the value of the invention of motion pictures from their inception through 1938 amounted to three percent of GDP per year. Real GDP data do not include the consumer surplus created by the difference in the quality between a 1905 nickelodeon showing a few silent moving images on the screen compared to the multidimensional 1939 experience of seeing *Gone with the Wind* with color, sound, and dazzling effects for an average price of 23 cents.

Relatively few estimates exist of the value of major inventions and innovations, and so this section provides a qualitative review of the post-1870 history of the U.S. standard of living to provide a reminder of the enormous importance of the steady stream of innovations that transformed American homes and workplaces, particularly between 1870 and 1970. This section concludes with a quantitative estimate of the most important invention of all, the combination of public health and medical innovations that virtually eliminated infant mortality between 1890 and 1950.

Starting with one of the most important inventions of the late 19th century, real GDP does not include the value for the brightness, safety, and instant off-on switching capability as contrasted to the inconvenience, danger, and dimness of the previous kerosene and whale oil lamps that replaced them. Electricity also made possible the elevator, which not only reduced the strain of walking up stairs, but also made possible the efficiencies created by vertical central business districts. Electricity was central to the revolution in urban transport that in only a few years between 1860 and 1910 allowed the transition from the horse-drawn omnibus and streetcar to the electric streetcar, elevated trains, and electrified subways.

The three necessities are food, clothing, and shelter. Missing from real GDP is the value of the increased variety of food available after 1870, with the invention of processed food, from corn flakes to Coca-Cola, and the increased availability of fresh meat made possible by refrigerated railroad freight cars and of fresh milk free from adulteration and contamination. Real GDP does not take account of successive marketing inventions, including the great urban department stores of the late 19th century that provided convenience and economies of scale, nor of the mail-order catalogues that, starting in 1872, created a multifold increase in the selection of goods available to America's rural population, not to mention sharply lower prices.

The invention of the internal combustion engine provides another set of examples of improvements missed by the GDP data, including the invention of a new form of leisure in the form of personal travel and the removal of horse droppings and urine from city streets and rural highways. The early years of the automobile create a unique example of quality change being missed by the GDP statistics, because there was an epochal increase in quality and decline in price of the motor car from the first models of 1900 to sleek streamlined cars of the late 1930s, yet the automobile was not introduced into the Consumer Price Index until 1935. The internal combustion engine also made possible the motor truck, which combined the intra-urban flexibility of horse-drawn cart with a much greater load-bearing capacity. It also made possible

commercial air travel, which greatly reduced the time cost of long-distance travel, particularly when the piston engine was replaced by the jet engine at the end of the 1950s.

Some improvements missed by real GDP did not involve inventions but rather the spread of known technologies, most notably the arrival of clean running piped water and separate sewer pipes in urban America between 1870 and 1940. These replaced the previous drudgery of carrying pails of water into the house from nearby wells or streams, and the need to carry dirty water back out of the house, as well as outhouses and outdoor privies. Also missed was the contrast between the comfort and privacy of taking a bath in a private enclosed bathroom in a tub or a shower as contrasted with the 1870 standard of a bath in a large bin of heated water in the communal kitchen. The change in female chores is a major category of missing consumer surplus, particularly the liberation of women who previously had to perform the Monday ritual curse of laundry done by scrubbing on a wash board, as well as the Tuesday ritual of hanging clothes out to dry. Electric appliances, including not only the washing machine and dryer, but also the refrigerator, dishwasher, and garbage disposal, had created by the late 1950s an utter contrast in domestic life compared with the 1870s.

Another missed dimension of improved welfare was the improvement of working conditions. The percentage of employment consisting of farmers and farm laborers declined between 1870 and 2010 from 46 to 1.1 percent, ending the discomforts of life on the farm in extreme heat and cold, not to mention the risks of droughts and insect infestations. Over the same time period the share of household servants declined from nearly eight percent to less than one percent. Many nonfarm workers in the late 19th century worked in hot and unpleasant conditions for much longer hours than are standard today; the standard workweek of steelworkers at the turn of the 20th century was 72 hours per week and 60 hours per week in the rest of manufacturing. As the percentage of employment on the farm fell to nearly zero, an ever larger share of workers were engaged in clerical, sales, managerial, and professional occupation, where an ever-increasing fraction of employees enjoyed the comfort of air-conditioned offices.

Most of the above-listed examples of previously unmeasured increases in consumer welfare occurred in the interval 1870-1940, with continuing improvements through 1970 in areas such as the development of commercial air transport, the interstate highway system, and air conditioning. There was a steady improvement in the quality of electric appliances and evidence of upward bias in price indexes for TVs (as discussed above in part 3). The price indexes from *Consumer Reports* contained in my 1990 book emphasized the failure of the CPI to take account of reduced energy consumption for appliances such as refrigerators, air conditioners, and clothes dryers, and quality improvements such as the improving ability of refrigerator freezer compartments to maintain the required temperature of zero Fahrenheit.

Two features of the CPI in the postwar years suggest that the upward bias may have been less than before 1940. First, the CPI for autos was aggressively adjusted for quality change based on estimates of the cost of quality improvements submitted to the CPI by auto manufacturers. These quality attributes included the value of government-mandated pollution

control equipment that some critics argued should have been treated as an increase in the price of the car. This contrasts with the prewar years during which there was until 1935 no coverage of automobile price declines and quality improvements in the CPI. Another source of downward bias in the postwar CPI was the treatment of rents as examined by Gordon and van Goethem (2007), due primarily to the fact that the CPI measured rent changes by surveying renters rather than landlords in a world in which many rent increases occurred with the turnover from one tenant to the next.

The most important category of all is the valuation of increasing life expectancy, made possible in part by the conquest of infant mortality in the first half of the twentieth century. The estimation of the monetary value of an additional life-year made possible by decreased mortality has been developed by William Nordhaus in one study and by Kevin Murphy and Robert Topel in another. Their technique shares the aim of measuring the value of an additional life-year by which to multiply the savings in life-years implied by historical mortality tables. To simplify this section, we present only the results obtained by Nordhaus (2003).

The Nordhaus calculations of the value of improved health provide four alternative estimates that are sufficiently similar that we average their values in translating his conclusions to Figure 5. Nordhaus expresses the value of health improvements as a share of conventional consumer expenditures, and we adjust his estimates to express them as a share of GDP. As shown in the graph, the Nordhaus calculations imply that the value of improvements in life expectancy during 1900–1950 was as large as the growth rate of real GDP per capita for all other reasons. Thus he doubles growth in potential GDP per capita from 2.05 percent per year to 4.2 percent per year. For 1950–2000, the value of increased longevity was 63 percent of the growth in the rest of GDP. Postwar growth including his health capital estimates was 3.5 percent compared to the conventional 2.1 percent. The most important conclusion to be reached from the Nordhaus study is that the health-augmented growth rate of real GDP per capita in the first half of the twentieth century was substantially higher than in the second half. Though the official measures suggest that growth was about 0.1 percent slower in the first half, the Nordhaus estimate suggests 0.7 percent faster. This result seems consistent with the history of missing consumer surplus in GDP, where the examples provided above suggests that the growth rate of welfare in the first half of the twentieth century has been significantly understated relative to the second half.

7. Conclusion

U.S. growth in total-economy labor productivity displays an alarming slowdown in the last five years to only 0.5 percent per year. For the past 11 years the growth rate of 1.0 percent contrasts with a much healthier 2.3 percent achieved during the decade 1994–2004. This paper asks whether measurement errors in the official price data could have contributed to the productivity growth slowdown. Such an explanation would require that any upward bias

evident in the official measures before 2004 to become larger since 2004. If the previous upward bias has become smaller, then this would cause true productivity growth to exhibit an even larger slowdown than in the official measures. If on balance there is no change in the extent of price index bias, then the productivity growth slowdown is real rather than illusory.

The paper suggests that there are three reasons why the previous upward bias in the official price indexes has become smaller, not larger. First, the CPI has introduced improvements, most notably geometric weights at the lower level that have largely eliminated the previous lower-level substitution bias, as well as much more frequent updating of the market basket. Johnson *et al.* (2006) suggest that these changes reduced the rate of inflation registered by the CPI by about 0.3 percent annually. Second, there has been a shift in the sourcing of computers and peripherals from domestic production to imports. If there is a constant upward bias in the BEA deflator for computers, the effect on GDP and labor productivity is reduced toward zero as the import share climbs toward 100 percent. Third, the large difference between the rate of price decline for computers registered by the Nordhaus and BEA indexes matters less in recent years than it did during the 1994-2004 heyday of productivity growth, since the share of investment in computers and peripherals has decreased from 1.2 percent in 2000 to 0.4 percent in 2015. Taken together the shift toward imports and the declining share of computer investment reduce the effect on GDP and productivity of the upward bias in computer price indexes by roughly 0.3 percent. Thus CPI improvements, the rising import share for computers, and the shrinking weight of computer investment, taken together suggest a reduction of price index bias by about 0.6 percent and an increase in measured GDP by about the same amount due to measurement issues.

The major offset to these sources of reduced positive price index bias is the consumer surplus created by free internet services over the period since 1995. The Brynjolfsson-Oh paper suggests an annual effect on GDP of 0.75 percent per year for 2007-11. Our critique of their approach comes up with an alternative positive GDP effect of 0.2 percent per year, in part by stretching out the growth effect over the full period since the internet was introduced in 1995 rather than limiting the effect to the four years 2007-2011. The difference between a 0.6 improvement in the price indexes and a 0.2 bias due to a failure to value internet services implies that the price indexes have been getting better, not worse, by roughly 0.4 percent. This leaves room for others to suggest new sources of increased positive price index bias, either by pushing back on the valuation of free internet services or by suggesting other sources of positive price index bias for aspects of the digital revolution that are produced domestically rather than imported, such as software.

The paper also provides a longer historical period on the issue of the understatement of gains in consumer welfare by GDP data. The inventions of electricity, the internal combustion engine, entertainment options such as radio, movies, and TV, the diffusion of running water and waste removal, the conquest of infant mortality, and the improvement of working conditions during the century between 1870 and 1970 made a bigger difference in everyday

living conditions than post-1970 improvements. The wide range of changes before 1970 contrasts with the limited number of dimensions of improvement from 1970 to 1995, including the microwave oven, the spread of air conditioning to residences, and the early benefits of the non-networked personal computer. Since 1995 there has likely been a rise and then decline in the importance of upward price index bias for computers and peripherals, due to the up-and-down cycle in the share of computer investment in GDP.

This leaves us with the conclusion that the post-2004 productivity growth slowdown, and the even sharper post-2009 slowdown, are real rather than a figment of measurement error. Productivity in business firms experienced a quantum leap upward during 1980-2005 as office work made its epochal and one-time-only transition from paper, typewriters, and file cabinets to multi-purpose networked personal computers and search engines. But since 2005 change has been much slower. Retail trade experienced a simultaneous boost to productivity through the transition to big box stores and the introduction of bar-code scanning and instant credit-card authorization. While retail productivity continues to improve as e-commerce spreads, as recently as 2014 e-commerce accounted for only 6.5 percent of retail sales. Similarly, financial markets made their transition from million-share days to billion-share days between the 1960s and 1990s with little further change since before the financial crisis. The U.S. economy is currently experiencing a paradoxical contrast between frenetic innovative activity with the frequent creation of billion-dollar “unicorn” firms and the underwhelming *impact* of innovation on economywide productivity growth.

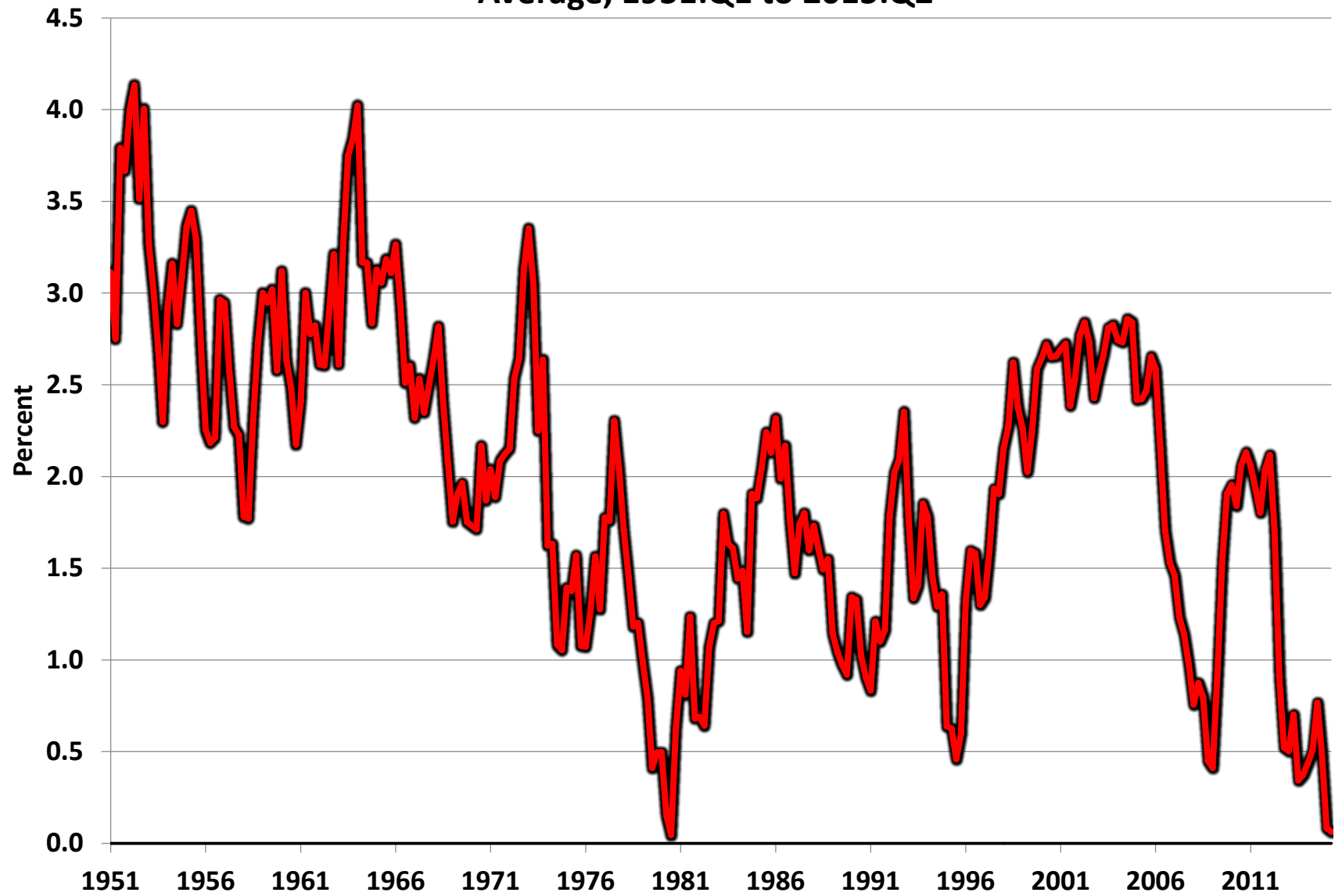
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Figure 1. Total Economy Productivity Growth, 12 Quarter Moving Average, 1951:Q1 to 2015:Q2



**Kalman Trend of Total Economy Productivity Growth,
1951:Q1 to 2015:Q2**

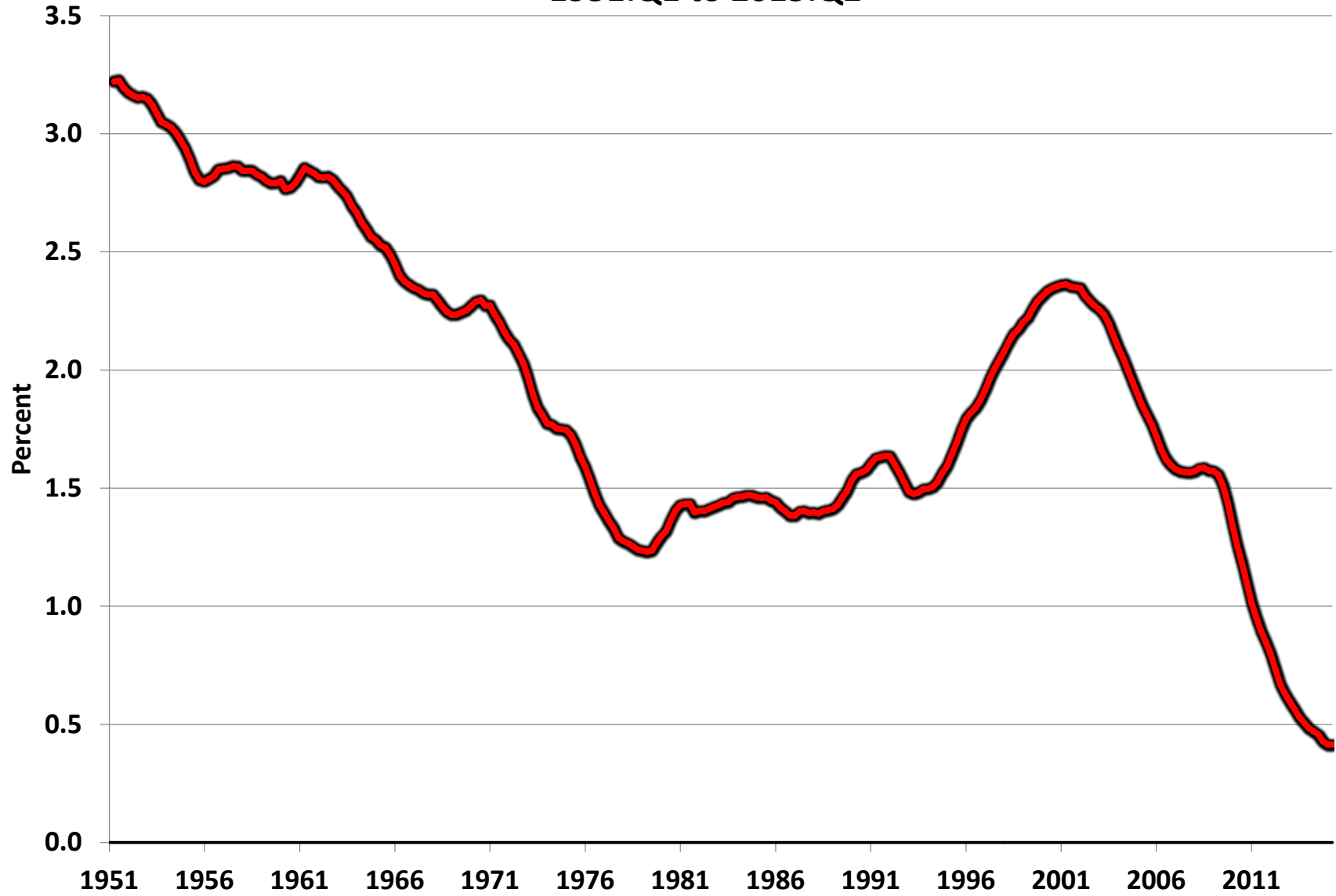


Figure 3. Import Percentage of Computer Equipment Investment

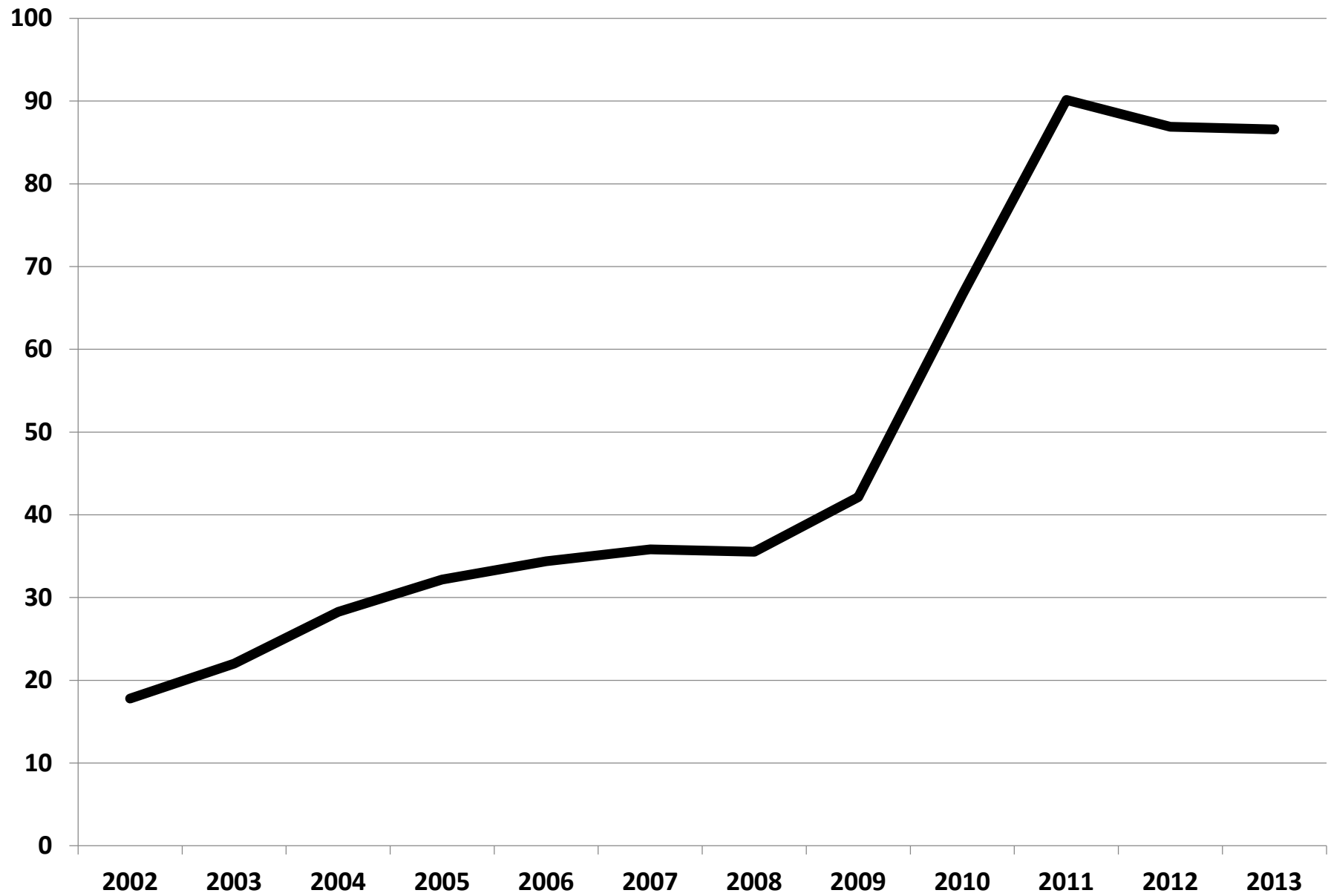


Figure 4. Alternative Price Indexes for Computer Equipment

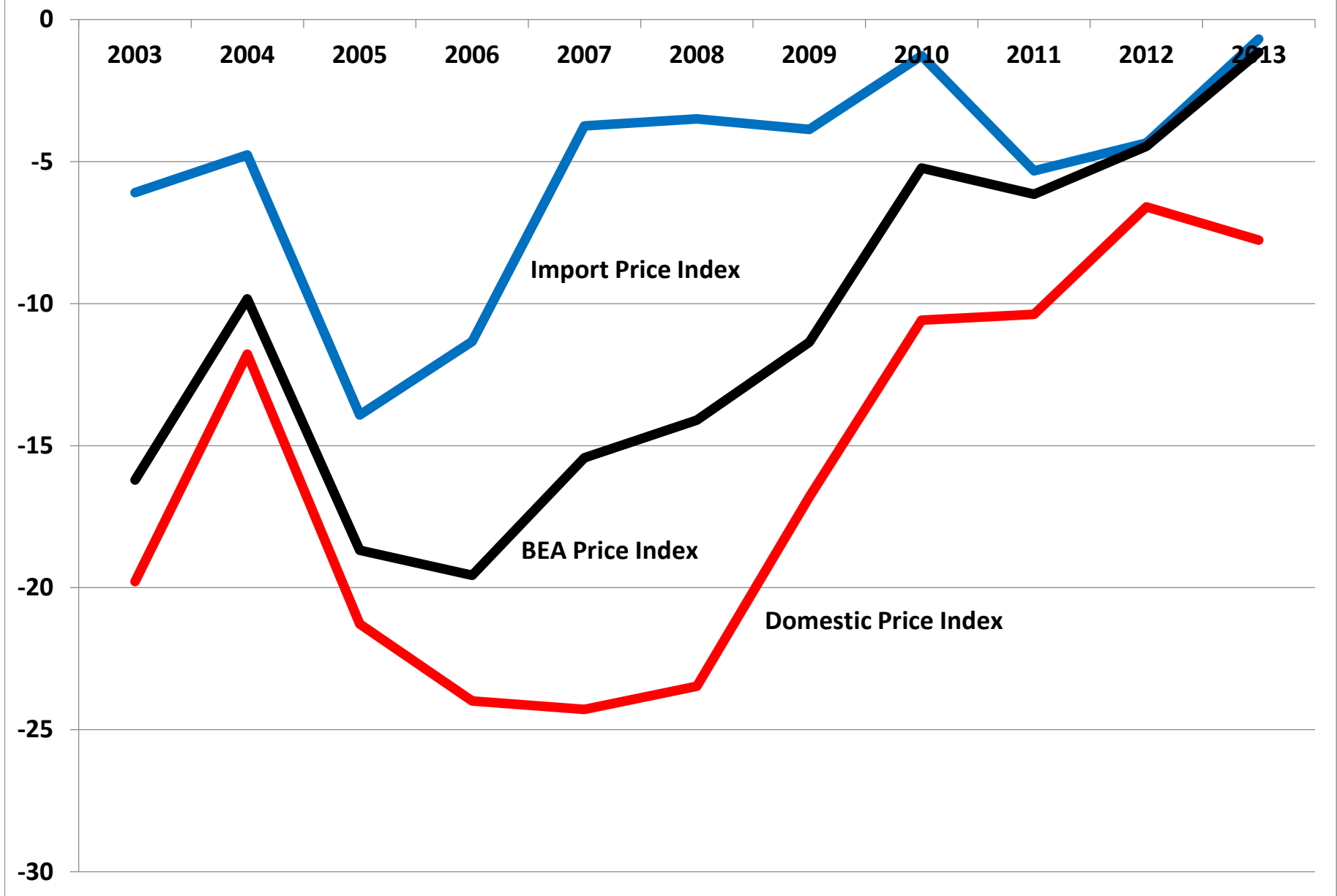
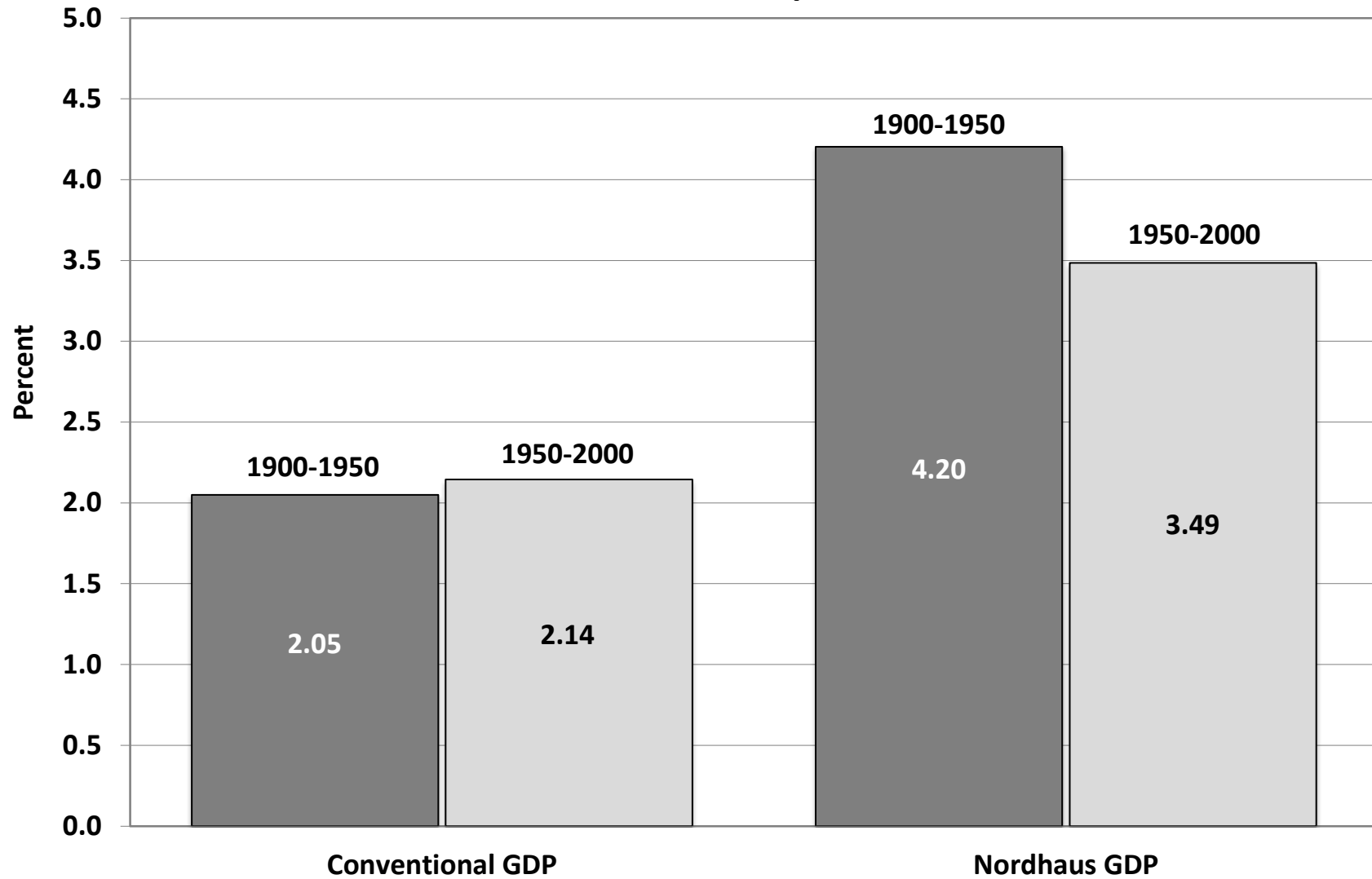


Figure 5. Average Annual Growth Rate in Per Capita GDP With and Without the Accumulation of Health Capital, 1900-1950 and 1950-2000



Sources: Nordhaus (2003) and HSUS series Ae7.

Table 1 Comparison of CPI-U, Chained CPI-U, and PCE Deflator, Annual Growth Rates, 1982-2014			
	CPI-U	Chained CPI-U	PCE Deflator
1982-1990	3.90	n.a.	3.74
1990-2000	2.64	n.a.	1.95
2000-2014	2.20	1.95	1.85
1982-2014	2.76	n.a.	2.35

Table 2 Growth Rates of Alternative Price Indexes for Television Sets, 1950-2014			
	CPI	CR Unadj.	CR Adj.
1950-1972	-2.13	-4.27	-6.35
1972-1983	0.07	0.19	-3.27
1983-1999	-3.80	-7.83	n.a.
1999-2014	-17.63	-19.51	n.a.

Notes: "CR" stands for *Consumer Reports* magazine.
Adjusted CR indexes take account of savings on repair costs and electricity use.

Sources: *Crindexes 1950-83* from Gordon (1990, p.).
Based on CR prices for selected screen sizes, from issues of 1983, 1992, 1999, 2004, 2005, 2010, and 2014.