Secular Stagnation on the Supply Side: U.S. Productivity Growth in the Long Run [(*)]

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Abstract: Secular stagnation refers not to the literal stagnation, i.e., stopping of economic growth but rather to the slowing of U.S. potential real GDP growth to half or less of its historical pace. The retardation of potential real GDP growth matters both because of its direct impact on the standard of living and also because of its indirect effect on net investment, which in turn feeds back to slower productivity growth. During the decade ending in 2014:Q4, U.S. real GDP grew at only 1.55% per year, almost exactly half the growth rate of 3.12% per year achieved during the previous three decades, 1974-2004, and an even smaller fraction of the 3.62% per year performance of 1929-1974. This paper predicts that slow growth of around 1.5% per year will continue over the next decade or two.

Part of the slowdown in output growth is due to a decline in the growth rate of the working-age population. A second reason is a shift in worker hours per capita from an increase due to the entry of women into the labor force during 1965-1995 to a future decrease due primarily to the retirement of the baby-boom generation. A third reason is an ongoing slowdown in the growth rate of output per hour, from 1.72% per year during 1974-2004 to 1.10% per year in 2004-2014 and to an even slower 0.55% per year during 2009-2014.

The sources of the decline in productivity growth combine diminishing returns that have set in following the ICT revolution of the 1996-2004 "dot.com" era with a decline in business dynamism, as the entry of new business firms has steadily declined over the past three decades relative to the exit of existing firms. Moore's Law describing the steady exponential increase in the number of transistors on a chip became obsolete a decade ago. The historic rise of educational attainment has slowed to a crawl, and the declining share of children growing up in two-parent families may lead to a future decrease in high-school completion and an increase in criminal activity among youth. While future productivity growth will be slower than before 2004, it will still continue as in the past decade at a rate slightly in excess of one% per year.

Key words: economic growth, total factor productivity, potential output, innovation, technology, hours of work.

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Alvin HANSEN (1939) popularized the term "secular stagnation", and we in 2015 are, at the suggestion of Larry SUMMERS (2014), considering the application of Hansen's term to the current U.S. economy, because the pace of output recovery in the five years since the business cycle trough of 2009 has been so slow. Yet the conditions of aggregate demand and supply in 2015 are the mirror image of those in 1938 when Hansen wrote. The nation in 1938 faced a crisis of woefully inadequate aggregate demand but not of aggregate supply, because the underlying rate of productivity growth in the late 1930s was as fast as at any time in U.S. peacetime economic history. In contrast the 2015 output gap is small and shrinking, while productivity growth has almost ground to a halt when viewed from the perspective of the last century.

The supply side of secular stagnation refers to potential real GDP growth, that is, the growth rate of output consistent with the natural rate of unemployment. [1] During the five years ending in 2014:Q4, actual real GDP grew at 2.2% per annum, while the unemployment rate declined steadily from 10 to 5.7%, implying that potential real GDP was growing substantially slower than actual output. The gap between the actual 5.7% unemployment rate and the natural rate is currently small. In turn a small gap implies that the ability of actual output to grow faster than potential output will be constrained in the medium term by the limited availability of skilled labor.

Potential real GDP growth is divided, by definition, between growth in potential output per hour and potential aggregate hours of work, components that can be approximated by the growth rates of actual values over long intervals. Actual average real GDP growth of 3.12% during 1974-2004 was double the 1.55 growth rate in the decade ending in late 2004 (i.e., 2004: Q4 to 2014: Q4). Of that decline of 1.55%, output per hour accounted for 0.51 percentage points and hours of work accounted for the remaining 1.04 points. The concern today is not about the literal stagnation, i.e., stopping, of economic growth but rather about the slowing of potential real GDP growth to half of its 1974-2004 pace. This distinction between slow and zero growth was understood by an early writer on secular stagnation, Alan SWEEZY, who wrote in 1943 (p. 69):

[1] The natural rate is taken to be the 5.5% currently adopted by the Congressional Budget Office, the 5.2% recently adopted by the Fed, or any other rate in the range of 5.0 to 6.0%.

> "A 'stagnant' economy in this sense is by no means a static unprogressive economy. Stagnation does not imply a cessation of technical progress, entrepreneurial initiative, or private investment."

For Hansen, Sweezy, and for us today the slowness of potential real GDP growth matters both because of its direct impact on the standard of living and also because of its indirect effect on net investment, which in turn feeds back to slower productivity growth. In this sense secular stagnation on the supply side has a negative impact both on future productivity growth and future aggregate demand, each operating through the channel of a lower share of net investment in GDP.

The central argument explaining slow growth in potential output is that the digital electronics revolution associated with rapid productivity growth in the 1994-2004 interval has begun to encounter diminishing returns. Evidence is provided showing that four dimensions of economic performance reached a peak during the dot.com era of the late 1990s and have exhibited a distinct slowdown since then. The unprecedented recent weakness in the growth of net fixed investment is also examined. The evidence is that the most fruitful years of the digital revolution have passed; moreover, recent research on micro data suggests a decline in the "dynamism" of the economy as measured by the rate of creation of new firms and a decline in the "fluidity" of labor markets as measured by the frequency of job changes. Slow productivity growth reflects not just the flagging pace of innovation but also the near-cessation of advance in educational attainment. The declining job prospects of men without a college education has in part caused a declining marriage rate and an increased percentage of children growing up in single-parent homes, a harbinger of a further shortfall in educational progress for the next generation.

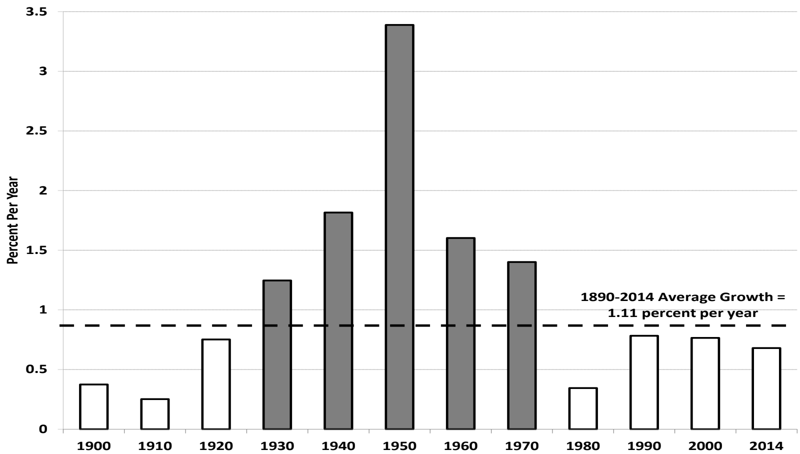
■ TFP growth and the three industrial revolutions

The pace of innovation is usually measured by the growth rate of total factor productivity (TFP). Many economists familiar with the postwar behavior of TFP may be surprised to examine the longer history of TFP growth, as shown in Figure 1. [2] Each bar represents the annual average

[2] TFP is defined as a weighted average of the ratio of output to labor input and the ratio of output to capital input. The TFP data displayed in Figure 1 are derived in Chapter 16 of GORDON (forthcoming 2016). They combine labor and GDP data from the BEA, BLS, and

growth rate of TFP in the decade ending in the year shown, starting on the left with 1890-1900 and ending on the right with 2000-2014. TFP growth since 1970 pales in comparison with the middle of the 20th century (1920-1970) when five straight decades registered TFP growth rates higher than the historical average of 1.11% per year. The champion decade was 1941-50 and the next most rapid TFP growth rate was registered in the 1930s, ending in 1940, supporting the description of the 1930s by Alex FIELD (2003) as "the most technologically progressive decade of the century." [3] No decade since 1970 had TFP growth close to the 1.11% average rate for 1890-2014.

Figure 1 - Annual growth rate of total factor productivity for ten years preceding years shown, years ending in 1900 to 2014



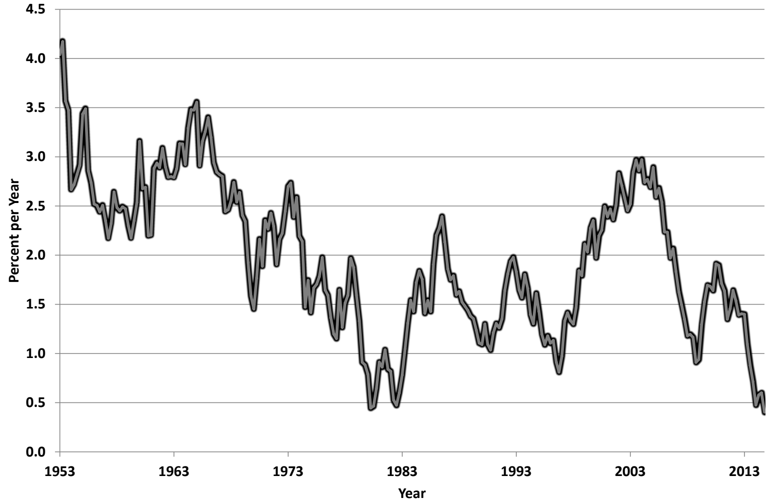
Today's "techno-optimists" who forecast a future of faster TFP growth dominated by robots, big data, and artificial intelligence, must look at the history of Figure 1 with dismay. Future growth is not going to be faster than in the past, because the economy during 1920-1970 achieved growth in TFP of a different order of magnitude than since 1970. Roughly three-quarters of observed TFP growth since 1890 occurred in the half century between 1920 and 1970, and the remaining one-quarter during the seven decades 1890-1920 together with 1970-2014.

KENDRICK (1961). The concept of capital input allows for variable retirement ages and includes certain types of government-financed capital input.

3 Field's accolade to the 1930s as the most progressive decade, i.e., that with the fastest TFP growth, hinges on his inclusion of growth in 1940-1941 as part of the 1930s rather than part of the 1940s.

The timing of the 1920-1970 upsurge in TFP growth reflects the dynamics of the industrial revolutions that created the modern economy. The first industrial revolution (IR #1) of steam engines created railroads, steamships, and the transition from wood to metal, with effects felt throughout the 19th century. The second industrial revolution (IR #2) combined the nearly simultaneous invention of a host of general purpose technologies (GPTs), including electricity, internal combustion engine, telephone, wireless, chemical engineering, and the conquest of infectious diseases. Paul DAVID (1990) has argued persuasively that there were good reasons for the long delay between the first electric power station in 1882 and the revolutionary introduction of electric machines in the early 1920s. The "David delay hypothesis" can be applied to the productivity impact of all the late 19th century GPTs, helping to explain why TFP growth was so much slower in 1890-1920 than after 1920. In particular two decades elapsed between the 1879 invention of the first reliable internal combustion engine and the introduction in 1896-97 of the first working motor vehicles. The productivity impact of motor vehicles awaited sufficient numbers as the total number of motor vehicles in the U.S. grew from 4,000 in 1900 to 469,000 in 1910 to 9.2 million in 1920 to 26.7 million in 1929. And rapid improvements continued after 1920 along every dimension of IR #2, including the electrification of industry, the development of the vertical city, the sensation caused by radio and motion picture "talkies," the spread of air conditioning, the development of petroleum-based plastics, the conquest of infant mortality, the invention of antibiotics, and the spread of commercial air transport which by 1970 had completed its transition from piston to jet engines. At about the same time as the impact of IR #2 began to encounter diminishing returns after 1970, along came the digital electronic third industrial revolution (IR #3). The benefits of IR #3 began in the 1960s and 1970s with mainframe computers replacing the tedious clerical work of manually preparing bank statements, telephone bills, and airline reservations, and continued into the 1980s with the PC, the ATM machine, and retail bar-code scanning. Yet as shown in Figure 2 the growth of output per hour was relatively slow in the 1970s and 1980s, leading to Robert Solow's famous 1987 quip that "we can see the computer age everywhere but in the productivity statistics." Soon afterwards DAVID (1990) developed his delay hypothesis, and he appeared to be prophetic when there was an upsurge of growth in output per hour that in Figure 2 is centered in the years 1996-2004. Productivity analysts have credited the dot.com revolution, with its marriage of the computer with communications and its invention of e-commerce and search engines, for the productivity growth revival of 1996-2004.

Figure 2 - Four-year moving average rate of change, total economy output per hour, 1953:Q1 to 2014:Q4



■ Could the third industrial revolution be almost over?

To understand the sources of today's secular stagnation, consider the decline in the growth rate of labor productivity in the past decade, displayed in Figure 2 as the average annual growth rate over the preceding four years. The growth in total economy output per hour was around 1.7% per year through 2008: Q2, then fell precipitously to 0.57% per year in 2014: Q4. What factors caused the productivity revival of the late 1990s to be so temporary and to die out so quickly?

Most of the economy has already benefitted from the internet and web revolution, and in this dominant sphere of economic activity methods of production have been little changed over the past decade. These major sectors include agriculture, mining, construction, retail trade, transportation, finance, insurance, real estate, professional and business services, education, health, arts and entertainment, accommodation and food services, and government. In each of these sectors paper-dependent business procedures had by 2004 been replaced by digitalization, and flat screens were everywhere. The revolutions in everyday life made possible by e-commerce and search engines were already well established – Amazon dates back to 1994, Google to 1998, and Wikipedia as well as iTunes to

2001. Facebook, founded in 2004, is now more than a decade old. Will future innovations be sufficiently powerful and widespread to duplicate the relatively brief revival in productivity growth that occurred between 1996 and 2004? [4]

Stasis in the office

The digital revolution centered on 1970-2000 utterly changed the way offices function. In 1970 the electronic calculator had just been invented but the computer terminal was still in the future. Office work required innumerable clerks to operate the keyboards of electric typewriters that had no ability to download content from the rest of the world. Memory typewriters were just being introduced, so in 1970 there was still repetitive retyping. Starting from this world of 1970, by the year 2000 every office was equipped with web-linked personal computers that not only could perform any word-processing task but also could download multiple varieties of content and also perform any type of calculation at blinding speed. By 2005 flat screens had completed the transition to the modern office. But then progress stopped. Throughout the world, the equipment used in office work and the productivity of office employees closely resembles that of a decade ago. [5]

Stasis in retailing

Since the development of "big box" retailers in the 1980s and 1990s, and the conversion of check-out aisles to bar-code scanners, little has changed in the retail sector. Payment methods have gradually changed from cash and checks to credit and debit cards. In the early years of credit cards in the 1970s and 1980s, check-out clerks had to make voice phone calls for authorization, then there was a transition to terminals that would dial the authorization phone number, and now the authorization arrives within a few seconds. The big box retailers brought with them many other aspects of the productivity revolution. Wal-Mart and others transformed supply chains,

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[4] This technological transition can be precisely dated. In the last stages of writing my data-intensive book that was completed in 1988, all of the computer output was delivered as huge printouts to the front porch of my home by a graduate research assistants. By 1994 all computer output arrived via e-mail attachment, and the piles of paper had disappeared forever.

[5] For instance, in most economics departments the revolution occurred back in the 1980s when professors began to do their own research papers with PC word processors, and most of them, particularly the younger faculty members, reveled at the new opportunity to set their own complex equations instead of having to monitor math-illiterate secretaries. Department staffs became smaller because the need for repetitive retyping disappeared. Yet then progress stopped; the Northwestern economics department staff in 2014 is the same size and carries out the same functions as that staff did in 1998.

wholesale distribution, inventory management, pricing, and product selection, but that productivity-enhancing shift away from traditional small-scale retailing is largely over. E-commerce raises productivity but thus far in 2014 accounts for only about six% of total retail trade (HORTAÇSU & SYVERSON, 2015, p. 7). The retail productivity revolution is high on the list of the many accomplishments of IR #3 that are largely completed and will be difficult to surpass in the next several decades.

Stasis in finance and banking

The ICT revolution changed finance and banking, along many dimensions from the humble street-corner ATM cash machine to the development of fast trading on the stock exchanges. But both the ATM and billion-share trading days are creations of the 1980s and 1990s. Nothing much has changed in more than a decade, except for the ups and downs of stock prices, and despite all those ATM's, the nation still maintains a system of 97,000 bank branches, many of which are empty much of the time.

Stasis in consumer electronics

Television made its transition to color between 1965 and 1972, then variety increased with cable television in the 1970s and 1980s, and finally picture quality was improved with high-definition signals and receiving sets. Variety increased even further when Blockbuster and then Netflix made it possible to rent an almost infinite variety of motion picture DVDs, and now movie streaming has become common. Further, homes have experienced the same access to web information and entertainment, as well as to e-commerce, that had arrived a few years earlier in the office. But now that smart phones and tablets have saturated their potential market, further advances in consumer electronics have become less impressive. The sense that technical change is slowing down in consumer electronic goods was palpable at the 2014 Consumer Electronics Show (CES):

But in some ways, this show was a far cry from the shows of old over the years it has been the place to spot some real innovations. In 1970, the videocassette recorder was introduced at CES. In 1981 the compact disc player had its debut there. High definition TV was unveiled in 1998, the Microsoft Xbox in 2001. This year's crop of products seemed a bit underwhelming by comparison. The editor of a gadget website [said]:

> "This industry that employs all of these engineers, and has all of these factories and salespeople, needs you to throw out your old stuff and

> buy new stuff – even if that new stuff is only slightly upgraded". (BILTON, 2014).

Decline in business dynamism

Recent research has used the word "dynamism" to describe the process of creative destruction by which new start-up and young firms are the source of productivity gains that occur when they introduce best-practice technologies and methods as they shift resources away from old low-productivity firms. The share of total employment accounted for by firms no older than five years declined by almost half from 19.2% in 1982 to 10.7% in 2011. This decline was pervasive across retailing and services, and after 2000 the high-tech sector experienced a large decline in startups and fast-growing young firms (DAVIS & HALTIWANGER, 2014, p. 14).

Related research on labor market dynamics points to a decline in "fluidity" as job reallocation rates fell more than a quarter after 1990, and worker reallocation rates fell more than a quarter after 2000. Slower job and worker reallocation mean that new job opportunities are less plentiful and it is harder to gain employment after long jobless spells.

> "For the employed it hampers their ability to switch employers so as to move up a job ladder, change careers, and satisfy locational constraints. job mobility facilitates wage growth and career advancement." (DAVIS & HALTIWANGER, 2014, p. 11).

This line of active current research has uncovered multiple dimensions of the declining "dynamism of American society" as indicated by the declining pace of startups, job creation, job destruction, and internal migration (DECKER *et al.*, 2014, p. 22).

■ Education and social decay subtract from future productivity growth

The contribution of education to productivity growth

Growth accounting has long recognized the role of increasing educational attainment as a source of economic growth. GOLDIN & KATZ (2008) estimate that educational attainment increased by 0.8 years per decade over the eight decades between 1890 and 1970. Over this period they also estimate that the improvement in educational attainment contributed 0.35 percentage points per year to the growth of productivity and output per capita. To the extent that American educational attainment is rising less rapidly now and in the future than in the past, the future growth rate of productivity will tend to be slower.

The increase of educational attainment has two parts, that referring to secondary education and the other relevant for higher education. The surge in high-school graduation rates – from less than 10% of youth in 1900 to 80% by 1970 – was a central driver of 20th century economic growth. But the percentage of 18-year-olds receiving bona fide high school diplomas has since fallen, to 74% in 2000, according to James Heckman. He found that the economic outcomes of those who earned not a high school diploma but rather a General Education Development (GED) certificate performed no better economically than high-school dropouts and that the drop in graduation rates could be explained, in part, by the rising share of youth who are in prison rather than in school. [6] The United States currently ranks 11th among the developed nations in high school graduation rates and is the only country in which the graduation rates of those aged 25-34 is no higher than those aged 55-64. [7]

The role of education in holding back future economic growth is evident in the poor quality of educational outcomes at the secondary level. A UNICEF report lists the U.S. 18th out of 24 countries in the percentage of secondary students that rank above a fixed international standard in reading and math. The 2012 OECD international PISA tests scores ranked the U.S. among the 34 OECD countries as 17th in reading, 20th in science, and 27th in mathematics [8]. A recent evaluation by the ACT college entrance test organization showed that only 25% of high school students were prepared to attend college with adequate scores on reading, math, and science.

At the college level longstanding problems of quality are joined with the newer issues of affordability and student debt. In most of the postwar period

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[6] An update of high school graduation rates is provided in MURNANE (2013). He concurs with HECKMAN that the graduation rate declined from 1970 to 2000 but presents data that there was an increase during 2000 to 2010. The 2010 graduation rate is slightly higher than in 1970 but the conclusion remains that high-school completion rates have stagnated for the past 40 years, particularly in comparison to the prior period between 1900 and 1970.

[7] http://globalpublicsquare.blogs.cnn.com/2011/11/03/how-u-s-graduation-rates-compare-with-the-rest-of-the-world/

[8] www.oecd.org/pisa/keyfindings/PISA-2012-results-US.pdf

a low-cost college education was within reach of a larger fraction of the population than in any other nation, thanks to free college education made possible by the GI Bill, and also minimal tuition for in-state students at state public universities and junior colleges. The U.S. led the world during most of the last century in the percentage of youth completing college. The percentage of 25-year-olds who have earned a BA degree from a four-year college has inched up in the past 15 years from 25 to 32%, but that is ranked now 12th among developed nations.

The poor achievement of American high school graduates spills over to their performance in college education. Many of the less capable enter two-year community colleges, which currently enroll 39% of American undergraduates, whereas the remaining 61% enroll in four-year colleges. The Center on International Education Benchmarking reports that only 13% of students in two-year colleges graduate in two years, although the percentage rises to 28% after four years. The low graduation rates reflect the need for most students to work part-time or full-time in addition to their college classes, and also the poor preparation of the secondary graduates who enter community colleges. Most community college students take one or more remedial courses. And the future does not look promising. The cost of a university education has risen since 1972 at more than triple the overall rate of inflation. [9] Even when account is taken of the discounts from full-tuition made possible by scholarships and fellowships, the current level of American college completion has been made possible only by a dramatic rise in student borrowing. Americans owe $1.2 trillion in college debt, substantially more than they owe on credit cards.

As a result of stagnation of educational attainment, JORGENSON *et al.* (2014) have estimated that education's growth contribution will decline in the future by 0.27% per year. JORGENSON's estimate has become a consensus view, being adopted in the latest series of sources-of-growth projections by BRYNE, OLINER & SICHEL (2013).

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[9] A comparison from the detailed NIPA tables of personal consumption expenditures suggests that the rise in the relative price of the higher education deflator compared to the personal consumption deflator emerges as an increase of 3.7 times conventional PCE inflation since 1972.

Socioeconomic decay

The decline of marriage as an institution among Americans who lack a college education is relevant to the future rate of productivity growth, because children – particularly boys – who grow up in households lacking a father are less likely to graduate from high school and complete college and more likely to drop out of high school and become engaged in criminal activity. An important source of this sociological change is the evaporation of good, steady, high-paying blue-collar jobs. Partly because men without a college education have lacked the incomes and steady employment to be attractive marriage partners, and partly because women have become more independent as opportunities in the labor market have opened up for them, fewer couples are getting married and as a result an ever-larger share of children are growing up without a father in the household.

For white high-school graduates the percentage of children born out of wedlock increased from 4% in 1982 to 34% in 2008 and from 21 to 42% for white high-school dropouts. For blacks the equivalent percentages are a rise from 48 to 74% for high-school graduates and from 76 to 96% for high-school dropouts (CARBONE & CAHN, 2014, p. 18). Not only is the rate of marriage declining but almost half of all marriages fail. The number of children born outside of marriage is drawing equal with the number of children born within marriage.

The American family is changing – and the changes guarantee that inequality will be greater in the next generation. For the first time, America's children will almost certainly not be as well educated, healthy, or wealthy as their parents, and the result stems from the growing disconnect between the resources available to adults and those invested in children (CARBONE & CAHN (2014, p. 1).

Charles MURRAY (2012) documents changes in social indicators for the bottom third of the white population. The percentage of married couples where either one or the other spouse worked 40 or more hours in the previous week declined from 84% in 1960 to 58% in 2010. The breakup of the family is documented by three complementary indicators, all referring to the 30-49 age group:% married down from 85 to 48%,% never married up from 8 to 25%, and% divorced up from 5 to 33% (MURRAY (2012, pp. 153-56). His most devastating statistic is that for mothers aged 40, the percentage of children living with both biological parents declined from 95% in 1963 to 34% in 2004 (MURRAY, 2012, Figure 8.11, p. 167). Children living in a single parent family, usually with the mother as the head of household, are more likely to suffer from poverty and a lack of motivation, and are more likely to drop out of high school. This sociological literature on marriage and single-parent households suggests further future slippage of the U.S. in the international league tables of high school college completion rates.

Other sources support MURRAY's emphasis on social decline in the bottom one-third of the white population. A recent study showed that between 1979 and 2009 the cumulative percentage of white male high-school dropouts who had been in prison rose from 3.8 to 28.0%. For blacks over the same time interval the percentage who had been in prison rose from 14.7% to 68.0%. That is, fully two-thirds of black male high school dropouts experience at least one spell in prison by the time they reach 40 years old. For black graduates from high school (including those with GED certificates) the percentage in prison rose from 11.0 to 21.4%. [10] Any kind of criminal record and especially time in prison severely limit the employment opportunities available to those whose prison sentences are ending. According to the FBI no less than one-third of all adult American males have a criminal record of some sort (not necessarily involving prison), and this stands as a major barrier to employment (EMSHWILLER, 2014, p. A1).

■ Will the productivity revival of the late 1990's be repeated?

In the postwar productivity history of Figure 4, the 1996-2004 revival is notable both for its magnitude, but also because it was temporary and could not sustain itself for more than eight years. A longer-term perspective is provided in Figure 3, which repeats the century-plus TFP history of Figure 1, but defines the subintervals differently. The post-1890 history is divided at 1920, 1970, 1994, and then every five years from 1994 to 2014, with the width of each bar on the chart proportional to the length of the time period. This perspective not only emphasizes again the magnitude of the advance achieved between 1920 and 1970 but also the extent of the post-1970 slowdown. In this chronology the dot.com TFP revival is limited to the five-year interval 1999-2004.

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[10] Data in this paragraph come from PETTIT (2012, Table 1.4).

Figure 3 - Average annual growth rate of total factor productivity, selected intervals, 1890-2014

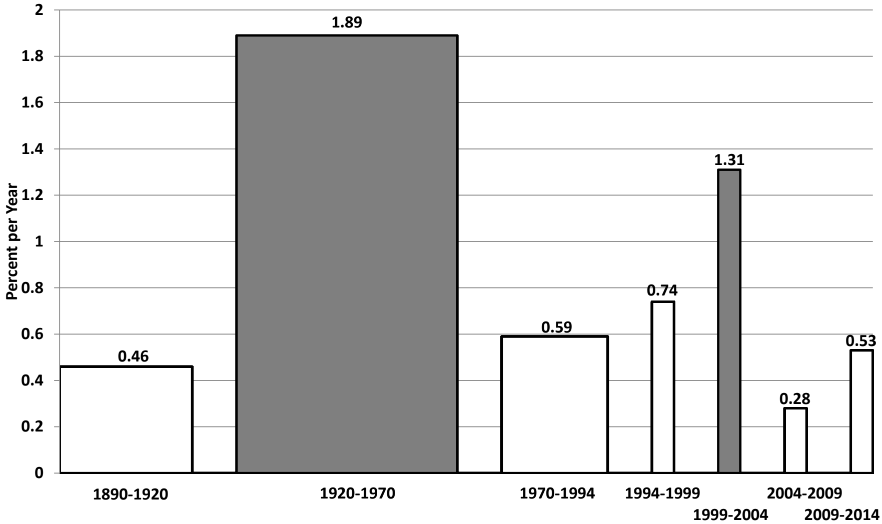
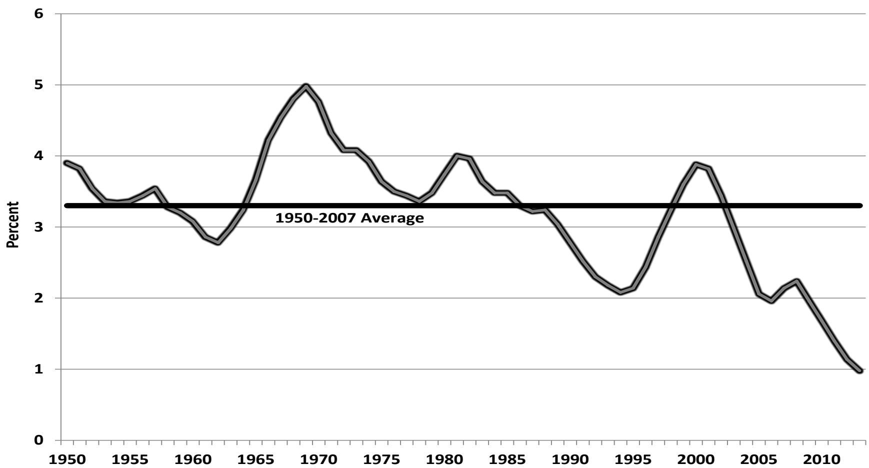


Figure 4 - Five-year moving average of ratio of net private business investment to private business capital stock, 1950-2013

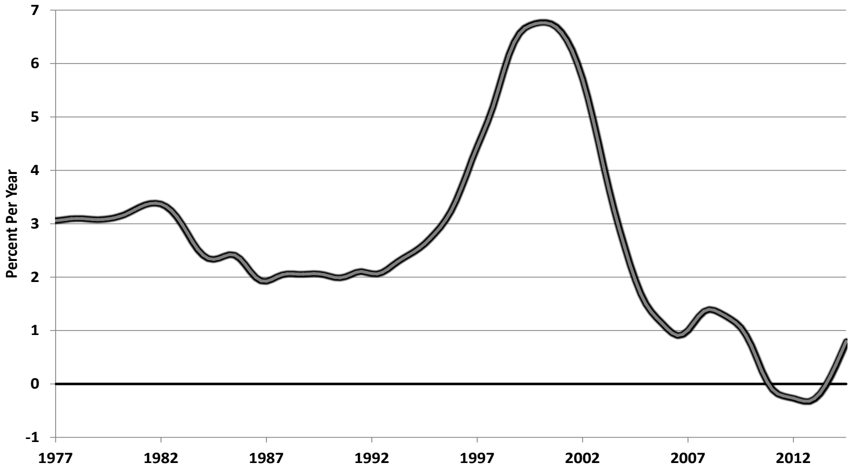


What are the prospects that another TFP growth revival similar to but longer-lasting than 1999-2004 could be waiting around the corner? An assessment is possible along two dimensions. First, we can look at other performance measures of the economy over the last few decades to determine whether behavior in the late 1990s was unique. Separately we can consider the future inventions that are widely discussed and conjecture whether they will have an impact on productivity growth sufficient to create another economy-wide revival.

Temporary features of the late 1990s

At the heart of Hansen's secular stagnation argument was the fear that declining population growth, in addition to overbuilding in the 1920s, had ended the need to equip new members of the population with residential and nonresidential capital. Hansen's fear was reflected in the collapse of both gross and net investment in the 1930s. Insufficient attention has been paid to the behavior of net investment in the U.S. in the past two decades. Displayed in Figure 4 is a five-year moving average of the ratio of net private fixed investment to the private capital stock, as well as a horizontal line showing the 3.3% annual growth rate of the ratio between 1950 and 2007. The long slump in net investment is evident in the diagram, where the five-year moving average is above the 3.3% line in every year between 1950 and 1986 except for 1958-64, and the moving average is below the 3.3% line in every year after 1986 except for 1999-2002. The 1.0% value of the moving average in 2013 was less than half of the previous low value in 1994. This is the first dimension along which the late 1990s were unusual, providing as they did a brief respite from the secular slump in net investment.

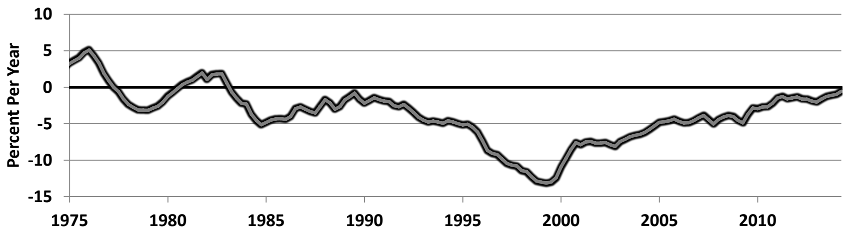
Figure 5 - Annualized Five-Year Change in Manufacturing Capacity, 1977-2014



Source: www.federalreserve.gov/datadownload/default.htm, G.17

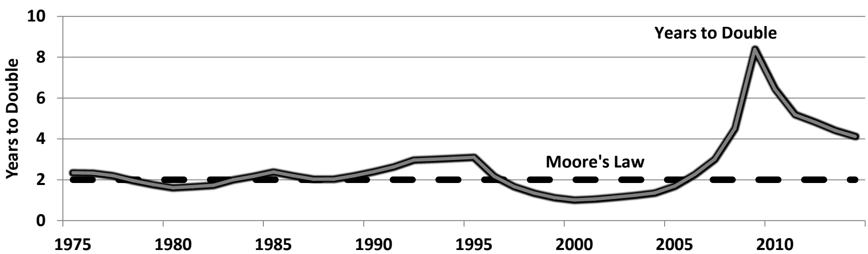
The temporary productivity revival of the late 1990s was also accompanied by an equally temporary acceleration of growth in manufacturing capacity. As shown in Figure 5, a five-year moving average of the annual growth rate of manufacturing capacity ranged between two and three% during 1977-1996 and then soared briefly to a peak of almost seven% in 1999-2000 but then declined precipitously and turned negative in 2011-2012.

Figure 6a - Rate of change of deflator for information and communications technology equipment, 1975-2014



Source: NIPA Table 5.3.4

Figure 6b - Years taken for number of transistors on a chip to double



Source: Intel Corporation website

The literature on growth accounting unanimously credits an acceleration of investment in information and communication technology (ICT) investment for the dot.com productivity growth revival. Analysts such as BYRNE, SICHEL & OLINER (2013) subdivide the ICT contribution into the separate contributions of capital deepening and TFP growth in both the ICT-producing and ICT-using industries. The driving force behind these contributions was the unprecedented decline in the ratio of price to performance of ICT equipment. As shown in the top frame of Figure 6, the rate of price decline of the ICT deflator in the national income accounts fluctuated between zero and minus five% between 1973 and 1996 and then plummeted to a record rate of decline of 14% in 1999-2000 before returning back nearly to zero in 2014.

Underlying the timing of price changes for ICT equipment was technological advance in the manufacture of computer chips. Gordon Moore, co-founder of Intel, in 1965 formulated the prophetic Moore's Law predicting that the number of transistors on a chip would double every two years. The bottom frame of Figure 6 compares the doubling time actually achieved as the black line with Moore's prediction of a fixed doubling time of two years, shown by the straight dashed line. Until 1995 the actual outcome was uncannily close to Moore's predicted doubling time of every two years. Then technical progress speeded up as the actual doubling time declined in the dot.com era and reached a pace of only 14 months in 2000-2001 and indeed was faster than Moore's Law over the entire period between 1996 and 2005, corresponding almost exactly to the timing of the productivity growth revival plotted above in Figure 2. However, starting almost a decade ago, Moore's Law went off the rails as the doubling time soared to eight years in 2009 and remained above four years between 2008 and 2014.

Thus we have seen that four different measures of economic progress exhibited a temporary acceleration in the late 1990s at the same time that economy-wide productivity was experiencing its temporary revival – the four are net investment, manufacturing capacity, the rate of decline of the price of computer equipment, and the speed of change in computer chip technology. The slowdown in the process by which computer chips became faster and more powerful likewise helps to explain why aggregate productivity growth has been so slow over the past few years. This slowdown is described by Kenneth Flamm, an expert on the economics of microchips:

> "The reason improvement in computer performance grew much more slowly after 2003 is that maximum clock speed in computer microprocessor chips hit fundamental technical limits related to heat dissipation requirements, which grow with power and clock rate and clock speed has basically been near-stationary ever since." (FLAMM (2014, p. 15).

■ The promise of future inventions

From the beginning of this paper we have interpreted the use of the term "secular stagnation" in the current context to mean "slow growth" not "no growth." Despite all the innovations of the post-1970 era, Figure 3 above shows that TFP growth was able to exceed 0.74% per year during only the single five-year interval of 1999-2004. Even including that revival period, TFP growth since 1970 averages only 0.65% per year, less than half of the

1.35 average achieved during 1890-1970. The previous sections suggested that the ICT revolution has begun to encounter diminishing returns, and so the next step is to assess the promise of future inventions.

There is no prediction here that innovation is coming to a halt nor that technological change is a thing of the past. Innovations will continue to flow in the future as they have throughout the past two centuries, but in assessing prospective future innovations to come we need to bear in mind two central questions. First, will these innovations be sufficiently important to cause TFP growth to exceed the post-1970 average? Second, are the future innovations truly new or do they represent a continuation of innovation already well underway?

Erik BRYNJOLFSSON & Andrew McAFEE (2013) are the most widely cited advocates of a future acceleration in the pace of technological changes. The future advances that they discuss can be divided into four main categories – medical, small robots and 3-D printing, big data and artificial intelligence, and driverless vehicles.

Medical and pharmaceutical advances

The most important sources of higher life expectancy were achieved in the first half of the 20th century, when life expectancy rose at twice the rate of the last half. Many of the current basic tools of modern medicine were developed between 1940 and 1980, including antibiotics, the polio vaccine, procedures to treat coronary heart disease, and the basic tools of chemotherapy and radiation to treat cancer. Public knowledge of the links between diet, smoking, obesity, and both coronary disease and cancer were already well developed by 1980. The current status of science in medical treatment and pharmaceutical advance is well described by Jan VIJG (2011). Progress on physical disease and ailments is advancing faster than on mental disease, so that we can look forward in two or three decades to an exponential rise in the burden of taking care of elderly Americans who are physically alive but in a state of dementia. Pharmaceutical research has reached a brick wall of rapidly increasing costs and declining benefits, with a decline in major drugs approved each pair of years over the past decade, as documented by Vijg (VIJG, 2011, Chapter 4).

Small robots and 3-D printing

Industrial robots were introduced by General Motors in 1961. By the mid-1990s, robots were welding auto parts and replacing workers in the lung-killing environment of the auto paint shop. Until recently, however, robots were large and expensive. Small, inexpensive robots suitable for use by small businesses have now been developed. Some can be reprogrammed to do a different task every day, while others can move around the floor of the factory or warehouse. The continuing development of robots is not a startling new invention but rather a continuation of robotic development that began more than half a century ago. So far robots have primarily shown to be useful in the manufacturing sector, which accounts for only eight% of U.S. employment, and in warehouses, which account for a few% more. It will be a long and gradual process before robots outside of the manufacturing and wholesaling sectors become a significant factor in replacing human jobs in the service or construction sectors.

Big data and artificial intelligence

The enthusiasts for future technical progress are fascinated by exponents, as when Brynjolfsson and McAfee write "exponential growth leads to staggeringly big numbers" (BRYNJOLFFSON & McAFEE, 2014, p. 47). What is lost by the enthusiasts for big data is that most of it is a zero-sum game. A substantial fraction of the big data being analyzed within large corporations is for marketing purposes. *The Economist* reported recently that corporate IT expenditures for marketing purposes were increasing at three times the rate of other corporate IT expenditures. The marketing wizards use big data to figure out what their customers buy, why they change their purchases from one category to another, and why they move from merchant to merchant. This is a zero-sum game, not an area that promises a breakthrough in the performance of aggregate TFP growth.

Marketing is just one form of artificial intelligence that has been made possible by big data. Another form is the ability to use modern search tools to find with blinding speed valuable nuggets of existing information. The demand for legal associates has declined in part because of the ability of computerized search tools to carry out the process of discovery and search for precedents. Similarly the demand for domestic radiologists has declined because results of CT scans and MRIs can be read in India or other low-wage nations. And there is the prospect that computers can read the images even better than the radiologist in India. Another ongoing development is the development of financial software that can perform the same services as personal financial analysts but at a small fraction of the cost.

These examples of advanced search technology and artificial intelligence indeed are happening now, but they are nothing new. The quantity of electronic data has been rising exponentially for decades without pushing TFP growth out of its post-1970 lethargy. The sharp slowdown in productivity growth in recent years has overlapped with the introduction of smart phones and computer tablets, which consume huge amounts of data. These sources of innovation have disappointed in what counts, their ability to boost output per hour in the American economy. As shown in Figures 2 and 3, there has been no response of labor productivity or TFP growth to the 2007 introduction of the smart phone or the 2010 introduction of the smart tablet.

Driverless cars and trucks

This category of future progress is demoted to last place because it offers benefits that are so minor compared to the invention of the car itself, or the improvements in safety that have created a ten-fold improvement in fatalities per motor vehicle mile since 1950. The most important distinction is between cars and trucks. People are in cars to go from A to B, much of it for essential aspects of life such as commuting or shopping. Thus the people must be inside the driverless car to achieve their objective of getting from point A to point B. What is the revolutionary achievement of consumer surplus by being able to commute without driving? Instead of listening to the current panoply of options, including bluetooth phone calls and internet-provided music, the driver can look safely at a computer screen, send texts, and respond to e-mail. This is a very small step forward, less significant than the invention of the smart phone.

Driverless trucks might be a potentially productivity-enhancing innovation, except that driving from place to place is only part of what many truck drivers do. Those driving Coca-Cola, beer, and bread delivery trucks do not just stop at the loading dock and wait for a store employee to unload the truck. Instead, the drivers are responsible for loading the cases of Coca-Cola or beer or the stacks of bread loaves onto dollies and placing them manually onto the store shelves. In fact, it is remarkable in this late phase of the computer revolution that almost all placement of individual product cans, bottles, and tubes, on retail shelves is achieved today by humans rather than robots. The fact that robots have made so few inroads into the realm of retailing suggests that the vast majority of retail jobs are not about to be replaced by robots anytime soon.

■ Slowing output growth is caused by slower hours growth, not just by slower productivity growth

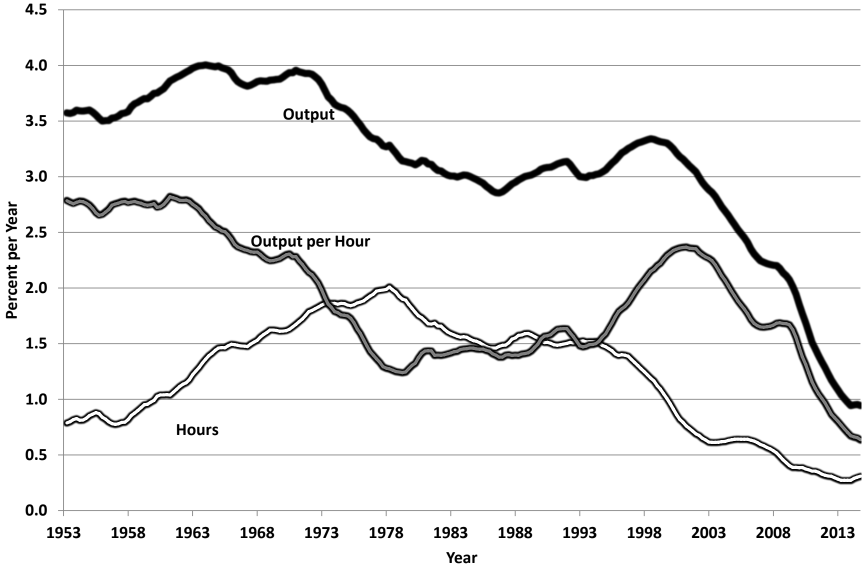
Innovation will continue to bring benefits and create productivity growth along numerous dimensions, but there is no breakthrough on the horizon comparable to the dot.com revolution and the total transformation that it created in the day-to-day operations of American offices, retail stores, and other enterprises throughout the economy. Now our focus turns from productivity growth to growth in output itself, which by definition is the sum of growth in output per hour plus growth in aggregate hours of work.

The introductory section above referred to the actual growth rate of real GDP during 2004-14 as an approximate estimate of potential output growth. Now we turn to a more formal method of separating cyclical from trend movements based on the Kalman filter. That method is used in Figure 7 to display the trend growth rate from 1953 to 2014 of real GDP, aggregate hours of work, and output per hour. [11]

The trend growth rate of potential hours shrinks from a peak of 2.0% in 1978 to a plateau of 1.5% between 1983 and 1996, followed by a decline in stages to just 0.25% in 2014. The trend growth rate of output, i.e., potential real GDP, is the sum of the productivity and hours trends and exhibits a two-stage slowdown. Potential output growth was as high as 4.0% per year in the 1960s, then slowed to a roughly 3.0% pace between 1980 and 2000, and then slowed steadily to only 1.0% in late 2014. That 1.0% output trend is the sum of 0.75 for trend productivity growth and 0.25 for trend hours growth.

[11] The technique filters out the cyclical component of each element by removing the component of its variance that is correlated with the unemployment gap, which in turn is the difference between the actual and natural rates of unemployment as calculated in GORDON (2013). While an updated version of the natural rate of unemployment from that paper is equal to 6.0% in 2012-2014, the more optimistic assumption is made – that the natural rate is still 5.0%, roughly its value in 2007. The lower the natural rate of unemployment, the larger the unemployment gap and the higher the growth rate of trend output and hours.

Figure 7 - Kalman growth trends of output, hours, and output per hour, 1953:Q1 to 2014:Q4



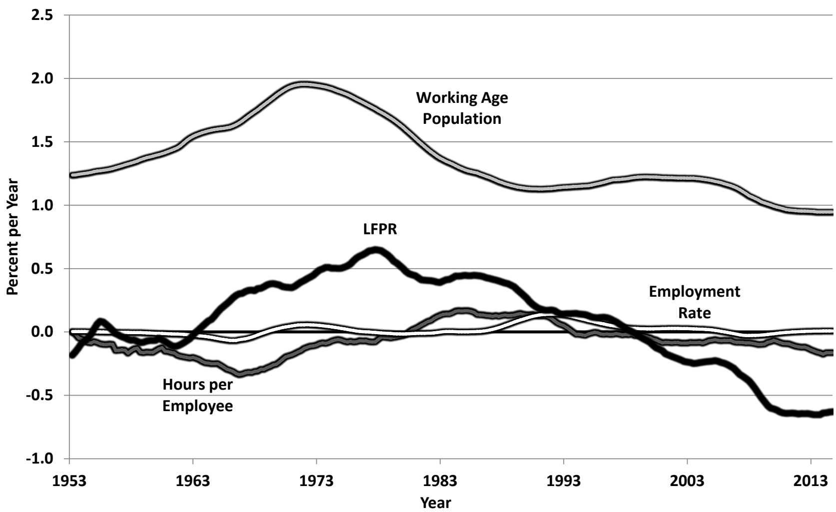
Why has the hours trend slowed so much? By definition the growth in hours is equal to the sum of four growth rates – those of hours per employee, the employment rate, the labor-force participation rate (LFPR), and the working-age population. The Kalman trends of these four growth rates are displayed in Figure 8. [12] The growth of the working-age population has been relatively stable with the exception of the 1963-1978 bulge associated with the entry at age 16 of the baby-boom generation into the working-age population. The prime driver of the decline in trend hours growth is the decline in the LFPR trend growth from a peak of +0.7% in 1978 to a trough of -0.7% during 2010-2014.

Recent research (HALL, 2014) has shown that about half of the 2007-2014 decline in participation is due to the aging of the population as the baby-boom generation retires. The other half is due to declining participation within age groups, particularly among youth and prime-age males. AARONSON *et al*. (2014) have concluded that all of the 2007-2014 decline in the LFPR has been due to secular factors and none to cyclical factors.

[12] Aggregate hours of work comes from the payroll survey, whereas hours per employee comes from the household survey. A fifth term, the ratio of payroll hours to household hours, is needed to complete the decomposition of hours growth. That series is omitted from Figure 8 to simplify the diagram.

Nevertheless there is some justification for the hope that the portion of the LFPR decline due to factors other than baby-boom retirement will stabilize or even reverse itself, and this possibility is supported by the fact that the LFPR declined by only 0.3% in the year ending in November, 2014, as compared to the Kalman trend of -0.7% in Figure 8.

Figure 8 - Kalman growth trends of hours per employee, employment rate, LFPR, and population, 1953:Q1 - 2014:Q4



To conclude from Figures 7 and 8 that potential output growth is only 1.0% per year would be overly pessimistic. The Kalman trend reflects the juxtaposition of slow output growth with the rapid decline of the unemployment gap over the past five years. An alternative approach would be to take a longer period as relevant as was already done in the introduction above. Table 1 displays growth rates of actual values of output, hours, and output per hour for the two five-year intervals making up the past decade, and the past decade as a whole. Productivity growth was much faster in 2004-2009 than in 2009-2014, and so the decadal average was 1.10% per year which exceeded the slower 0.55% achieved in the past five years. Hours growth switched from negative to positive after 2009 and averaged 0.45% per year over the decade.

One possible scenario for the future over the next decade or so would be for productivity growth to equal the pace of the past decade rather than the past five years and thus to average 1.10% per year, and for trend hours growth to average 0.4% per year. This would imply potential real GDP growth of 1.50% per year. This scenario of hours growth would be consistent with growth in the working age population equal to its Census forecast of about 0.9% per year minus 0.1% per year for hours per employee minus 0.4% per year for the baby-boom retirement component of the LFPR. The productivity forecast is based on the optimistic hope that the actual 0.55% growth rate of the past five years may be to some extent an outlier and may understate the underlying trend.

The suggested future path is compared in Table 1 with the actual record of the 30 years between 1974 and 2004, with output growth of 3.12%, more than double that of the 1.50 trend forecast. Of the 1.62% shortfall between 3.12 and 1.50%, exactly 1.0 percentage points is attributable to hours and 0.62% to productivity. By coincidence, this hours shortfall of 1.0 percentage point is quite close to the population shortfall of 1.2% that faced Hansen when he wrote about secular stagnation. [13]

Table 1 - Annual Growth Rates, Selected Intervals, 2004-14

	Real GDP	*Aggregate Hours*	*Real GDP per Hour*
2004:Q4 - 2009:Q4	0.83	-0.82	1.65
2009:Q4 - 2014:Q4	2.28	1.73	0.55
2004:Q4 - 2014:Q4	1.55	0.45	1.10
Future Trend	1.50	0.40	1.10
Memo: 1974-2004	3.12	1.40	1.72

■ Conclusion

Secular stagnation is evident in every measure of economic performance over the past five years, most notably the trend growth rates of output, labor productivity, and aggregate hours of work, respectively estimated for 2014 by a Kalman trend filter as 1.0, 0.75, and 0.25% per year. An alternative horizon of ten instead of five years computes 2004-2014 actual growth rates of these three variables as 1.5, 1.1, and 0.4% per year. Whether potential real GDP is currently running at one-third or one-half of the 3.12% average annual growth rate of output during 1974-2004, the repercussions are significant. Growth in real per-capita income over the past ten years has

13 The shortfall of 1.2 was calculated above as the difference between the 1.8% population growth achieved during 1895-1914 and 1920-1924 and the 0.6% average of 1933-1937.

been only 0.6% per year, less than one-third of the 2.1% achieved from 1890 to 2007. Further, the ratio of net investment to the capital stock has declined over the past five years to 1.0%, less than one-third of the average ratio achieved between 1950 and 2007.

This paper focuses on the slowing pace of innovation as the underlying cause of the slow rate of productivity growth achieved over the past five years. Innovation as measured by the growth rate of TFP reached its peak during the half century between 1920 and 1970, and since 1970 TFP growth has achieved only slightly more than one-third of the 1920-1970 average. The post-1970 productivity growth slowdown is attributed to diminishing returns in the payoff from the multi-dimensional innovations of the second industrial revolution that began in the late 19^{th} century. The third industrial revolution associated with digitalization and ICT achieved an impressive peak of productivity growth in the late 1990s, but its interval of rapid productivity growth lasted for only eight years as compared to the 50-year span achieved during 1920-1970.

The paper provides two separate arguments to explain slow productivity growth in the past five years. The first is that fundamental changes in business methods were concentrated in the dot.com era of rapid productivity growth and, once new equipment was installed and new business practices were adopted, the impact on productivity growth of the ICT revolution began to encounter diminishing returns. A second argument points to the measures of economic performance which all had the same timing, peaking in the late 1990s and declining to low levels in the last few years, including the ratio of net investment to the capital stock, the growth in manufacturing capacity, the rate of decline in the ICT price deflator, and the speed of improvement of microchip technology. Other waning measures of economic performance include the rate of new business start-ups and the fluidity of labor markets as measured by worker and job reallocation.

Secular stagnation is revealed as well in the contribution to productivity growth of declining educational attainment, which exhibits slowing progress, as measured by high school test scores, high school dropout rates, and rates of college completion. Social indicators, including declining rates of marriage, an increasing percentage of children living in one-parent households, and increasing incarceration rates of high-school dropouts and high school graduates, all suggest a future in which U.S. educational performance continues to deteriorate relative to that of other advanced nations.

HANSEN's original 1938 formulation of secular stagnation focused on population growth rather than potential GDP growth, not only because the concept of potential GDP had not yet been formulated, but because productivity growth was so rapid in the late 1930s. Today the U.S. faces three sources of declining potential real GDP growth emanating from the behavior of productivity, population, and labor-force participation. Slower growth in potential output from the supply side reduces the need for capital formation and cuts the share of total output devoted to net investment, and this in turn subtracts from aggregate demand and reinforces the decline in productivity growth. In the end secular stagnation is not about just demand or supply but also about the interaction between demand and supply.

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