The Demise of U. S. Economic Growth: Restatement, Rebuttal, and Reflections

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*This paper provides a sequel to my previous NBER working paper "Is U.S. Economic Growth Over: Faltering Innovation and the Six Headwinds," WP 18315, August 2012. Part of this research has been supported by the Kauffman Foundation. Jordan Jones and R. J. Singh were the talented research assistants who created the data set and charts. Andrew Sabene and Ryan Ayres provided comments and additional graphs. Several issues about future growth in this paper are informed by Erik Brynjolfsson and Andrew McAfee's new book (2014) and previous public debates with each of them. Carol Corrado generously provided the data in Figure 9 that help solve a puzzle posed by Figure 8. William Nordhaus provided a correction to my summary of his estimates of the cost in lost GDP of future global warming. Ian Savage provided a comparative analysis of the office support staff of the Northwestern economics department in 1998 and 2013.

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ABSTRACT

The United States achieved a 2.0 percent average annual growth rate of real GDP per capita between 1891 and 2007. This paper predicts that growth in the 25 to 40 years after 2007 will be much slower, particularly for the great majority of the population. Future growth will be 1.3 percent per annum for labor productivity in the total economy, 0.9 percent for output per capita, 0.4 percent for real income per capita of the bottom 99 percent of the income distribution, and 0.2 percent for the real disposable income of that group.

The primary cause of this growth slowdown is a set of four headwinds, all of them widely recognized and uncontroversial. Demographic shifts will reduce hours worked per capita, due not just to the retirement of the baby boom generation but also as a result of an exit from the labor force both of youth and prime-age adults. Educational attainment, a central driver of growth over the past century, stagnates at a plateau as the U.S. sinks lower in the world league tables of high school and college completion rates. Inequality continues to increase, resulting in real income growth for the bottom 99 percent of the income distribution that is fully half a point per year below the average growth of all incomes. A projected long-term increase in the ratio of debt to GDP at all levels of government will inevitably lead to more rapid growth in tax revenues and/or slower growth in transfer payments at some point within the next several decades.

There is no need to forecast any slowdown in the pace of future innovation for this gloomy forecast to come true, because that slowdown already occurred four decades ago. In the eight decades before 1972 labor productivity grew at an average rate 0.8 percent per year faster than in the four decades since 1972. While no forecast of a future slowdown of innovation is needed, skepticism is offered here, particularly about the techno-optimists who currently believe that we are at a point of inflection leading to faster technological change. The paper offers several historical examples showing that the future of technology can be forecast 50 or even 100 years in advance and assesses widely discussed innovations anticipated to occur over the next few decades, including medical research, small robots, 3-D printing, big data, driverless vehicles, and oil-gas fracking.

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1. Introduction

A controversy about the future of U.S. economic growth was ignited by my paper released in late summer 2012.[1] The debate began with my prediction that over some indefinite period of time into the future, perhaps 25 to 40 years, the growth of real per-capita disposable income of the bottom 99 percent of the U.S. income distribution would average 0.2 percent per year, compared to 2.0 percent per year in the century before 2007.[2] This prediction set off a firestorm of controversy with commentary, blogs, and op-eds around the world.

That paper was explicitly about the U.S. and recognized that there is plenty of room for "catch-up growth" in the emerging markets of the world. The growth concept is "potential" real GDP per capita from 2007, not actual real GDP from 2013. It attributed the slowness of future growth mainly to such "headwinds" as demography, education, inequality, and government debt. The subtitle "Faltering Innovation and the Six Headwinds" seemed to place primary emphasis on a future world with no innovation, and the primary role of the headwinds in predicting slow future growth escaped notice in the initial round of controversy about innovation.

This sequel paper recasts the debate to focus on the headwinds, which are formidable for the U.S. economy and may be less important in some other nations. In this sequel, there is no need to forecast that innovation in the future will "falter," because the slowdown in the rate of productivity growth over the past 120 years already occurred more than four decades ago. This sequel paper explains why the pace of innovation declined after 1972. The future forecast assumes that innovations in the next 40 years will be developed at the same pace as the last four decades, but reasons for skepticism are provided for that prediction..

The epochal set of inventions that occurred between 1870 and 1900, with continuing benefits to 1972, represent the fruits of the "Second Industrial Revolution" (IR #2). The growth rate of American productivity in the eight decades before 1972 was 2.36 percent per year, compared to 1.59 percent per year since 1972. That permanent decline of 0.8 percent per year represents a new way to measure the extent to which the single-dimension digital "Third Industrial Revolution" (IR #3) has fallen short of the multi-dimensional IR #2.[3]

This sequel paper compares the actual condition of the current 2013 U.S. economy with both optimistic and pessimistic future growth paths. By any measure, the U. S. economy continues to operate below even the most pessimistic projected post-2007 growth path, and we shall see that real per-capita income (for everyone, not just the bottom 99%) in 2013 was only one percent higher than six years earlier.

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[1] "Is U. S. Economic Growth Over? Faltering Innovation and the Six Headwinds" (Gordon, 2012).

[2] The 2012 paper, and even more this paper, are careful to distinguish forecast economy-wide productivity growth of 1.3 percent per year, output per capita for the total population of 0.9 percent per year, income per capita of the bottom 99% of the income distribution of 0.4% per year, and the disposable income (adjusting for faster tax growth and slower transfer growth) of 0.2 percent for the bottom 99%.

[3] Industrial Revolution #1, or IR #1, consisted of the invention of the steam engine, the cotton gin, and modern manufacturing in cotton mills in the period 1870-1820, culminating in the invention of the railroad and steamship. These IR #1 inventions were gradually eclipsed in most dimensions by IR #2, except for the railroad and steamships.

In addition to providing a new interpretation of the predicted future post-2007 path of potential real GDP per capita, this sequel paper assesses several different criticisms directed at the earlier paper. All of these issues involve future innovation, and none of the critics have denied that the headwinds facing the U.S. economy are formidable. Rather, the headwinds have largely been ignored by the critics who concur that any skepticism about future innovation reflects a lack of imagination.

An initial round of criticism pointed to the impossibility of forecasting future innovations. This paper counters with five historical examples from 1863, 1875, 1900, 1939, and 1949 in which many of the most important innovations of the following 50 to 100 years were accurately forecast and sketched out in substantial detail. In the same way, every techno-optimist has a list of revolutionary inventions that will occur over the next decade or two, including medical advances, small robots, big data, driverless cars, and oil-gas fracking. It is legitimate to compare today's forecasts of future inventions with those late 19th century inventions that were accurately forecast in 1863 or 1875. Which are more important?

The set of criticisms based on a faith in the future of technology can be simplified if we use the term "techno-optimists" to describe those who foresee an acceleration in the pace of innovation to a rate faster than has occurred in the past 40 years. A recent theme of the optimists has been that official measures of real GDP understate the consumer surplus provided by free entertainment and information available on the internet. This paper reminds readers that real GDP measures have *always* missed vast amounts of consumer surplus since the dawn of the first industrial revolution almost three centuries ago, and few examples are more compelling than the replacement of horses and horse manure in urban streets by the motor vehicle between 1900 and 1930.

This paper points to a contradiction between the actual macro data on productivity growth and the techno-optimists' predictions of accelerating growth. They fail to relate the "exponential growth of Moore's Law" to the reality that the economy's productivity performance for almost 10 years since 2004 shows no evidence of any any stimulus provided by the explosion of big data or invention of smart phones and tablets. Why should this be surprising? Marginal cost equals marginal benefit, and as electronic data becomes costless, its marginal benefit quickly approaches zero.

In the techno-optimist view, technological change is accelerating. Taken literally, this means that innovation will raise the growth rate of future productivity during 2013-23 faster than the rate of advance during 2003-13, which in turn must have been faster than the rate of change during 1993-2003. In contrast, this paper argues that diminishing returns have set in. Four pieces of evidence are provided that the post-1972 pace of technological change peaked in 1996-2000 and has been slowing down since then.

By its focus on potential real GDP growth after 2007, this paper has nothing to say about the pace of catch-up of actual real GDP to potential. During the catch-up period that began in mid-2009, we would exact actual real GDP to grow faster than potential. Because the output gap (the log percentage difference between actual and potential real GDP) remains substantial, actual real GDP could grow at 3.0 percent or more for several years without contradicting the forecast of this paper that potential growth over the next 25 to 40 years will be well below 2.0 percent per year.[4]

2. The Historical Record: Distinguishing Between Per-Capita Output and Productivity

The historical record of U. S. growth in real GDP per capita is shown on a log scale in Figure 1 for the 12 decades between 1891 and 2013. Viewed through this wide-angle lens, the green line traces the 2.0 percent annual trend achieved between 1891 and 2007 and extends it out 70 years from 2007 to 2077.[5] The steadiness of the 2.0 percent growth rate appears relentless and inexorable despite the vicissitudes of the Great Depression and the postwar recessions. Notice that the wide-angle lens hides the fact that per-capita GDP in 2013 was only 1.1 percent higher than in 2007, rather than the 12 percent higher implied by a 2.0 percent annual growth rate.

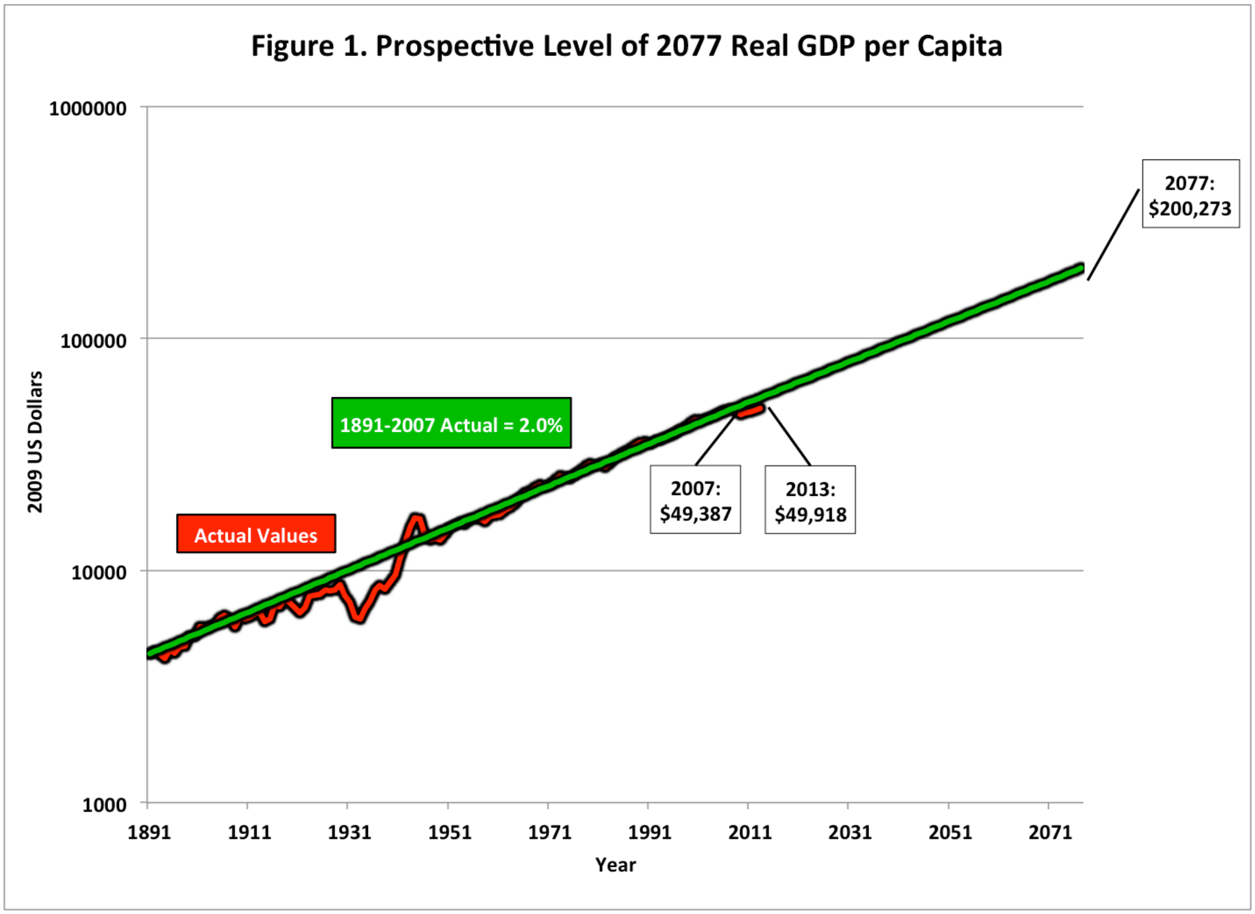
The "rule of 70" implies that any quantity growing at 2.0 percent per year doubles in 35 years and quadruples in 70 years. Hence the projection of the green line soars from a per-capita income of $49,387 in 2007 to a much higher $200,273 in 2077.[6]

(Figure 1 is at the top of page 4)

[4] Census Bureau projections of the total U.S. population imply growth through 2032 of 0.6 to 0.65 percent per year. Added to our forecast of 0.9 percent annual growth in per capita real GDP, the Census projections imply potential output growth of 1.50 to 1.55 percent per year.

[5] Data revisions since the earlier 2012 paper have nudged up the 1891-2007 growth rate from 2.01 to 2.08. For expositional convenience the historical growth rate is still summarized here as 2.0 percent per year.

[6] All national income data in this paper are in 2009 dollars and reflect the July, 2013, benchmark revisions of the National Income and Product Accounts. Thus all the numbers in these charts differ from those in the 2012 working paper. The "Rule of 70" is based on the fact that the natural log of 2.0 is 0.693. Thus a quantity growing at 2.0 percent per year quadruples in 69.3 rather than 70 years. This explains why the 2077 value in Figure 1 is slightly more than four times higher than the 2007 value.



The organizing principle to understand the significance of the headwinds is a simple identity:

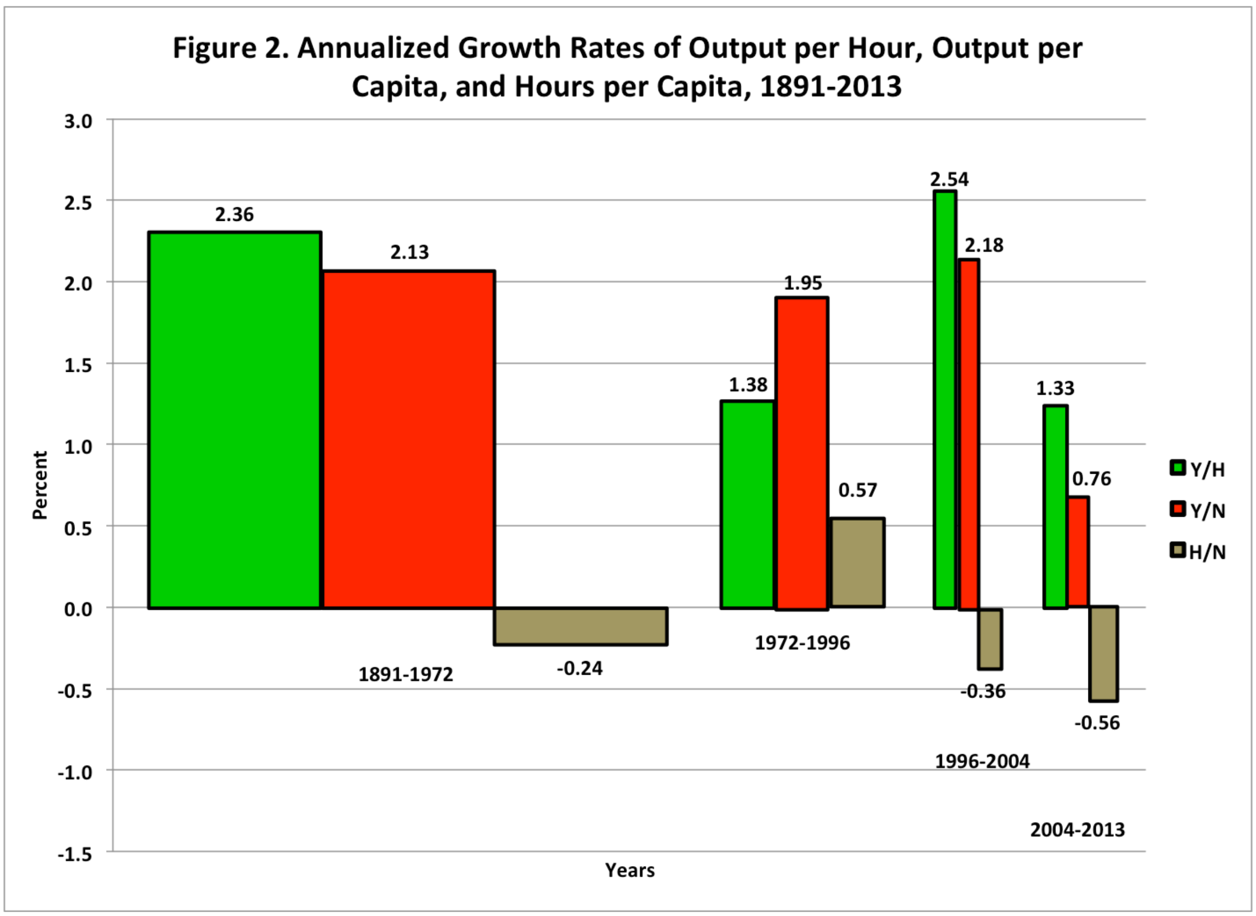
(1) $$\frac{Y}{N} \equiv \frac{Y}{H} \cdot \frac{H}{N} \cdot$$

This relates total output (Real Gross Domestic Product or *Y)* to aggregate hours of work in the total economy *(H)* and the total population *(N).* It states the truism that the standard of living measured by output per capita (*Y/N)* by definition equals labor productivity or output per hour *(Y/H)* times hours per capita *(H/N).*

Any factor that reduces the growth of productivity or of hours per capita must by definition reduce the growth rate of the standard of living, that is, output per capita. The headwinds can be introduced by an indication of their role in slowing future growth in per-capita real output. The first, demography, reduces hours per capita. It thus drives a wedge between the growth of productivity and the growth of output per capita. The second headwind involves education, which directly reduces productivity growth and *pari passu* translates into slower per-capita output growth without any necessary implications for hours per capita. The third headwind is growing inequality, and this does not directly impact any of the terms in equation (1), but rather limits the access of the bottom 99 percent of the income distribution to the *average* growth rate of per-capita real GDP. The fourth headwind is the eventual need to raise the growth rate of government tax rates and/or reduce the growth of transfer payments to put the budgets of the federal, state, and local branches of government onto a sustainable long-run growth path. This also does not directly impact the elements of equation (1), but rather reduces the growth of disposable income relative to pre-tax, pre-transfer income.

Two additional headwinds were introduced in the "Is Growth Over?" paper – globalization and energy/environment. While these are discussed below, no numerical quantities are proposed here for their impact on future growth.

Figure 2 puts equation (1) into motion by dividing the 122 years since 1891 into four shorter intervals, with the length of each interval indicated by the width of the bars. The height of each bar is measured in annual growth rates; the green bar is for productivity, the red bar for output per capita, and the grey bar for hours per capita.[7]



[7] The data sources for Figure 2 and all the other charts in this paper combine for output the current NIPA estimates for 1929-2013, ratio-lined to Kendrick (1961, Table A-IIa) from 1891 to 1929. Hours of work for the total economy covering 1948-2013 come from an unpublished quarterly BLS series that we obtain on request each quarter, linked in 1948 to Kendrick's aggregate "manhours" series going back to 1891 (Kendrick, 1961, Table A-X). The total population comes from Historical Statistics of the U.S. series Aa7 linked to Census Bureau series since 1999. Total economy productivity (Y/H) is the ratio of these linked real GDP series to the corresponding real hours series, an output per capita is the same real GDP series divided by the total population..

Each of these four intervals has distinct characteristics.[8] The first for 1891-1972 displays the normal tendency of hours per capita to decline, by definition forcing output per capita to grow more slowly than productivity. This relationship was reversed in the next 1972-96 interval, when females moved from home into market work, causing hours per capita to rise by 0.57 percent per year. This allowed output per capita to grow at 1.95 percent per year, that is, 0.57 percent *faster* than productivity growth. Note that productivity growth itself declined by a full percentage point between the first two intervals. The entry of females (and also baby-boom teenagers) into the labor force allowed real GDP per capita to grow during 1972-96 almost as rapidly as in 1891-1972, even though productivity growth was substantially slower.

The most fertile subperiod of IR #3 occurred between 1996 and 2004. Productivity growth in Figure 2 soared between the second and third periods from 1.38 to 2.54 percent per year, enough to lift per-capita output growth to 2.18 percent despite a historically unprecedented decline in hours per capita at an annual rate of 0.36 percent per year. What is notable about the third period of 1996-2004 is not only how short-lived was the productivity revival associated with the invention of e-mail, the internet, the web, and e-commerce, but also how part of this short-lived productivity revival was offset by the beginning of a historic decline in hours per capita.

Everything collapsed after 2004. Productivity growth returned from its temporary 1996-2004 growth rate of 2.54 to a mere 1.33 percent in the nine years ending in 2013. Hours per capita declined at an annual rate of more than half of a percentage point per year, leaving the standard of living to grow at its slowest rate of the four periods in Figure 2, a mere 0.76 percent per year.

A possible reaction is that the abysmal results for 2004-2013 can be ignored, because "it's all due to the recession and slow recovery." Unfortunately, the collapse of productivity growth cannot be so easily dismissed, because productivity growth is no longer procyclical. My own econometric research and that of others demonstrates that the previous procyclical responses of productivity changed after the mid 1980s, and that productivity growth now has no regular relationship to the business cycle.[9]

What accounts for the decline of hours per capita after 1996? By definition, the ratio of hours per capita is equal to hours per employee, times the ratio of employment to the labor force (that is, unity minus the unemployment rate expressed in decimals), times the labor-force participation rate. In symbols, $H/N \equiv H/E * E/L * L/N$. The table below calculates the 1996-2013

[8] Data displayed in Figure 2 differ from charts displayed in presentations and speeches over the past year by repairing inconsistencies. Previous charts mixed the total population for 1891-1948 with the working-age population for 1948 to the present, whereas all charts in this paper are based on the total population. The data in this paper also extend the analysis to 2013 and incorporate the July, 2013, revision of the national accounts and all recent revisions up to December 5, 2013, in BLS data on aggregate hours of work in the total economy from 1948:Q1 to 2013:Q3. Another difference is that all growth rates here are calculated from annual average levels, whereas postwar growth rates in the 2012 paper were calculated between the first quarters of the listed years, e.g., 1948:Q1-1972:Q1.

[9] See Gordon (2010) for evidence that productivity changes are no longer procylcical.

growth rates of the components of this definition, taking note that there are two alternative definitions of the population. The first is the total population of the United States, 316.1 million in 2013. The second is the working-age population aged 16 and higher, 245.7 million in 2013. The difference is made up of children between ages zero to 15.

Components of Hours per Capita, Annual Growth Rates 1996-2013	
1 Payroll Hours / Total Population (H/N)	-0.47
2 Payroll Hours / Household Employment (H/E)	-0.28
3 Household Employment / Labor Force (E/L)	-0.13
4 Labor Force / Working-Age Population (L/WAP)	-0.32
5 Working-Age Population / Total Population (WAP/N)	+0.25
6 Payroll Hours / Working-Age Population (H/WAP)	-0.72

Shown in the table are two quite different growth rates for hours per capita *(H/N).* The rate of decline is substantially faster when the population is defined as those aged 16+ than when data for the total population are used. This distinction matters for forecasts, as population growth over the 2015-2050 period is predicted to be roughly 0.6 percent per year for both the total and working-age population concepts.[10] The historical behavior of hours relative to the working-age population is what matters to guide forecasts, since hours of work for children aged 0 to 15 are meaningless. Differences in the growth rates of the total and working-age population reflect short-term variations in birth and death rates and the pace of immigration rather than workplace-related decisions of those aged 16 and older.

During the interval 1996-2013 the employment rate (100 percent minus the unemployment rate) declined at an annual rate of -0.13 percent. For long-run forecasts, the employment rate should be roughly constant over decades and so its rate of change should be zero. Payroll hours divided by household employment *(H/E)* declined at the relatively rapid rate of -0.28 percent per year during 1996-2013, reflecting the continuing pressure by firms to force their employees into part-time work, as well as an ongoing preference by some groups in the population for part-time work.

The largest component of change was in the labor-force participation rate, which changed over this interval at an annual rate of -0.32 percent per year. Since the retirement of the baby-boomers had hardly started until the very end of the 1996-2013 interval, this relatively rapid rate of decline in the *L/N* ratio reflects the continuing process of labor-force drop-out by adults and youth discussed below, only a small part of which is explained by increased participation by youth in higher education.

[10] Population growth estimates for 2012-2050 can be found at http://www.census.gov/population/projections/data/national/2012/summarytables.html

3. A Restatement of the Case for Slow Future Growth: The Headwinds

The 2012 paper emphasized the contrast between IR #2 and IR #3, providing many examples to explain why the set of inventions that created a new world between 1870 and 1970 could not be repeated. The role of the headwinds in slowing recent and future growth was an afterthought, treated at the end of that paper. This sequel reverses this ordering, since the headwinds are both more important and less controversial. The role of the headwinds is discussed in this section, and later we turn to the role of innovation in the past, its slowdown four decades ago, and its likely behavior in the future.

3.1 The First Headwind: Demography

A standard assumption in every economic forecast is that the retirement of the baby boomers will reduce hours per capita independently of any other cause. The denominator of the H/N ratio is the total population. Whenever a person retires, he or she remains in the population while making a transition from positive to zero hours of market work. The baby-boom retirement phenomenon matters because of the bulge in the fertility rate extending from 1946 to 1964. The 1946 babies were eligible for early Social Security status at age 62, that is, in 2008, while the oldest group born in 1964 will be eligible for full benefits at age 70 in 2034. That period, 2008-2034, represents a full quarter of a century in which baby-boom retirement will drag down hours per capita.

But that is not all. Even if the future unemployment rate returns to its 2004 value of 5.5 percent and the employment rate returns to 94.5 percent, there will still be downward pressure on the other two components of hours per capita, namely hours per employee and the labor-force participation rate. The former has been reduced in part by America's dysfunctional medical care insurance system, which ties medical insurance to employment rather than providing it as a right of citizenship. Firms have increasingly pushed employees into part-time status in order to avoid paying medical insurance costs, and today roughly eight million Americans are involuntarily working part-time while seeking full-time employment.

A unique feature of the slow 2009-2013 economic recovery has been the fact that the employment rate has been steadily improving while the participation rate has been declining, so that there has been virtually no improvement in the employment-to-population ratio ($E/N \equiv E/L*L/N$). In fact, over the four years of recovery between December 2009 and December 2013, the employment rate increased from 90.1 to 93.3 percent, but the E/N ratio barely budged from 58.3 to 58.6 percent (this compares to prior peaks of 64.4 percent in 2000 and 63.0 percent in 2007. The decline in the labor-force participation rate has prevented any recovery in the employment-population ratio.

The decline in the participation rate involves more than just baby-boom retirement. In late July, 2013, President Obama toured several rust-belt cities which have lost most of their manufacturing jobs base. Cities like Galesburg IL, Scranton PA, and Syracuse NY are now mainly reliant on government, health-care, and retail jobs. In Scranton 41.3 percent of those over 18 have withdrawn from the work force, while in Syracuse that percentage is an even higher 42.4 percent.[11]

The devastating effect of manufacturing plant closures throughout the Midwest is captured by remarks of the newly appointed British Consul-General in Chicago, who toured the Midwest during the autumn of 2013 in the first three months of his four-year term. Asked for impressions of his travels, he said "what surprised me most was the deterioration and decay of the former one-factory small and middle-sized manufacturing towns." [12] Asked for a comparison with Northern England, he responded that Northern English towns are much closer together so are not dependent on any individual factory, and that immigration from India and Pakistan had done much to revive them.

What does the 1996-2013 experience, as recorded above in the in-text table, imply for the future? Holding the employment rate constant, hours per capita for the working-age population declined at -0.60 percent per year, combining the -0.28 rate of decline for hours per employee and the -0.32 rate of decline for the labor-force participation rate. Since baby-boom retirement began only at the end of this time interval, a forecast for the participation rate would anticipate a more rapid rate of decline than occurred since 1996. However, part of the declining participation rate of prime-age adults and youth may reflect the depressed labor market of 2013 and may reverse as prosperity returns in the future.

Over the historical period 1891-2007, hours relative to the total population declined at only about -0.1 percent per year. For our projections, we take the conservative choice of -0.4 percent per year in the future in preference to the actual -0.6 percent per year registered during 1996-2013 by the sum of the rates of decline of hours per employee and the labor-force participation rate. Thus the first demographic "headwind" subtracts -0.3 percent per year from future growth over the next few decades following 2007 as compared to the -0.1 percent rate of change experienced during 1891-2007.

3.2 The Second Headwind: Education

Since Edward Denison's (1962) first attempt, growth accounting has recognized the role of increasing educational attainment as a source of economic growth. Goldin and 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. In separate research, I have adjusted Denison's estimates for 1913-79 to current BLS methodology and find an average contribution of education of 0.38 percent per year, almost identical to that of Goldin and Katz.

[11] http://opinionator.blogs.nytimes.com/2013/08/21/hard-times-for-some/?hp

[12] This paragraph reports on a dinner conversation at the home of the British Consul-General in Chicago on November 20, 2013.

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 percent of youth in 1900 to 80 percent 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 percent 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.[13] 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.[14]

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 below a fixed international standard in reading and math. The international PISA tests in 2013, again referring to secondary education, rated the U.S. as ranked 21st in reading, 24th in science, and 31st in math. A recent evaluation by the ACT college entrance test organization showed that only 25 percent 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 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 30 percent, but that is ranked now 16th among developed nations.

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.[15] Between 2001 and 2012 funding by states and localities for higher education declined by fully one-third when adjusted for inflation. In 1985 the state of Colorado provided 37 percent of the budget of the University of Colorado, but last year provided only 9 percent. Presidents of Ivy League colleges and other elite schools point to the lavish subsidies they provide as tuition discounts for low- and middle-income

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[13] 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.

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

[15] 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.

students, but this leaves behind the vast majority of American college students who are not lucky or smart enough to attend these elite institutions.

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 trillion in college debt. While a four-year college degree still pays off in a much higher income and lower risk of unemployment than for high-school graduates, still about one-quarter of college graduates will not obtain a college-level job in the first few years after graduation. "Dear graduate, face your future as an indebted taxicab driver or barista."

Students taking on large amounts of student debt face two kinds of risks. One is that they fall short of the average income achieved by the typical college graduate, through some combination of unemployment after college and an inability to find a job in the chosen field of study. Research has shown that on average a college student taking on $100,000 in student debt will still come out ahead by age 34, with the higher income made possible by college completion high enough to offset the debt repayment. But that break-even age becomes older if future income falls short of the average graduate. There is also completion risk. A student who takes out half as much debt but drops out after two years never breaks even because wages of college drop-outs are little better than those of high-school graduates. These risks are particularly relevant for high-achieving students from low-income families -- Stanford's Caroline Hoxby has shown that they seldom apply to elite colleges, which are prepared to fund them completely without debt, so they wind up at sub-par colleges loaded with debt (Hoxby-Avery 2013).

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 percent of American undergraduates, whereas the remaining 61 percent enroll in four-year colleges. The Center on International Education Benchmarking reports that only 13 percent of students in two-year colleges graduate in two years, although the percentage rises to 28 percent 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.

As a result of stagnation of educational attainment, Harvard's Dale Jorgenson has estimated that education's growth contribution will decline in the future by 0.27 percent per year. Jorgenson's estimate has become a consensus view, being adopted in the latest series of sources-of-growth projections by Bryne, Oliner, and Sichel (2013). In assessing the importance of the headwinds for future growth, we conservatively mark down the Jorgenson -0.27 growth subtraction to -0.2 percent per year. Together with the -0.3 percentage point subtraction for demography, this brings predicted future growth of real GDP per capita down from 2.0 to 1.5 percent per year.

3.3 The Third Headwind: Inequality

The share of the top one percent of the income distribution was high during the early years of the historical record from 1913 to 1929, fell dramatically to a much lower level during the 1950s through early 1970s, and has increased steadily since the late 1970s until it once again has reached the high share of 1913-29. Thus when we calculate growth rates of real income for the bottom 99 percent of the distribution, they are the same as the average when 2007 is compared with 1913, but they are substantially lower than the average over the past three decades. The web site of Emmanuel Saez reports that between 1993 and 2012, the average growth rate of real income for the bottom 99 percent of the income distribution was 0.53 percent slower than for the average of all income recipients. My adjustment for the effect of inequality in the future assumes that the widening of the income distribution continues at a rate that causes the growth of real income of the bottom 99 percent to grow 0.5 percent per year slower than the average.

Another indicator of the sharp divide between median and average real income growth is provided in the Census series on median real household income. Expressed in 2011 dollars real median household income in 2012 was $52,100, below the 1998 level of $53,700. For median household income to exhibit no growth over the past 14 years provides evidence beyond the Saez tax-based data that real income growth in middle America has already reached zero. For many Americans my pessimistic predictions for the future have already become a fact.

Recently there has been substantial publicity for the plight of fast-food workers, most of whom are paid little more than the minimum wage. The bottom 20 percent of American workers classified by income earn less than $9.89 per hour, and their inflation-adjusted wage fell by five percent between 2006 and 2012, while average pay for the median worker fell 3.4 percent. Holding down wages is an explicit corporate strategy at retail firms like Wal-Mart, which hires only temporary workers to fill job openings and forces many of its workers onto part-time shifts.[16] Similarly, the *Wall Street Journal* writes that

> Economic changes over the past decade have led to a decline across the country in well-paying jobs, such as those in manufacturing, and an increase in jobs that pay less, such as those in hotels and food services . . . Positions are increasingly being filled not with the young and inexperienced, but by older and more skilled workers who can't find other jobs.[17]

The Caterpillar corporation has become the poster child of rising inequality. It has broken strikes in order to enforce a two-tier wage system in which new hires are paid half of existing workers, even though both groups are members of the same labor union. In contrast there was an 80 percent increase over the past two years in the compensation of Caterpillar's CEO, whose quoted mantra is "we can never make enough money . . . we can never make enough profit."[18]

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[16] Facts in this and the next paragraph come from Steven Greenhouse, "Fighting Back Against Wretched Wages," *New York Times*, July 28, 2013.

[17] "Roots of the Living Wage Wave," *Wall Street Journal*, August 10, 2013.

[18] http://www.chicagobusiness.com/article/20130517/BLOGS08/130519807/caterpillar-ceo-we-can-never-make-enough-profit

Foreign companies like Volkswagen continue to open plants in the non-union right-to-work states; by lowering wages as compared to the union-dominated northern states, this surely helps to keep overall U.S. manufacturing employment from declining further. But this countervailing pressure against continuing manufacturing employment is contingent on maintaining worker wages at about half the level that the auto union had achieved for its workers before the bankruptcy of General Motors and Chrysler. In the 2009-2013 recovery, manufacturing regained only 600,000 of the 6 million jobs that had been lost since 2001, and most of those were contingent on hiring workers at wage rates that were much lower than were common in manufacturing as recently as 2001.[19]

And the downward pressure on wages at the bottom and middle continues, with Boeing's threats to move the manufacturing of its latest 777-X model away from the unionized Seattle area after the Seattle union workers rejected a contract that called for a wage freeze, a reduction in company-paid medical benefits, and a transition from the previous defined-benefit pension plan to a new IRA-type defined contribution plan. After Boeing offered a new contract proposal that was slightly more favorable to the workers, they voted narrowly and reluctantly to accept the reductions in wages and pension contributions in order to preserve their jobs.

Any optimist who thinks that the rise of inequality has ended is not paying attention to the deterioration of the social and economic condition of Americans, as family breakup and breakdown deprive millions of children of the traditional support of a two-parent household. Charles Murray's *Coming Apart* (2012) documents the decline of every relevant social indicator for the bottom third of the white population.

Murray admirably presents his data in a series of charts from government data sources that uniformly extend from 1960 to 2010. For the bottom one-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 percent in 1960 to 58 percent in 2010. The breakup of the family is documented by three complementary indicators all referring to the 30-49 age group: percent married down from 85 to 48 percent, percent never married up from 8 to 25 percent, and percent divorced up from 5 to 33 percent.

The most devastating statistic of all is that for mothers aged 40, the percentage of children living with both biological parents declined from 95 percent in 1960 to 34 percent in 2010. Children living in a single parent family, usually with the mother as the head of household, are more likely to suffer from poverty and lack of motivation, and are more likely to drop out of high school. The educational and inequality headwinds interact in a multiplicative way and predict a continuing slippage of the U.S. in the international league tables of high school college completion rates. .

In previous sections we have reduced the future growth rate of per-capita income from the historic pre-2007 growth rate of 2.0 per year to 1.5 percent as a result of the demographic

[19] Rattner (2014).

and education headwinds. The inexorable rise of inequality reduces prospective future growth further by 0.5 percent, from 1.5 to 1.0 percent per year, for the bottom 99 percent of the income distribution. There is room for debate as to whether the gap between the top one percent and the bottom 99 percent will continue at the same rate as in the past two decades, but there is no doubt that it is continuing to rise.[20]

3.4 The Fourth Headwind: Repaying Debt

The future reckoning for the indebtedness of government at the federal, state, and local levels will arrive at some unknown year over the next several decades. While the Congressional Budget Office currently estimates that the federal ratio of debt to GDP will stabilize between 2014 and 2020, its optimism is based on unrealistically optimistic economic forecasts.

But even the CBO projects that trouble lies ahead beyond 2020. The Medicare trust fund is predicted to reach a zero balance in 2026, while the zero-balance date for Social Security has steadily advanced (due to slow economic growth and larger disability claims) from the projected 2047 date estimated six years ago to the latest projected zero-balance date of 2033. By definition any stabilization of the federal debt-GDP ratio, compared to its likely steady increase with current policies, will require more rapid growth in future taxes and/or slower growth in transfer payments. This is the fourth headwind, the near-inevitability that over the next several decades the disposable income of the bottom 99 percent of the income distribution will decline relative to the average real income before transfers of the same bottom 99 percent group.

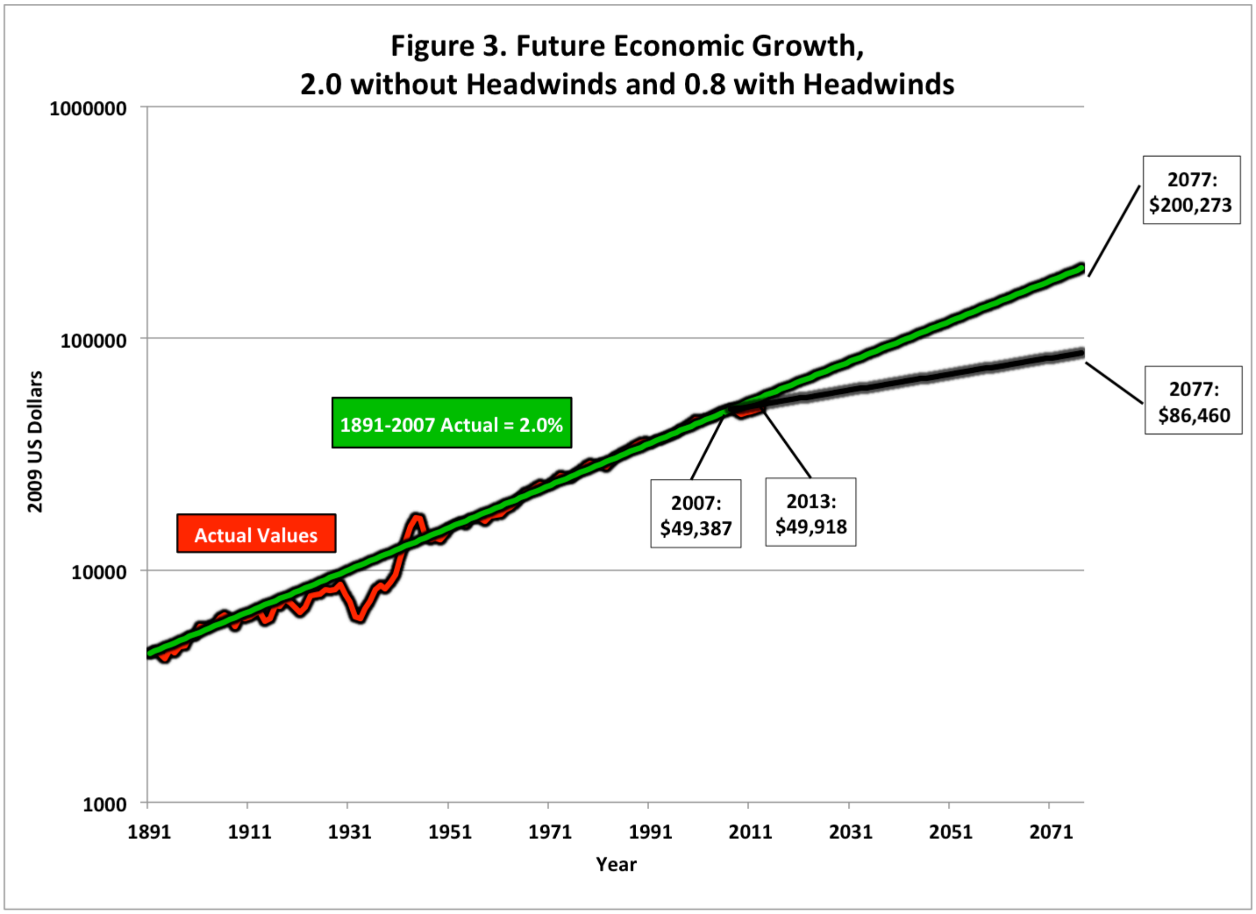
A sole focus on the federal debt ignores the unfunded pension liabilities of many of America's states and localities. The bankruptcy of Detroit has led municipal bond experts to ask whether Illinois and Chicago could be far behind, not to mention other large states with massive unfunded pension liabilities. The projection in this paper that future growth in tax rates and/or slower growth of government transfers will reduce the growth rate of disposable income in the future by 0.2 percent is admittedly arbitrary but a reasonable number in face of the risks.

Starting from the 2.0 percent annual growth rate of real per-capita GDP between 1891 and 2007, we have now subtracted 0.3 percentage points for demography, 0.2 for education, 0.5 for inequality, and 0.2 for future fiscal corrections. This brings the total down to 0.8 percent even though no mention has yet been made of innovation or productivity growth. These four headwinds alone are sufficient to cut likely future U. S. economic growth by more than half, again with the careful qualification that this future projection refers to the *disposable income of the bottom 99 percent of the income distribution*, not the average per-capita income of the nation as a whole.

We started with the green projected line growing at 2.0 percent per year. This was sufficient to bring the level of real per-capita output to $200,273 in 2077. Now, with the

[20] The income share of the top one percent exhibits fluctuations that reflect the ups and downs of the stock market. The 32 percent gain of the S&P 500 stock market index in 2013 (including dividends) assures that the income share of the top one percent will reach a new high in 2013 relative to previous local maximums in 2000 and 2007.

adjustment for the four headwinds, the 2077 projection is a much lower $86,460, as shown in Figure 3.



3.5 Other Headwinds

The 2012 working paper included two additional headwinds called "globalization" and "energy/environment." There is no need to quantify their possible future influence, as the headwinds discussed above are sufficient to validate the pessimistic forecasts contained in the 2012 paper. This section places these additional headwinds in perspective.

Globalization is difficult to disentangle from other sources of rising inequality. Plant closings caused by off-shoring are also responsible for part of the demographic headwind by causing prime-age workers to leave the labor force when their one-factory town experiences a plant closure. There has been a major loss of high- paying manufacturing jobs that long antedates the 2008 financial crisis and 2007-09 recession. Charles, Hurst, and Notowidigdo (2013) have shown that roughly half of the seven million person loss of manufacturing jobs between 2000 and 2011 occurred before 2008. The time period 2000-07 witnessed the maximum impact of the increase in Chinese manufacturing capacity that flooded the U.S. with imports, boosted the trade deficit, and caused plant closings and ended the chance of millions of workers to enjoy middle-income wages with no better than a high-school diploma. According to their analysis, the only reason that the economy experienced an economic expansion rather than contraction in the years leading up to 2007 was the housing bubble which allowed many of the displaced manufacturing workers to obtain temporary jobs in the construction industry.

Globalization is also responsible for rising inequality through another channel. The U.S. has benefitted from foreign investment, particularly in the auto industry, but this has been directed almost exclusively at the right-to-work states, largely in the south, where foreign firms are free to pay workers whatever they want. Wages of $15 to $20 per hour, compared to the old standard of $30 to $40 per hour achieved before 2007 in union states like Michigan and Ohio, are welcomed by residents of the southern states as manna from heaven, and new plant openings are greeted by long lines of hopeful workers at the hiring gates. Globalization is working as in the classic economic theory of factor price equalization, raising wages in developing countries and slowing their growth in the advanced nations.

Another headwind discussed in the 2012 paper was "energy/environment." This set of complementary topics remains highly controversial. Optimistic pundits point to vast new fields of gas and oil made possible by fracking as fundamentally changing the competitiveness of American industry by creating a cheap source of energy that is not available to other countries outside the North American continent.

The first distinction to make is between oil fracking and gas fracking. The price of oil is set in world markets, and so additional oil discoveries that may ultimately make the U. S. oil-independent have no impact on the price of oil in the world and in the U.S. That depends on the worldwide balance of oil demand and supply. In mid-January 2014 the price of West Texas crude oil was $94 per barrel compared to $11 per dollar in February 1999. The sustained increase in the price of crude oil over the past decade, due in large part to the increased demand from China and other emerging economies, hangs as an ominous shadow over current and future U. S. economic growth. Higher oil prices raise not just gasoline prices at the pump and increase airline fares, draining household disposable income, but increase manufacturing costs for any product based on petroleum, including most types of plastics.

Because natural gas cannot be easily transported between continents, the gas fracking revolution in the U.S. is more of a boon. But this is not a positive boost to productivity in the sense of the invention of commercial aviation, air conditioning, or the interstate highway system. Rather, the cheaper price of gas that is unique to the North American continent will help offset the rising cost of oil and will lead to a welcome substitution of gas not just for oil but for coal, helping to reduce the growth of carbon emissions as well as reducing costs in energy-intensive industries. Gas fracking represents an example of an innovation that has recently occurred and will continue into the future, but its overall impact is to provide an offset to higher oil prices, not as a new independent source of economic growth analogous to electricity or the motor vehicle. Gas fracking has been a boon to employment in North Dakota but has caused despair in the coal-mining areas of Kentucky and West Virginia.

It is beyond the scope of this paper to discuss the large topic of global warming and environmental policy. While the extent and likely effects of global warming are subject to debate, there is little doubt that they are occurring and will create weather events – whether coastal flooding or more frequent and violent tornadoes – that will reduce future economic growth and raise insurance premia. Future carbon taxes and direct regulatory inventions like the CAFÉ fuel-economy standards will divert investment from true innovations into research that has the sole purpose of improving energy efficiency and fuel economy. Economic or regulatory pressures that force households and firms with machinery or consumer appliances that are operationally equivalent but more energy-efficient, at substantial capital cost, are quantitatively and qualitatively different than the early 20th century innovations that replaced the ice-box by the electric refrigerator or replaced the horse by the car.

One of the world's great experts on global warming, William Nordhaus (2013) has quantified its effects on economic growth. A stunning aspect of his research is that the impact of a 3 degree (C) warming in the global temperature in the next 70 years would reduce global real GDP per capita by only around 2.5 percent.[21] That translates as an annual subtraction of growth of -2.5/70 or 0.036 of a percentage point per year, trivial compared to the estimates in this paper of a negative impact of -0.3 percent for demography and -0.2 percent for education. Nordhaus' estimates are based on a hypothetical failure of worldwide policy to take explicit new measures to fight global warming.

One last headwind was not discussed in the 2012 paper nor is it pursued here. The unique American decision as a society to base medical care insurance on the status of employment, instead of making medical care protection a right of citizenship, reduces the current and future efficiency of the American economy by as much as six or seven percent of GDP. David Cutler and Dan Ly (2011) have calculated that if the U.S. had the same ratio of medical care expenses to GDP as does Canada, the level of U. S. medical care expenditure would be lower by $1 trillion per year. A medical care system on the Canadian model would not only save enormous resources that could be devoted to other social purposes but would raise life expectancy by allowing the entire population access to preventive medical care.[22]

4. Comparing Current Per-Capita Real GDP with Optimistic and Pessimistic Projections

All the projections in this paper compare the 2.0 realized growth rate of U. S. per-capita real GDP between 1891 and 2007 with alternative forecasts beyond 2007. The horizon date of 2077 is chosen for arithmetic convenience related to the "rule of 70." If real GDP per capita were to continue to grow at 2.0 percent per year, it would quadruple between 2007 and 2077.

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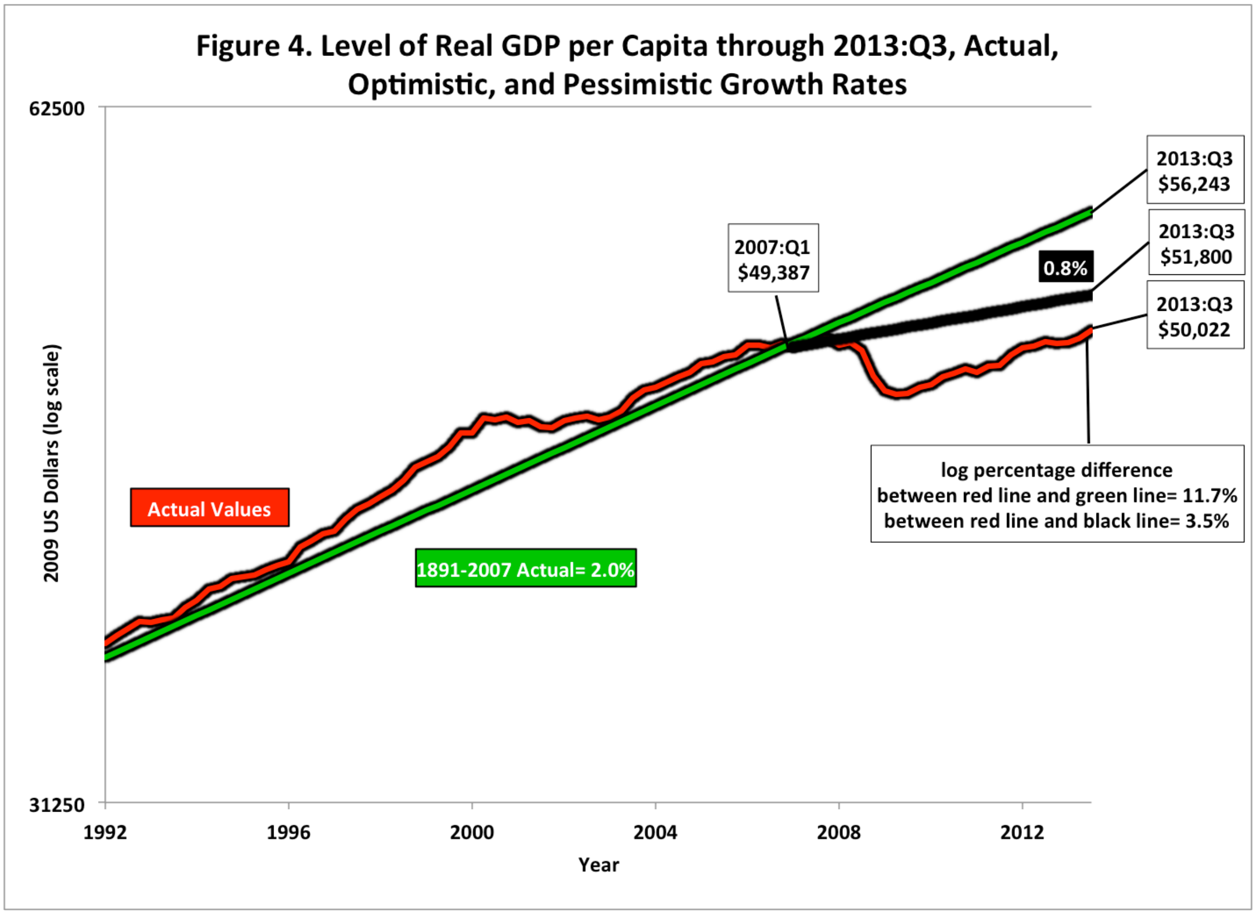
[21] Thanks to Bill Nordhaus for correcting the numbers in this sentence. He reports that this calculation is based on the DICE-2013R model. DICE stands for "Dynamic Integrated model of Climate and the Economy."

[22] According to the World Health Organization, Canada is tied in fourth place with a life expectancy at birth of 82 years, while the U.S. is tied in 33rd place with a life expectancy of 79 years.



We are not in 2077 to assess the outcome, but rather we are near the beginning of the forecast period. The red line in Figure 4 displays the level of actual real per-capita GDP through 2013:Q3 and compares the actual outcome with the optimistic (green line) forecast that growth after 2007 will continue at 2.0 percent and the pessimistic (black line) forecast of 0.8 percent growth after 2007. This comparison is biased in favor of the actual outcome to date, because the data plotted are *average* real GDP per capita rather than the realized income of the bottom 99% which is the focus of the pessimistic forecast. Nevertheless it is enlightening to see how far is the economy below the 0.8 percent post-2007 growth path, much less the 2.0 percent post-2007 growth path.

If per-capita real GDP had grown at 2.0 percent after 2007:Q4, then by 2013:Q3 the amount would have increased to $56,243. Yet the actual amount of $50,022 fell short of the optimistic prediction by 11.7 percent, and it even was 3.5 percent below the pessimistic black-line forecast that takes account of growing inequality. It is easy to dismiss these ratios as "transitory" because the economy is mired in a "slow recovery." Meanwhile, when growing inequality is considered, median real household income still remains below its value in 1998.

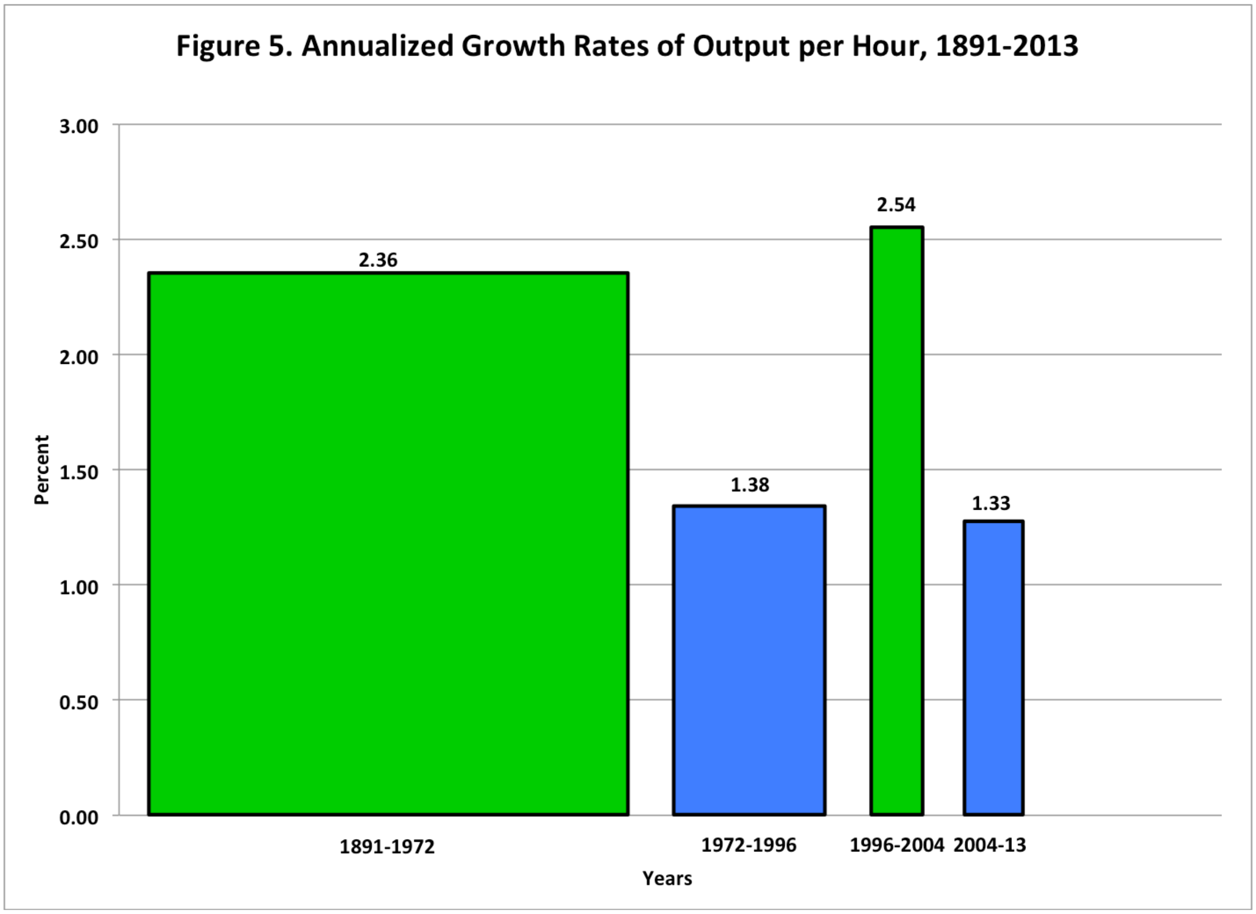
5. A Restatement of the Innovation Contribution and Its Future

5.1 The Data Since 1891

The pessimistic forecast in this paper for future U.S. economic growth in the disposable income of the bottom 99 percent of the income distribution does not depend on any skepticism about the pace of future innovation. The forecasts here are consistent with a continuation of innovation at the pace of 1972-2013, which produced productivity growth substantially slower than the eight prior decades of 1891-1972. We start from the historical record displayed above in Figure 2 on the growth rates of productivity, output per person, and hours per person over the four intervals 1891-1972, 1972-96, 1996-2004, and 2004-2013. Now we simplify that graph to show only the growth rates for productivity, that is, total economy output per hour, over the same intervals as in Figure 2.

When the time intervals are divided in this way, we discover an important fact about historical productivity growth that has not been widely recognized. American history since 1891 can be divided into two "good" (i.e., green) intervals and two "bad" (i.e., blue) intervals. In my interpretation IR #2 of the late 19th century and all of its complementary inventions that extended until 1972 created an unbroken chain of 81 years in which productivity grew fast enough to double every 29 years. There was a distinct watershed at 1972 for reasons discussed below, and the following 41 years include the two blue periods interrupted for only 8 years by the green productivity growth interval associated with the invention of the internet, web, and e-commerce. Subsequently we will examine other dimensions of the 1996-2004 period that make it unique and unlikely to be repeated.

The post-1972 slowdown which lasted until 1996 created its own large literature on the cause or causes of the slowdown, containing speculation about energy prices, infrastructure, education, and much else. Robert Solow in 1987 captured the frustration created by the slow pace of productivity growth by quipping "We can see the computer revolution everywhere but in the productivity statistics." But soon the revolution began to revive the productivity statistics – it took the experts a few years to wake up, but the post-1995 revival was first noticed in early 1999 and then popped into widespread recognition with the benchmark revisions of the National Income and Product Accounts that occurred in July, 1999.



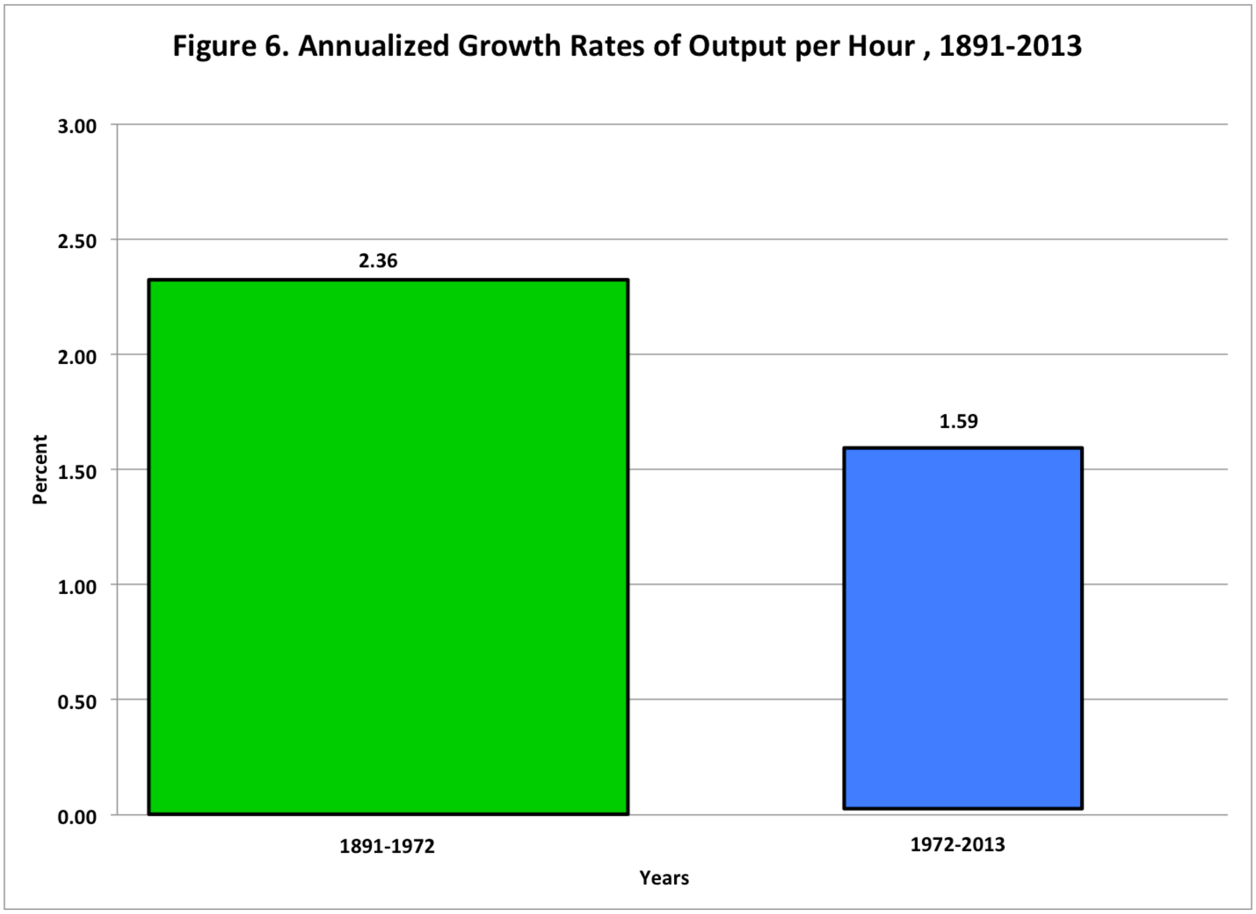
However, the internet-led productivity revival did not last long, and thus was a big disappointment compared to the eight-decade stretch of rapid productivity growth between 1891 and 1972.. The boom of the late 1990s was driven by an unprecedented and never-repeated rate of decline in the price of computer speed and memory (see Figure 10 below), and a never-since matched surge in the share of GDP devoted to information and communication technology (ICT) investment. The ICT share in GDP declined along with the stock market in 2000-2002, leaving a subsidiary mystery of why productivity growth continued to be so strong until early 2004. Convincing research by Erik Brynjolfsson and his colleagues suggested that there was a substantial lag between the production and purchase of computer investment and the learning curve of how to use all the new equipment efficiently and productively.[23] One of many examples was the installation in airport lobbies of electronic check-in kiosks, a product of late 1990s technology that was not implemented until 2001-04.

The further time moves forward year after year beyond that golden 1996-2004 interval, the more clear it becomes that the effect of the internet in creating IR #3 provided only a temporary boost to productivity growth. Why is the effect of computers not visible in the productivity statistics for 1972-96? Mainframe computers created bank statements and phone bills in the 1960s, airline reservation systems in the 1970s, personal computers, ATMs, and bar-code scanning in the 1980s, all before the internet revolution of the 1990s. The slow growth of productivity evident in the Figure for 1972-96 indicates that the contributions of the first round

[23] See Brynjolfsson, Hitt, and Yang (2002).

of computer applications partially masked an even more severe slowdown in productivity growth than would have occurred without the contribution of the early applications of computers.

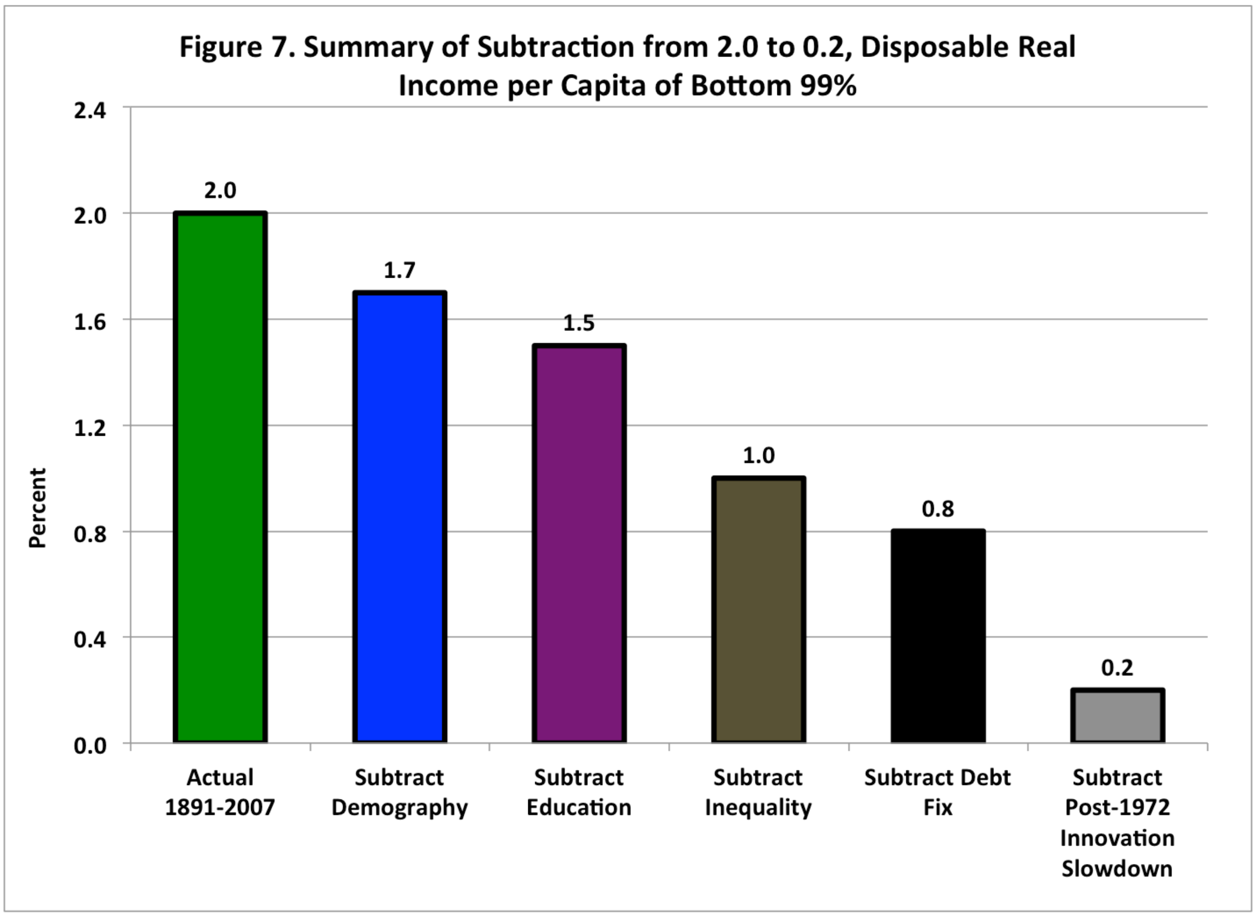
The final blue bar in Figure 5 displays productivity growth over the nine-year period 2004-2013 and reinforces the finding that the dot.com boom period of the late 1990s was unique and thus far has not been repeated. The growth rate of output per hour during 2004-2013 was slightly slower than the "dismal" productivity growth slowdown" of 1972-96.



It is easy to average the blue and green post-1972 areas displayed in Figure 5, and the resulting average for 1972-2013 provides a succinct summary of the relative contributions of IR #2 and IR #3 in creating productivity growth. Output per hour in the total economy grew at 2.36 percent per year from 1891 to 1972 and then at 1.59 percent from 1972 to 2013. Thus in the past 41 years output per hour grew at 2/3 of the rate of the 81 years prior to 1972. Since the post-1972 interval is half the time duration of the earlier 81-year interval, the result is that the pre-1972 years contributed fully three-quarters of the cumulative gain in productivity growth since 1891.

It is conventional in growth accounting to subdivide the observed growth in output per hour into the separate contributions of capital deepening, improvements in capital quality, improvements in labor quality through education and training, and a residual term called "total factor productivity" (TFP), sometimes described as "a measure of our ignorance." Yet capital deepening and changes in capital quality are not separate sources of growth, but rather a side-effect of innovation. As Evsey Domar famously remarked in 1961, "without technological change, capital accumulation would amount to piling wooden plows on top of wooden plows." Similarly, changes in capital quality reflect the shift from long-lived structures which exhibit little technical change to shorter-lived equipment, particularly computers, which are short-lived precisely because rapid innovation makes them quickly obsolescent.

If capital deepening and changes in capital quality are endogenous to innovation, then this leaves only two sources of labor productivity growth, namely innovation and improvements in labor quality achieved by increased educational attainment. These two sources of economic growth, together with Figure 6, form the basis of my forecast of future productivity growth.



In previous sections we have subtracted the effect of four headwinds from the 2.0 percent per annum growth of per-capita real GDP from 1891 to 2007. We reached a rate of 0.8 percent per year after subtracting from the demographic, education, inequality, and debt headwinds. How much should we subtract for the slowdown of innovation after 1972? The growth rate of output per hour was 2.2 percent between 1891 and 2007, as compared to the 1.6 percent that we predict for the next 40 years on the basis of the actual performance since 1972. That amounts to a subtraction for innovation of about 0.6 percent a year, bringing future growth in the per-capita disposable real income of the bottom 99% of the income distribution down from the 0.8 percent implied by the headwinds to 0.2 percent. Figure 7 summarizes the five different sources of subtraction that lead us from 2.0 to 0.2 percent.

5.2 What Was the Second Industrial Revolution?

The achievements of the Second Industrial Revolution were set out in the 2012 paper and need only be summarized here. Within three months in the year 1879 three of the most fundamental "general purpose technologies" were invented that spun off scores of inventions that changed the world. Two of these are well known but the third is not. In October, 1879, Thomas Edison created the first working electric light bulb and by 1882 was distributing power by wire to customers in lower Manhattan, a revolution that made possible not only electric light, elevators, high-rise cities, stationary and portable electric power tools, consumer appliances, but also air conditioning that transformed life and work, especially in the American South.

Between 1890 and 1930 the American household became fully "networked," replacing its previous isolation by five types of connections – electricity, gas, telephone, running water, and sewer pipes. Running water and sewers in turn contributed not just to the first phase of female liberation but also laid the foundations for the conquest of infant mortality in the first half of the 20th century.

Two months after Edison's electric light, Karl Benz achieved the first reliable and workable internal combustion engine, and his initial patent is dated 1879. The third great invention of that year is less known – an Englishman named David Edward Hughes succeeded in sending a wireless signal several hundred meters in London almost two decades before Marconi won his earliest wireless patents (Smil, 2005, p. 241).

The diffusion process of the epochal inventions of electricity and the internal combustion engine was surprisingly similar. Electricity had little initial impact before 1900 except in showpiece displays like the 1893 Chicago Columbian Exposition and the interior of department stores. But after 1900 the use of electricity took off with such speed that by 1929 virtually all urban dwellings were connected to power. The 792-foot landmark Woolworth skyscraper was completed in 1913, and most of Manhattan became vertical by 1929. The transition to electrification of manufacturing was concentrated in the period 1915-29.[24]

Similarly, there was a gestation period when inventors pondered how to combine the power of an internal combustion engine with the previously flimsy structure of a horse-drawn carriage and to develop the transmissions, brakes, and other essential components. As if in a race, the horseless carriage bolted out of the starting gate from zero vehicles in 1900 to such an extent that by 1929 the ratio of motor vehicles to the number of American households had reached 89 percent. By that year 93 percent of Iowa farmers owned a motor vehicle.

[24] Reasons for the long delay in the impact of electricity in manufacturing are provided in the classic and oft-cited paper by David (2000).

At least three aspects of the Second Industrial Revolution have received less attention than they deserve. First is the multi-dimensional nature of the revolution. Unlike the one-dimension ICT revolution of the past 40 years, the creations of IR #2 spanned multiple dimensions – electricity and its spinoffs; running water and sewers; motor vehicles and their complementary inventions such as highways, personal travel, and supermarkets; entertainment from the phonograph to the radio, TV, and motion pictures; public health and reduced mortality; and a revolution in working conditions that eliminated child labor and utterly changed life on the job from brutal and short to less physically demanding and more comfortable work.

The second surprising aspect is that everything happened all at once. When all these transformations are layered on top of each other, they hardly existed in 1880 yet were nearly complete in urban America by 1929. The third surprising aspect is that economic progress through 1972 mainly consisted of consolidating the incomplete aspects of IR #2 across many subsidiary and complementary inventions, including the spread of consumer appliances through the 1950s, the invention of television to supplement the radio and motion picture, the spread of air conditioning from commercial to residential ubiquity, the interstate highway system during 1958-72 as a complement to the motor car, and finally the development of commercial air transport from its primitive and tiny footprint in 1940 to its creation of rapid business and personal travel with the spread of jet planes which was accomplished by 1972.

Two criteria help to capture the uniqueness of IR#2. First, something cannot be more than 100 percent of itself. The years 1890-1930 in urban America witnessed almost 100 percent of urban housing units connected to electricity, gas, telephone, water and sewer connections. The diffusion of electric household appliances into the American household had reached nearly 100 percent by 1970. The percentage ratio of motor vehicles to the number of households had reached 90 percent by 1929. Productivity was enhanced by the transition from farm to city, which was largely complete by the early postwar years, and the percentage of urban vs. rural cannot exceed 100 percent.

The second criteria is that some indicators cannot go below zero. Most important was the decline in the variance of indoor temperature between winter and summer, from a large number to nearly zero as central heating and air condition became pervasive. Infant mortality during 1900-1950 fell from 20 percent almost to zero. Fatality rates among employees in the railroad, mining, and manufacturing industries fell rapidly and death rates from auto accidents declined by a factor of at least 15 in the 20^{th} century..

6. Anticipating the Next 40 Years of Innovation

As indicated above, there is no need to predict any faltering or slowdown in the rate of innovation over the next 40 years. My baseline productivity growth forecast (for the total economy) of 1.30 percent per year starts from the realized growth rate over 1972-2012 of 1.59 percent and subtracts Jorgenson's 0.27 percent for the likely effect of the slower advance of educational attainment.

6.1 What Was Invented in the Past 40 Years?

The benefits of IR #2 petered out in the early 1970s and were replaced by the one-dimensional fruits of IR #3. Yet from our current perspective as we peer out into the future, the achievements of the past 40 years set a hurdle that is dauntingly high. The achievements that must be matched for importance in the next four decades include

- Memory typewriters, the personal computer, word-processing and spreadsheets
- Bar-code scanning, ATM banking, cable and satellite TV
- Internet, e-mail, web browsing, e-commerce
- Google, Amazon, Wikipedia, Linked-In, Facebook
- Mobile phones, smart phones, ipads
- CDs, DVDs, i-tunes, Netflix, movie streaming
- Airline reservation systems, supply-chain monitoring systems, electronic library catalogs
- Throughout every sector, paper, typewriters and mechanical calculators have been replaced by flat screens running powerful software.

What is in store for the next 40 years? The usual stance of economic historians like Joel Mokyr is that the human brain is incapable of forecasting future innovations. He states without qualification that "History is always a bad guide to the future and economic historians should avoid making predictions."[25] He assumes that an instrument is necessary for an outcome. As an example, it would have been impossible for Pasteur to discover his germ theory of disease if Joseph A. Lister had not invented the achromatic-lens microscope in the 1820s. Mokyr's optimism about future technological progress rests partly on the dazzling array of new tools that have arrived recently to create further research advances – "DNA sequencing machines and cell analysis," "high-powered computers," and "astronomy, nanochemistery, and genetic engineering." One of Mokyr's central tools in facilitating scientific advance is "blindingly fast search tools" so that all of human knowledge is instantly available.

Mokyr does not follow Erik Brynjolfsson and other techno-optimists down the trail of small robots, big data, and driverless cars. His examples do not center on digitalization but rather involve fighting infectious diseases, the need of technology to help reduce the environmental pollution caused by excess fertilizer use, and the evocative query whether "can new technology stop [global warming]?" He joins Brynjolfsson and others in worrying whether the machines will displace human workers, but he rightly appeals to two centuries of mechanical inventions that replaced workers by machines without causing mass unemployment.

Mokyr finishes by citing Keynes' 1931 essay "Economic Possibilities for Our Grandchildren" without any mention that Keynes suggested that technological change would "solve mankind's economic problem" and (in a section that Mokyr does not quote) allow men to reduce their work load to 15 hours per week. We are still waiting for the 15-hour week for

[25] This and other quotes in this section come from Mokyr (2013).

prime-age adult workers, just as we are still waiting for Jetson-like vertical take-off personal airplanes.

6.2 Aspects of the Future *Can* Be Predicted

My forecast of 1.3 percent annual total-economy productivity growth in the future does not require any foresight beyond suggesting that the past 40 years are a more relevant benchmark of feasible productivity growth than the 80 years of before 1972. Yet most of the observers of the debate about future U. S. economic growth appear to believe that "technological change is accelerating."[26] A central problem in assessing the optimistic view is that there is rarely any examination of the past. "Accelerating" relative to what? Will future productivity growth accelerate beyond the dot.com boom period of 1996-2004, or are the optimists suggesting that the slowdown experienced in 2004-2013 is temporary? Who knows, because the techno-optimists do not provide time horizons or specific numbers, just a haze of incantations about artificial intelligence and geometric growth of big data processing capacity.

A lynchpin for the optimists made explicit by Mokyr (2013) is that the future cannot be forecast; any pessimist gazing into the future is condemned by a lack of imagination and doomed to repeat the mistakes of past pessimists. But the common assumption that future innovation is non-forecastable is wrong. There are many historical precedents of correct predictions made 50 or 100 years in advance. After we review some of these, we will return to today's forecasts for the next two to four decades.

An early forecast of the future of technology is contained in Jules Verne's 1863 manuscript *Paris in the Twentieth Century*, in which Verne made bold predictions about the Paris a century later in 1960.[27] In that early year, before Edison or Benz, Verne had already conceived of the basics of the 20th century. He predicted rapid transit cars running on overhead viaducts, motor cars with gas combustion engines, and street lights connected by underground wires.

Much of IR#2 was not a surprise. Looking ahead in the year 1875, inventors were feverishly working on turning the telegraph into the telephone, trying to find a way to transform electricity coming from batteries into the power source to create electric light, trying to find a way of harnessing the power of petroleum to create a lightweight and powerful internal combustion engine. The 1875 diaries of Edison, Bell, and Benz are full of such "we're almost there" speculation. Once that was achieved, the dream since Icarus of human flight became a matter of time and experimentation.[28]

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[26] In June 2013 the *Economist* blog ran a debate using Oxford Union rules. A stark proposition "Technological Change is Accelerating," a set of initial statements, rebuttals, and closing statements, and then the vote. My opponent Andrew McAfee of MIT won the vote by 71 percent to 29 percent.

[27] Details about the Verne book and its predictions come from Vijg (2011, pp. 35-36).

[28] Details of the invention of electricity, the internal combustion engine, wireless transmission, and many other late-19th century innovations are contained in Smil (2005). A broader horizon of the history of invention is presented by Mokyr (1990). The hour-by-hour drama of the discovery of the first working electric light bulb in October, 1879, is provided by Stoss (2007).

Some of the most important sources of human progress over the 1870-1940 period were not new inventions at all. Running water had been achieved by the Romans, but it took political will and financial investment to bring it to every urban dwelling place. The first industrial revolution made possible steam-powered water pumps to distribute water within cities, and IR #2 soon replaced the steam pumps with more economical electricity-driven pumps. A separate system of sewer pipes was not an invention, but implementing it over the interval 1870-1930 required resources, dedication, and a commitment to using public funds for infrastructure investment.

A source of technological forecasting appeared in November, 1900 in the most unlikely publication medium, the *Ladies Home Journal* (Watkins, 1900). Some of the predictions were laughably wrong and unimportant, such as strawberries the size of baseballs. But there were enough accurate predictions in this page-long three-column article to suggest that much of the future can be known. Some of the more interesting forecasts were:

- "Hot and cold air will be turned on from spigots to regulate the temperature of the air just as we now turn on hot and cold water from spigots to regulate the temperature of the bath."
- "Ready-cooked meals will be purchased from establishments much like our bakeries of today."
- "Liquid-air refrigerators will keep large quantities of food fresh for long intervals."
- "Photographs will be telegraphed from any distance. If there is a battle in China a century hence, photographs of the events will be published in newspapers an hour later."
- "Automobiles will be cheaper than horses are today. Farmers will own automobile hay-wagons, automobile truck-wagons . . . automobiles will have been substituted for every horse-vehicle now known.
- "Persons and things of all types will be brought within focus of cameras connected with screens at opposite ends of circuits, thousands of miles at a span. . . the lips of a remote actor or singer will be heard to offer words or music when seen to move."

The Jules Verne 1863 and the *Ladies Home Journal* 1900 visions of future technological progress were true leaps of imagination. Somewhat less challenging were predictions of the future made at the 1939-40 New York Worlds' Fair. By 1939-40, IR#2 was almost complete in urban America, so it is no surprise that the exhibits at the Fair could predict quite accurately the further complements to IR #2 inventions, such as superhighways and air conditioning.

What could have been predicted in 1939 about the post-1940 era? Surely the war and the details of its aftermath were a surprise, but for domestic consumer goods the 1939-40 New York World's Fair provided an accurate preview of the 1950s and 1960s. A future of air-conditioned homes and businesses was no intellectual stretch at the fair, as air conditioning in movie theaters began in 1922 and was nearly ubiquitous in theaters by the late 1930s.

Television was introduced at the fair, and it was easy to predict then that television over the next two decades would follow the American model of commercially-supported radio, with entertainment provided over several large networks spanning the continent. Elaborate scale models at the New York fair showed the future high-rise city straddling multi-lane superhighways where travel on the inner lanes occurred at 100 miles per hour. Exhibits previewed the typical kitchen and its appliances almost exactly as they came true in the 1950s and 1960s. While commercial aviation was primitive in 1939, still it was easy to forecast from the rapid progress in the size and speed of aircraft over the 1926-40 period that much larger aircraft could fly much longer distances, and indeed it took only a few years before the DC-6 and DC-7 were spanning the continent and the globe prior to the epochal introduction of the Boeing 707 jet in 1958.

What was missing at the 1939-40 Worlds' Fair was any vision of the computer revolution that created IR #3. But Norbert Wiener, a visionary, in a 1949 essay that was ultimately rejected by the *New York Times*, got a lot of the future of IR #3 right. Among his 1949 predictions were

> These new machines have a great capacity for upsetting the present basis of industry, and of reducing the economic value of the routine factory employee to a point at which he is not worth hiring at any price. . . . if we move in the direction of making machines which learn and whose behavior is modified by experience, we must face the fact that every degree of independence we give the machine is a degree of possible defiance of our wishes. The genie in the bottle will not willingly go back in the bottle, nor have we any reason to expect them to be well-disposed to us. (Markoff, 2013).

Just as some future inventions have been a surprise, including the entire electronics and digital revolutions, other anticipated inventions never came to pass. The Jetsons' vertical commuting car/plane never happened, and in fact high fuel costs caused many local helicopter short-haul aviation companies to shut down.[29] Dick Tracy's wrist radio in cartoon comic strips of the late 1940s finally is coming to fruition 70 years later with Google's miniaturized smart phone for the wrist, but the marginal utility of a wrist device compared to the existing smart phone sinks into the insignificance of small things. In the famous quip of Peter Theil, "we wanted flying cars, and they gave us 140 characters."

7. The Inventions That Are Now Forecastable

Our basic forecast of future productivity growth assumes that innovation over the next four decades will proceed at the same rate as over the past four decades. A bit of skepticism is warranted about the next four decades of innovation, because we have already experienced the digital revolution for the past 40 years during which the most fruitful applications of electronics have by now occurred.

[29] When I arrived home in Berkeley from college or graduate school near Boston, I often traveled by the SFO helicopter line which flew frequent schedules from the SFO airport to the Berkeley marina. This company abruptly shut down in 1974 as a result of the first oil shock.

The Brynjolfsson-McAfee (2014) sales pitch for technological optimism is misleading. In contrast to the account provided above which gives primacy to IR#2, Brynjolfsson and McAfee skip over IR#2 completely, as if they have hit the "delete" button. For them, there is a giant leap from the steam engine to the computer, with no electricity nor internal combustion engines in between, must less all of the multiple dimensions of improvement that took place between 1870 and 1970. This is why they title their book *The Second Machine Age* rather than *The Third Machine Age,* because they would prefer to forget that IR#2 was the big event in the history of technological change. Their leap across IR#2 is evident from the beginning, when they write "we're finally refining computers just as steam engines were refined" (Brynjolfsson-McAfee, p. 9).

The optimists assert that "we're at an inflection point" (Brynjolfsson-McAfee, 2014, p. 44), apparently between a past of slow technological change and a future of rapid change. They appear to believe that Big Blue's chess victory and Watson's victory at the TV game show *Jeopardy* presage an age in which robots outsmart humans in every aspect of human work effort. They remind us Moore's Law that predicts endless exponential growth of the performance capability of computer chips, without recognizing that the translation from Moore's Law to the performance-price behavior of ICT equipment peaked in 1998 and has declined ever since. The price of ICT equipment relative to its performance, instead of declining at 15 percent per year as in 1998, has steadily retreated in the rate of decline until in 2012 it barely declined at all. (see Figure 10 below).

Timing is a basic problem in the Brynjolfsson-McAfee scenario. For instance, they provide an example, presumably to demonstrate accelerating technological change, that goes like this: "These days, of course, instead of handing Erik a disk, Andy is more likely to attach the file to an e-mail message." This is not an example of technological progress in 2013 but in 1993. Most of us have been trading computer files as e-mail attachments for at least two decades. The big question is, can the inventions that occur in 2014 and beyond match those that have already occurred over the past few decades, including all of those reported by the two authors as representing the future whereas by now they are part of the past.[30]

7.1 Stasis in the American Office and Home

The digital revolution centered on 1970-2000 utterly changed the way offices function everywhere. 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 a web-linked personal computer that could do not just word-processing without repetitive retyping, but also download multiple types of content and also perform any type of calculation at blinding speed.

[30] 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.

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.[31]

In contrast to office work, life at home has hardly changed since the 1950s, by which time all the major household appliances (washer, dryer, refrigerator, range, dishwasher, and garbage disposer) had been invented, and by 1972 they had reached most American households. The only inventions since 1970 to alter life at home have been the microwave oven, the diffusion of central air-conditioning (an invention of the 1920s) and the succession of improvements in the quality and variety of audio and video equipment. Listening to sound made the transition in the early 1950s from the 78 rpm record and record changer to 45 rpm records for pop music singles and 33 rpm records for albums. Audio technology improved by progressing from records to 8-track tapes to cassette tapes to CDs and then to digital music sold by i-tunes and listened to on the i-pod. Similarly, television made its transition to color between 1965 and 1972, then variety increased with cable television, 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 throughout the 1990-2005 period, homes experienced the same access to web information and entertainment, as well as to e-commerce, that happened a few years earlier in the office.

This long and continuous process is similar both in duration and character to the improvement of motor vehicles over the first five to six decades from 1900 to 1960, as the flimsy open and low-powered cars of 1901 became the powerful, sleek, and accessory-laden cars of the 1950s. 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).

[31] 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 they 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 2013 is the same size and carries out the same functions as that staff did in 2002.

7.2 Which Future Inventions Can be Forecast?

Just as the 1939 World's Fair forecast numerous life-changing inventions and further diffusion of existing inventions like air conditioning and television, so today's future-looking literature can credibly identify several directions of major advance. Yet when more closely examined, the value to consumers of these hypothetical inventions seem of small scale compared to those that could be foreseen at the 1939-40 New York World's Fair, by the *Ladies' Home Journal* in 1900, or by an acute observer at the dawn of IR #2 in 1875.

The future advances that are widely forecast can be divided into four main categories – medical, small robots and 3-D printing, big data, and driverless vehicles. Enthusiasts of "big data" sometimes label this category of advance as "artificial intelligence." It is worth examining the potential of each of these categories of future innovation in turn, and then we will ask whether what Brynjolfsson and McAfee call the "inflection point" leads to faster growth as they believe or to slower growth or, most plausibly, no change.

Medical and Pharmaceutical Advances. Future advances in medicine related to the genome have already proved to be disappointing. The most important sources of higher life expectancy in the 20th century were achieved in the first half of that century, when life expectancy rose at twice the rate of the last half. This was the interval during which infant mortality was conquered by the discovery of the germ theory of disease, the development of anti-toxins for diphtheria, and the near-elimination of air-and water-distributed diseases through the achievement of constructing urban sanitation infrastructure (Cutler and Miller, 2005).

Many of the current basic tools of modern medicine were developed between 1940 and 1980, including antibiotics, the polio vaccine, heart procedures, chemotherapy, and radiation. The current status of science in medical treatment and pharmaceutical advance is well described by Jan Vijg (2011, especially his Chapter 4). 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 mental 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 (2011). At enormous cost drugs are being developed that will treat esoteric types of cancer at costs that no medical insurance system can afford. Vijg is highly critical of the current regime of drug testing in the U.S. as inhibiting risk taking, an example of the overregulation of the U.S. economy.

Small Robots, Artificial Intelligence, and 3-D Printing. Much attention has been paid in the popular media to small robots since "Baxter," the inexpensive $25,000 robot, made his debut on the TV program *60 Minutes*. The appeal of the Baxter example is that the cost is so cheap. Baxter can perform the functions of a human, as long as it can stand in place and not be expected to move. From a broader time-perspective, however, Baxter elicits a big yawn. 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.[32]

Reflections on Baxter lead to skepticism that it/he is a major threat to American jobs outside of routine tasks in manufacturing, which only makes up 8 percent of American employment. For his demonstration at the TED conference in Long Beach in late February, 2013, Baxter had to be packed in a suitcase. He could not get his own boarding pass and walk onto the plane. This is the problem with robots – they are both mentally and physically limited to narrow tasks. They can think but can't walk, or they can walk but can't think. Their homeland is in manufacturing plants and in wholesale distribution warehouses, where they find the Amazon books and bring them to the packer, who so far remains a human because the robots have not yet figured out how to arrange books in a package. Google is experimenting with robots shaped like wild animals that can run at great speeds, but it remains to be seen if any robot can be created that combines the multiple functions of the UPS driver at driving the truck, finding the package, and knowing from memory just where to place it at the office, condo, or residential home location.

This lack of multitasking ability is dismissed by the robot enthusiasts – just wait, it is coming. Soon our robots will not only be able to win at *Jeopardy* but also will be able to check in your bags at the sky cap station at the airport, thus displacing the skycaps. But the physical tasks that humans can do are unlikely to be replaced in the next several decades by robots. Surely multiple-function robots will be developed, but 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.

What is often forgetten is that we are well into the computer age, and every Home Depot, Wal-Mart, and local supermarket has self-check-out lines that allow you to check out your groceries or paint cans by scanning them through a robot. But except for very small orders it takes longer, and so people still voluntarily wait in line for a human instead of taking the option of the no-wait self-checkout-lane. The same theme – that the most obvious uses of robots and computers have already happened – pervades commerce. Airport baggage sorting belts are mechanized, as is most of the process of checking in for a flight.

For more than three decades payments have been made by plastic cards instead of by cash or checks as in our parents' and grandparents' era, but that revolution is over and the marginal utility of paying by swiping a cell phone is at the outer limit of small gains. 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 little terminals that would dial the authorization phone number, and now the authorization arrives within a few seconds. That is part of the many accomplishments of IR #3 that will be difficult to surpass in the next 40 years.

3-D printing is another revolution described by the techno-optimists, but its potential impact is limited. Recent reports suggest that 3-D printing is a small deal best suited for one-off

[32] These comments on mid-1990s automobile factory technology come from my membership of the NBER "pin factory group" that organized plant tours for NBER-affiliated research staff at that time.

customized operations, such as the ability to create a crown in a dentist office instead of having to send out a mold. 3-D printing represents custom production rather than mass production, and thus retreats from the economies of scale and efficiency of Henry Ford's 1913 assembly line. Doubtless it will raise productivity in design labs that create models of new products but has less potential to raise economy-wide productivity growth.

Big Data. The enthusiasts for future technical progress are fascinated by exponents, as in "exponential growth leads to staggeringly big numbers" (Brynjolffson and McAfee, 2014, p. 47). Using Moore's Law, they forecast big data extending beyond trillions and quadrillions and quintillions to far beyond into orders of magnitude that are only now being named. But real-world growth has never happened at hundreds and thousands of percent per year. All growth rates are exponential; there is nothing uniquely exponential about the growth of big data. A 2.0 percent growth rate in per-capita income of the U.S. over 1891-2007 represents an exponential increase of EXP(116*2/100) = 10.2. What is more exponential than that? One thing is clear – as the cost of data bytes reaches zero, so the ratio of GDP to data bytes reaches zero as well. There is no longer any connection between Moore's Law or the growth of data with the growth rates of two of the most most important ratios of the economy: output per capita and output per hour.

What is lost by the enthusiasts for big data is that most of it is a zero-sum game. The vast majority of big data is being analyzed within large corporations 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.

With enough big data, Corporation A may be able to devise a strategy to steal market share from Corporation B, but B will surely fight back with an onslaught of more big data. An excellent and current example involves the large legacy airlines with their data-rich frequent flyer programs. The analysts at these airlines are constantly trolling through their big data to try to understand why they have lost market share in a particular city or with a particular demographic group of travelers.

Every airline has a "revenue management" department that decides how many seats on a given flight on a given day should be sold at cheap, intermediate, and expensive prices. Vast amounts of data are analyzed, and computers examine historical records, monitor day-by-day booking patterns, factor in holidays and weekends, and come out with an allocation. But at a medium-sized airline JetBlue, 25 employees are required to monitor computers, and the humans must constantly override the decisions of the computers. The director of revenue management at JetBlue describes his biggest surprise in taking over his job as "how often the staff has to override the computers."[33]

[33] Discussion with Scott Resnick, Director of Revenue Manager of JetBlue Airlines, New York, December 6, 2013.

The quantity of electronic data has been rising exponentially for decades. But diminishing returns have set in. The sharp slowdown in productivity growth in recent years has overlapped with the introduction of smart phones and ipads, 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. Indeed U. S. productivity growth has been growing at less than one percent per year during the heyday of the roll-out of smart phones and tablets.[34]

Driverless Cars. 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 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, internet-provided music, or home-provided i-tunes music, you can actually look at a computer screen and do your e-mail. This is not a potential revolution even on a par with the invention of the iphone, much less the web or e-commerce, much less the invention of the automobile itself.

That leaves the potential future productivity advantage offered by driverless trucks. This is a potentially productivity-enhancing innovation, albeit within the tiny slice of U.S. employment consisting of truck drivers. However, driving from place to place is only half of what truck drivers do. UPS drivers jump off truck, find the package inside the truck, and deliver the package to businesses and residences, knowing whether to place the packages on the front porch or a back-porch hiding place.

Wholesale trucks arrive at supermarkets and stop at the back loading dock. The drivers are responsible for loading the cases of Coca-Cola or the stacks of bread loaves onto dollies and placing them manually on the 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.

7.3 Is the Inflection Point One of Speeding Up or Slowing Down?

Brynjolfsson and McAfee do not define the exact dating of their transition. They often write as if everything digital that has already occurred over the past two decades should be included in the benefits of future invention. Instead, this paper takes the chronology more literally. What has already been invented, including the iphone and ipad, is part of the past history of IR #3, and the question is what will be invented in the future to match or surpass the achievements of the digital age since 1972?

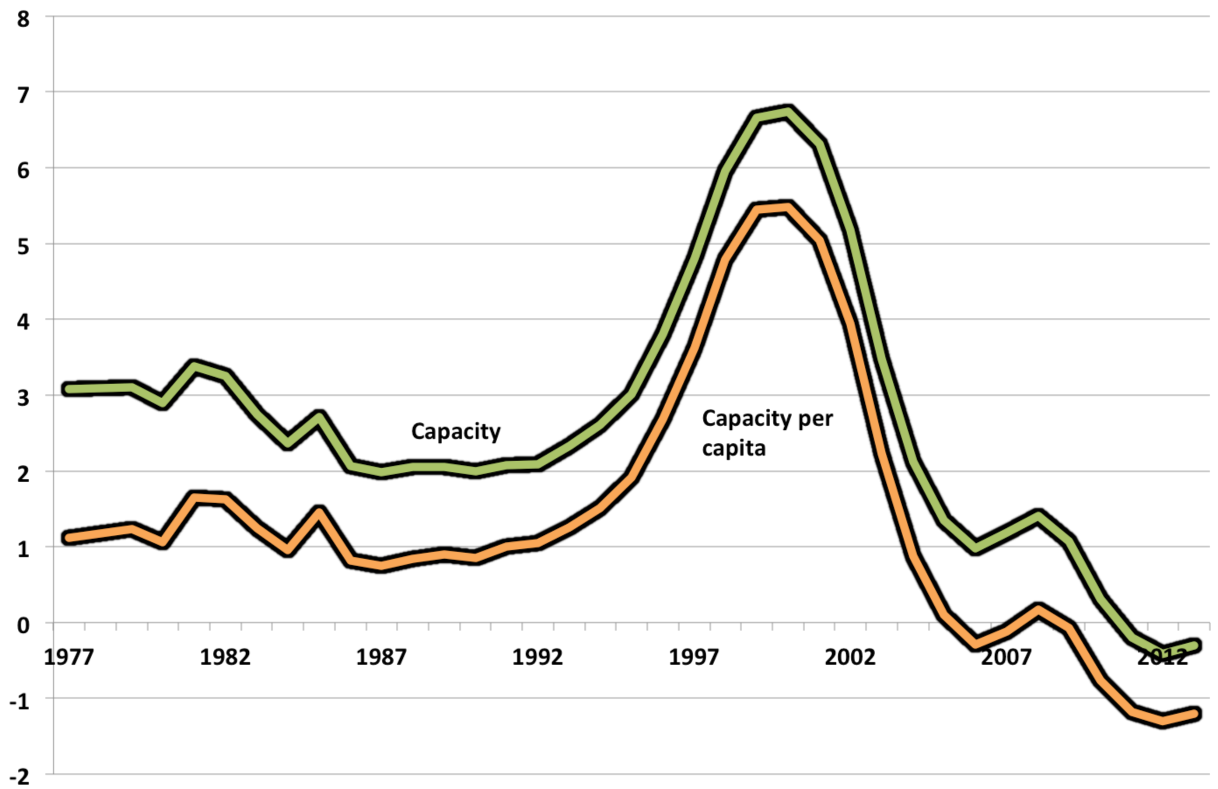
[34] Total economy output per hour grew at an annual rate of 0.75 percent per year between 2010:Q1 and 2013:Q3.

This section reminds the techno-optimists that there is a strong case that technological change is slowing down, not speeding up. Previous sections of this paper have already shown that productivity growth was 0.77 percentage points slower in the 41 years since 1972 as in the 81 years prior to 1972.

We have seen in Figure 2 and 5 that there was a temporary revival of productivity growth between 1996 and 2004. But productivity growth was much slower in 1972-96 and in 2004-13, i.e., in 33 of the past 41 years. The techno-optimists ignore the temporary character of the late 1990s dot.com productivity revival. In this section we examine three new pieces of evidence that the third industrial revolution (IR #3) was uniquely concentrated in those eight years 1996-2004 and contributed remarkably little to productivity growth before or since.

The Federal Reserve reports monthly its Index of Industrial Production and Industrial Capacity. It also reports the ratio of the two, the rate of capacity utilization. Shown in Figure 8 is the annual growth rate of manufacturing capacity, both by itself and expressed as a ratio to the working-age population. The uniqueness of the 1996-2004 interval is clearly evident in the graph. The growth of manufacturing capacity proceeded at an annual rate between two and three percent from 1972 to 1994, then surged to seven percent in the late 1990s, and then came back down, declining to a negative growth rate in 2011-2012. The lower line showing growth in per-capita manufacturing capacity has been in negative territory since 2007.

Figure 8. Annualized Five-Year Change in Manufacturing Capacity and Capacity per Capita, 1977-2013



The implications of a decline in manufacturing capacity per capita evokes memories of the hysteresis hypothesis developed in the 1980s in the context of soaring unemployment in Europe. Calculations for Western Europe showed that by 1990 there was insufficient industrial capacity to employ the labor force at the low unemployment rates experienced in Europe before 1975. Figure 8 immediately raises a corollary question – why was capacity growth in the late 1990s so disproportionately higher than in the years before or since?

Much of the answer comes from a little known data series displayed in Figure 9, displaying the ratio of value-added in ICT-producing industries to value-added in total U.S. manufacturing. The ratio in 2013 was three percent, just the same as in 1972. In between, the same ratio rose to an initial plateau between 1983 and 1994 before soaring to a peak of 8.5 percent in late 2000. Then it plunged in 2002-04, followed by a steady erosion back down to three percent.   While we are all familiar with the fact that most ICT manufacturing is performed in Asia, nevertheless the startling disappearance of ICT production from the American domestic economy is a surprise and does not bode well for future productivity growth in the manufacturing sector.

Figure 9. Share of ICT Manufacturing Value-Added in Total Manufacturing Sector, 1972-2013

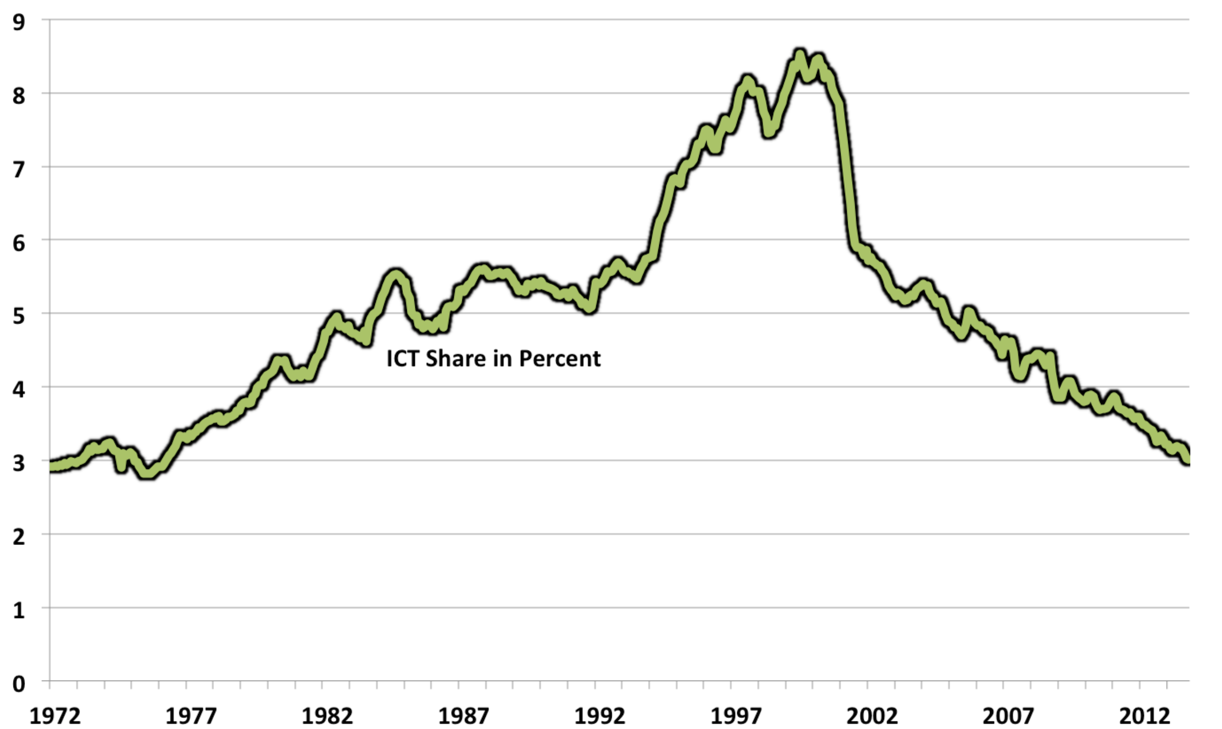
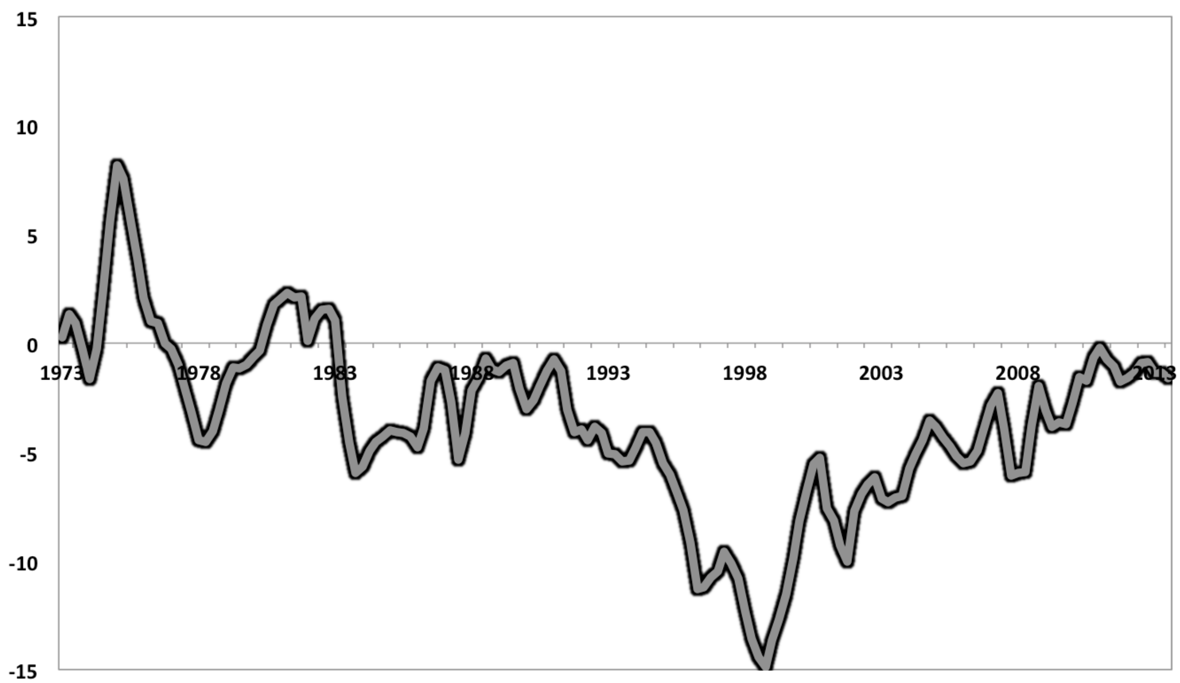


Figure 10. Annual Growth Rate of BEA Price Deflator for All ICT Equipment



The third piece of evidence that the late 1990s were unique is more familiar and has been discussed before. That interval witnessed the most rapid rate of decline in performance-adjusted prices of ICT equipment in the history of the digital IR #3. The rate of decline of the ICT equipment deflator peaked at minus 15 percent in 1998, but its rate of decline has steadily diminished to barely minus one percent in 2012.

8. Conclusion

This paper contrasts a realized 2.0 percent growth rate per year in real per-capita GDP over 1891-2007 to a future post-2007 growth rate of 1.3 percent per year for productivity, 0.9 for average output per capita, 0.4 for the pre-tax pre-transfer income received by the bottom 99% of the income distribution, and 0.2 for the disposable income of the bottom 99%. Our discussion of the headwinds calls attention to the interactions among demography, education, and inequality. Workers with low levels of education are dropping out of the labor force as a result of globalization that has moved economic activity to foreign countries or from unionized northern states to nonunion southern states. These labor-force drop-outs help to explain why hours per capita have declined so rapidly in the past 16 years, more rapidly than can be explained by the retirement of the baby-boomers.

The socioeconomic decay of the bottom one-third of the white population, as documented by Charles Murray, paints a picture of declining percentages of marriage and increasing percentages of divorce and "never married" status. This interacts with the future outcome of educational attainment, because the rapid decline in the percentage of children living with both biological parents predicts future high-school dropping out, a stagnation of high-school graduation rates and college completion rates. Separately, the growth of college student debt to more than $1 trillion leads to a prediction of delays in marriage and child birth, and a decline in the rate of population growth which aggravates the other sources of the future growth slowdown.

The forecast of slower U.S. growth relies for about 2/3 of its prediction on the impact of the six headwinds, of which four are quantified here in terms of their impact on future growth. What about innovation? This paper recognizes that it is not necessary to forecast that future innovation will be any less important than the record of innovations already achieved in the four decades since 1972.

Instead, the sense in which innovation has been "faltering" is not a prediction about the future compared to the recent past, but rather is a comment from the raw data about American economic growth in the 80 years before 1972 as contrasted to less rapid growth in the four decades after 1972. That slowdown is the best available evidence that the third industrial revolution (IR #3, mainly digital, post-1972) was a mere shadow of the second industrial revolution (IR #2, multi-dimensional, 1875-1972).

While there is no need to forecast that future innovations will be less important than the past, some skepticism is offered here. When young audiences are confronted with the question "Is Technological Change Accelerating?" they vote en masse "yes." They appear to treat the iphone and ipad as a major technical advance, forgetting that their hand-held devices rest on the shoulders of previous advances including personal computers, laptops, cell phone technology, not to mention the air conditioning which makes their homes and offices comfortable year-round, all of which rests in turn on the electricity upon which they rely to recharge their devices every night.

Techno-optimists remind us that much of the innovation that originates in the U.S. travels around the world with blazing speed through purchases of smart phones and the software that has been developed for them. But other countries can have the free lunch of enjoying American innovation including thousands of smart-phone apps without being saddled with American socio-economic decay, poor educational test scores, massive student debt, high school drop-outs, rising poverty together with explosive growth of incomes at the very top, and the need to reform entitlement programs that are in trouble in part because the U.S. has refused to make medical care a right of citizenship. Today we can only guess which nations will replace the U.S. and remove it from its potential position of leadership due both to the size of its population and its world-leadng real GDP per capita.

After years of debate about this topic, the most interesting questions remain to be discussed. Clearly Canada, the Nordic nations, and Switzerland suffer less from the headwinds than does the U.S. They are less subject to the interlocking quagmire of poverty, low school achievement, high college costs, an expensive and inefficient medical system, and lack of child care than the U.S.

How many other nations suffer less from the headwinds? Does it matter to the rest of the world whether U. S. innovation falters or not? The great American inventions of the last two decades have spread across the globe with impressive speed. My final and perhaps most radical thought is that innovation is a free good for the world as a whole, while headwinds are uniquely nation-specific. This leads to the suggestion that over the next 50 years the slowing growth of the American standard of living will result in a passing lane in which one country after another exceeds real GDP per capita of the United States, by being able to buy American innovation while facing headwinds that for many countries are mild breezes compared to the gale force headwinds experienced by the United States. Today we can only guess whether the passing lane includes one or more nations from Europe, East Asia, or our neighbor to the north.

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