

NBER WORKING PAPER SERIES

EDUCATION, PARTICIPATION, AND THE REVIVAL OF U.S. ECONOMIC GROWTH

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Working Paper 22453

<http://www.nber.org/papers/w22453>

NATIONAL BUREAU OF ECONOMIC RESEARCH

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July 2016

The views expressed in this paper are solely those of the authors and not necessarily those of the U.S. Bureau of Economic Analysis or the U.S. Department of Commerce. We are grateful to Douglas Elmendorf and the editors, Charles Hulten and Valerie Ramey for their comments on an earlier version of our manuscripts. We are also grateful to the BEA for sharing their labor input estimates. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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Education, Participation, and the Revival of U.S. Economic Growth
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NBER Working Paper No. 22453
July 2016, Revised March 2017
JEL No. E01,E24,O4,O47

ABSTRACT

Labor quality growth captures the upgrading of the labor force through higher educational attainment and greater experience. We find that average levels of educational attainment of new entrants remain high, but will no longer continue to rise. Growing educational attainment will gradually disappear as a source of U.S. economic growth. We find that the investment boom of 1995-2000 drew many younger and less-educated workers into employment. Employment rates for these workers declined during the recovery of 2000-2007 and dropped further during the Great Recession of 2007-2009. Based on estimates of labor quality growth, growth in total factor productivity, and growth in capital quality, we project labor productivity to grow at 1.3% per year. This implies a GDP growth rate of 1.8%.

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Introduction

Labor quality growth captures the upgrading of the labor force through higher educational attainment and greater experience. While much attention has been devoted to the aging of the labor force, the implications of the coming plateau in educational attainment have been neglected.¹ Average levels of educational attainment remain high for people entering the labor force, but will no longer increase. Rising average educational attainment will gradually disappear as a source of U.S. economic growth.

We define the employment rate as the number employed as a proportion of the corresponding population. We find that the employment rate for each age-gender category increases with educational attainment. The investment boom of 1995-2000 drew many younger and less-educated workers into employment. After attaining a peak in 2000, the employment rates for these workers declined during the recovery of 2000-2007 and dropped further during the Great Recession of 2007-2009. The employment rates for the highly educated groups also fell during the Great Recession, but by 2015 they have recovered more than the employment rates of the less educated groups.

In order to assess the prospects for U.S. economic growth in more detail, we present a new dataset on U.S. output and productivity growth by industry for the postwar period 1947-2014. This includes outputs for the 65 industries represented in the U.S. National Income and Product Accounts (NIPAs). The new dataset also includes inputs of capital (K), labor (L), energy (E), materials (M), and services (S), hence the acronym KLEMS. Where productivity is defined as the ratio of output to input, the key indicator of the rate of innovation for each industry is the rate of growth of productivity.

¹ See: Aaronson, Daniel, Loujia Hu, Arian Seifoddini and Daniel Sullivan (2014) and Aaronson, Stephanie, Tomaz Cajner, Bruce Fallick, Felix Galbis-Reig, Christopher Smith and William Washer (2014).

A distinctive feature of our new U.S. dataset is detailed information on employment for the U.S. labor force. This covers the period 1947-2014 and enables us to characterize the relationship between employment and the age, gender, and educational attainment of workers over more than six decades. Since the revival of U.S. economic growth depends critically on the recovery of U.S. employment rates, we utilize this new information on employment in assessing the prospects for a U.S. growth revival.

Are the lower employment rates of the less-educated workers a “new normal” for the U.S. labor force that will persist for some time? Or, will the continuing economic recovery enable these workers to resume the higher employment rates that preceded the Great Recession? The answers to these questions are critical for the future growth of the U.S. economy. In order to assess the prospects for recovery of employment as a potential source for the revival in U.S. economic growth, we account for the employment rate of each age-gender-education group.

We build on the work of Jorgenson, Ho, and Kevin J. Stiroh (2005), who presented and industry-level dataset for outputs, inputs, and productivity for the U.S. economy for the period 1977-2000. For the earlier period 1947-1977 our new dataset captures the postwar recovery of the U.S. economy, ending with the energy crisis of 1973. For the recent period 2000-2014 our new dataset highlights the slowdown in productivity growth after 2007, the fall in investment during the Great Recession of 2007-2009, and the slow recovery since 2009.

Paul Schreyer (2001)’s OECD Manual, *Measuring Productivity*, established international standards for economy-wide and industry-level productivity measurement. These standards are based on the production account for the U.S. economy presented by Jorgenson, Frank M. Gollop, and Barbara M. Fraumeni (1987) in their book, *Productivity and U.S. Economic Growth*. This was recommended by the Statistical Working Party of the OECD Industry Committee (2001). The

Statistical Working Party was chaired by Edwin Dean, formerly Associate Commission for Productivity of the U.S. Bureau of Labor Statistics (BLS).

We present a prototype production account within the framework of the U.S. national accounts. This production account includes newly available estimates for the growth of outputs and intermediate inputs for the period 1998-2014 from the Bureau of Economic Analysis (BEA). We combine these estimates with data from the production account for the U.S. for the period 1947-2012 that we presented in Jorgenson, Ho, and Samuels (2016). We aggregate industries by means of the production possibility frontier employed by Jorgenson, Ho, and Stiroh (2005) and Jorgenson and Schreyer (2013). This links industry-level data on U.S. growth and productivity to the economy-wide data from the U.S. national accounts presented by Michael Harper, Brent R. Moulton, Steven Rosenthal, and David B. Wasshausen (2009).

The first application of our new industry-level dataset on outputs, inputs, and productivity is to analyze the sources of postwar U.S. economic growth. We divide the Postwar Period, 1947-2014, into three sub-periods – the Postwar Recovery, 1947-1973, the Long Slump following the 1973 energy crisis, 1973-1995, and the recent period of Growth and Recession, 1995-2014. We provide more detail on the period of Growth and Recession by considering the sub-periods of the Investment Boom, 1995-2000, the Jobless Recovery, 2000-2007, and the Great Recession, 2007-2014.

We show that nearly eighty percent of U.S. economic growth since 1947 is due to the growth of capital and labor inputs. This reflects the expansion and upgrading of the labor force and investments in plant, equipment and intangible assets like research and development and software. Only twenty percent of U.S. growth is due to growth in productivity, output per unit of input, which captures innovation. Of course, economic growth involves both accumulation of capital and labor

inputs and the introduction of new technologies, but factor accumulation greatly predominates as a source of U.S. economic growth.

Our finding on the relative unimportance of innovation is the reverse of the well-known conclusions of Robert M. Solow (1957) and Simon Kuznets (1971). Solow and Kuznets found that innovation, represented by productivity growth, accounts for eighty percent of U.S. economic growth, while accumulation of capital and labor inputs, the primary factors of production, accounts for only twenty percent. The sharp reversal of this conclusion is the most important empirical finding from several decades of research on productivity growth summarized by Jorgenson (2009) and Jorgenson, Fukao, and Timmer (2016).²

The reversal of the key empirical findings from the research of Solow (1957) and Kuznets (1971) can be traced to the critically important changes in methodology introduced by Jorgenson, Gollop and Fraumeni (1987) and Jorgenson, Ho, and Stiroh (2005). These changes are summarized by Schreyer's (2001) OECD Manual *Measuring Productivity*, and Schreyer's (2009) OECD Manual *Measuring Capital*, 2nd Edition. The new methodology for measuring productivity has had an enormous impact on the practice of productivity measurement. More than forty countries have employed the new methodology for productivity measurement and more than a dozen of these countries, including the United States, use this methodology to generate official estimates of productivity growth within the framework of the national accounts.

The predominant role of growth in capital and labor inputs in U.S. economic growth is crucial for the formulation of economic policy. During the prolonged recovery from the Great Recession of 2007-2009, economic policy must focus on reviving investment and re-establishing

² An industry-level production account for the U.S. for the period 1947-2012 is presented in our paper, Jorgenson, Ho, and Samuels (2016). The official industry-level production account for the period 1998-2012 is presented by Steven Rosenthal, Matthew Russell, Samuels, Erich H. Strassner, and Lisa Usher (2016), BEA/BLS Industry-Level Production Account for the U.S.: Integrated Sources of Growth, Intangible Capital, and the U.S. Recovery, Ch. 11 in Jorgenson, Fukao, and Timmer (2016), pp. 377-428.

the pre-recession employment rates of the labor force. Policies for stimulating innovation would have a very limited impact.

The second application of our new data set is to project the future growth of the U.S. economy. For this purpose we employ the methodology of Jorgenson, Ho, and Stiroh (2008).³ We aggregate over industries to obtain data for the U.S. economy as a whole. We project the future growth of labor input and productivity. We then determine the future growth of output consistent with the assumption that output and capital must grow at the same rate. This assumption eliminates the transitional dynamics associated with the accumulation of capital. We discuss the methodology for projecting future U.S. economic growth in more detail in the Appendix to this paper.

We first consider the growth of labor input as a determinant of U.S. economic growth. We project the size of the labor force from the growth and composition of the population. We then project the future growth of labor quality from the educational attainment of age cohorts of the population as they enter the labor force and the increase in experience as these cohorts age. Finally, we account for the employment rates for each age-gender-education category of the labor force, projecting them from 2014 levels.

We next consider productivity growth as a determinant of future U.S. economic growth. To characterize the uncertainty that characterizes future trends, we construct a Base Case projection based on productivity growth for the period of Growth and Recession, 1995-2014. We then develop a Low Growth Case that also incorporates productivity trends for 1973-2014, including the Long Slump of 1973-1995, as well as the period 1995-2014. Finally, we present a High Growth Case based on productivity growth during the Investment Boom of 1995-2000 and the Jobless Recovery of 2000-2007. This excludes the Recession and Recovery of 2007-2014.

³ Jorgenson and Khuong M. Vu (2017) employ this methodology to project the growth of the U.S. and the world economy.

We find that U.S. economic growth will continue to recover from the Great Recession of 2007-2009 through the resumption of growth in productivity and labor input. However, the growth rate of the U.S. economy in the next decade will depend critically on the revival of employment rates that prevailed before the Great Recession. We compare our results with the projections by the Congressional Budget Office (2016) and John Fernald (2014, 2016). The final section of the paper presents our conclusions.

A Prototype Industry-Level Production Account for the United States, 1947-2014.

Our first objective is to construct a new dataset for growth and productivity of the U.S. economy at the industry level. This is greatly facilitated by the progress of the Bureau of Economic Analysis (BEA) in developing a system of industry accounts within the framework of the U.S. National Income and Product Accounts. BEA has successfully integrated three separate industry programs – benchmark input-output tables, released every five years, annual input-output tables, and annual estimates of gross domestic product by industry. BEA’s system of industry accounts is described by Nicole M. Mayerhauser and Erich H. Strassner (2010).

Stefanie H. McCulla, Alyssa E. Holdren, and Shelly Smith (2013) summarize the 2013 benchmark revision of the NIPAs. A particularly significant innovation is the addition of intellectual property products such as research and development and entertainment, artistic, and literary originals. Intellectual property products are treated symmetrically with other capital expenditures. Investments in intellectual property are included in the Gross Domestic Product and the capital services generated by these investments are included in the national income.

Donald D. Kim, Strassner and Wasshausen (2014) describe the 2014 benchmark revision of BEA’s industry accounts. These accounts include annual input-output tables and gross domestic product by industry and cover the period 1997-2012. BEA’s industry data are consistent with the

2013 benchmark revision of the NIPAs and the benchmark input-output table for 2007. The industry accounts and the annual input-output tables have been updated to 2013 and 2014 by BEA.

Amanda S. Lyndaker, Thomas F. Howells III, Strassner, and Wasshausen (2016) have extended BEA's estimates of output and intermediate inputs to the period 1947-1996. This extension incorporates earlier benchmark input-output tables for the U.S., including the first benchmark table for 1947. BEA has linked these benchmark input-output tables to the annual input-output tables and industry accounts for 1997-2014. The BEA industry data are available for 46 industries for 1947-1962 and 65 industries for 1963-2014. BEA's historical data set includes estimates of output and intermediate input in current and constant prices. We incorporate these estimates into our prototype industry-level production account.⁴

BEA has prepared estimates of capital and labor inputs for the period 1998-2014. Our labor input estimates are taken from Jorgenson, Ho, Samuels (2016) for 1947-2012. We extrapolate these estimates to 2014, using the version of our labor data set maintained by BEA. This labor data set is used to generate an integrated industry-level production account beginning in 1998 by Steven Rosenthal and Lisa Usher of BLS and Matthew Russell, Samuels, and Strassner of BEA (2016) in their paper, "BEA/BLS Industry-Level Production Account for the U.S.: Integrated Sources of Growth, Intangible Capital, and the U.S. Recovery."

Similarly, our estimates of capital input for 1947-2012 are taken from Jorgenson, Ho, Samuels (2016) and updated to 2014, using capital input estimates in the BEA-BLS integrated industry-level production account. Combining the estimates of labor and capital inputs with estimates of output and intermediate inputs, we obtain an industry-level production account for the United States. This prototype production account covers the period of 1947-2014 in current and

⁴ For the period before 1998, BEA uses the industry, commodity and import prices developed in Jorgenson, Ho, Samuels (2016) to estimate constant-price industry output and intermediate input. For the 1963-2014 period, we use the BEA estimates in current and constant prices. For the 1947-1962 period, we scale the 65-sector estimates developed by Jorgenson, Ho, and Samuels (2016) to the 46 industries published by the BEA.

constant prices for all 65 industries included in the U.S. national accounts. Jorgenson and Schreyer (2013) show how to integrate our prototype industry-level production account into the United Nations' (2009) *System of National Accounts 2008*.

Our new KLEMS-type data set for the U.S. is the culmination of our previous research on industry-level outputs, inputs, and productivity for the postwar period. This data set is consistent with BEA's industry accounts and annual input-output tables for 1947-2014 and provides greater industry detail for 1947-1962. The BEA/BLS integrated industry-level production account for 1998-2014, released on January 13, 2017, uses similar methodology. However, our industry-level production account covers the entire postwar period, beginning in 1947.

Changing Structure of Capital Input

Swiftly falling IT prices have provided powerful economic incentives for the rapid diffusion of IT through investment in hardware and software. A substantial acceleration in the IT price decline occurred in 1995, triggered by a much sharper acceleration in the price decline for semiconductors. The IT price decline after 1995 signaled even faster innovation in the main IT-producing industries – semiconductors, computers, communications equipment, and software – and ignited a boom in IT investment. Figure 1 presents price indices for 1973-2014 for asset categories included in our measures of capital input – equipment, computers, software, research and development, artistic originals, and residential structures.

The price of an asset is transformed into the price of the corresponding capital input by multiplying the asset price by the *cost of capital* introduced by Jorgenson (1963). The cost of capital includes the nominal rate of return, the asset-specific rate of depreciation, and the rate of capital loss due to declining prices. The distinctive characteristics of IT prices – high rates of price

decline and rates of depreciation – imply that cost of capital for the price of IT capital input is very high, relative to the cost of capital for the price of Non-IT capital input.

Schreyer's (2009) OECD Manual, *Measuring Capital*, provides detailed recommendations for the construction of prices and quantities of capital services. Incorporation of data on labor and capital inputs in constant prices into the national accounts is described in Chapters 19 and 20 of the United Nations *2008 System of National Accounts* (2009). In Chapter 20 of *2008 SNA* (page 415), estimates of capital services are described as follows: "By associating these estimates with the standard breakdown of value added, the contribution of labor and capital to production can be portrayed in a form ready for use in the analysis of productivity in a way entirely consistent with the accounts of the System."

To capture the impact of the rapid decline in IT equipment prices and the high depreciation rates for IT equipment we distinguish between the flow of capital services and the stock of capital. Capital quality is defined as the ratio of the flow of capital services to capital stock. Figure 2 gives the share of IT in the value of total capital stock, the share of IT capital services in total capital input, and the share of IT services in total output. The IT stock share rose from 1960 to 1995 – on the eve of the IT boom – and reached a high in 2001 after the dot-com bubble. This share fell during the Jobless Recovery with the plunge in IT investment.

The share of the IT service flow in the value of total capital input is much higher than the IT share in total capital stock. This reflects the rapid decline in IT prices and the high depreciation rates of IT equipment that enter the formula for the cost of capital associated with the IT service flow. The share of the IT service flow was fairly stable during the period 1960-80 and then began to rise, reaching a peak in 2000. The IT service flow then declined and ended with a sharp plunge during the Great Recession.

The IT service industries, information and data processing and computer system design, have shown persistent growth. The share of the output of these two industries in the value of the GDP, shown in Figure 2, declined slightly from 2000 to 2005 and then continued to rise, reaching a high in 2014. This reflects the displacement of IT hardware and software by the growth of IT services like cloud computing.

Investment in intellectual property (IP) products since 1973 is shown as a proportion of the GDP in Figure 3. This proportion grew during the Investment Boom of 1995-2000 and has declined only slightly since the peak around 2000. Investment in research and development also peaked around 2000, but has remained close to this level through the Great Recession.

Changing Structure of Labor Input

Our measure of labor input recognizes differences in labor compensation for workers of different ages, educational attainment, and gender, as described in by Jorgenson, Ho and Stiroh (2005, Chapter 6). The rate of labor quality growth is the difference between the growth rate of labor input and the growth rate of hours worked. For example, a shift in the composition of labor input toward more highly-educated workers, who receive higher wages, contributes to the growth of labor quality. Figure 4 shows the decomposition of changes in labor quality into age, education, and gender components.

During the Postwar Recovery of 1947-1973 the massive entry of young, lower-wage workers contributed negatively to labor quality growth. The rapidly increasing female labor force also contributed negatively, reflecting the lower average labor compensation of female workers. Rising educational attainment generated substantial growth in labor quality. During the Long Slump of 1973-1995, the increase in employment of female workers accelerated and the contribution of the gender composition became more negative. The aging of the labor force

contributed positively to labor quality through increased experience, while educational attainment continued to rise and the growth of labor quality became more rapid.

The contribution of higher educational attainment to labor quality growth accelerated during the period of Growth and Recession, 1995-2014. The negative impact of increased female employment diminished and labor quality continued to grow as workers gained experience. Considering the period of Growth and Recession in more detail in Figure 5, we see that labor quality rose steadily throughout the period. The growth rate declined slightly in 1995-2000, relative to the Long Slump of 1973-1995, as a consequence of a jump in employment by younger and less-educated workers. The less negative gender contributions during the Jobless Recovery of 2000-2007 and the Great Recession of 2007-2014 reflect the fact that unemployment rates rose much more sharply for men than for women.

The level of educational attainment of U.S. workers is shown in Figure 6. In 1947 only a modest proportion of the U.S. work force had four or more years of college. By 1973 the proportion of college-educated workers had risen dramatically and this proportion has continued to grow. There was a change in classification in 1992 from years enrolled in school to years of schooling completed. By 2014 almost a third of U.S. workers had completed a BA degree or higher. The fall in the share of workers with lower educational attainment accelerated during the Great Recession.

Figure 7 shows that educational attainment of the 25-34 age group improved substantially during the Postwar Recovery from 1947-1973, followed by a pause during the Long Slump of 1973-1995. Gains in educational attainment resumed during the Investment Boom of 1995-2000 and have continued to the present. During the Great Recession, less-educated workers had much higher unemployment rates and the average educational attainment rose for workers.

Figure 8 gives employment rates of males and females for three age groups – 25-34, 35-44, and 45-54 years old. Better-educated workers are much more likely to be employed for both

genders and all three age groups. Male workers with BA degrees have very high employment rates for all years except the recessions. Employment rates for males with high school diplomas are substantially lower. The Investment Boom of 1995-2000 drew in many less-educated and younger workers, raising their employment rates. The employment rates have fallen since 2000 for the less-educated. These rates declined further during the Great Recession.

Although the decline in employment is widely discussed, employment rates by gender, age, and educational attainment, like those presented in Figure 8, have not been considered until now. A model of employment and unemployment is presented by Kory Kroft, Fabian Lange, Matthew J. Notowidigdo, and Lawrence F. Katz (2016). This model has been elaborated by Alan B. Krueger, Judd Cramer, and David Cho (2014).

The modeling of employment and unemployment could be extended to a more detailed breakdown of alternatives to employment for members of the working age population. These would include disability status and increased participation in welfare programs. Both of these increased as a proportion of the working age population during the Great Recession with relaxation of requirements for eligibility. Employment may have been adversely affected by extended benefit periods for the unemployed, now expired, and lower income requirements for food stamps.⁵

The increase in the “college premium,” the difference between wages earned by workers with college degrees and wages of those without degrees, has been widely noted. In Figure 9 we plot the compensation of workers by educational attainment, relative to those with a high school diploma (four years of high school). We see that the four-year college premium was stable in the 1960s and 1970s, but rose during the 1980s and 1990s. The college premium stalled throughout the

⁵ The long-term decline in labor force participation for prime-age males is analyzed along these lines by the Council of Economic Advisers (2016).

2000s. The Masters-and-higher degree premium rose even faster than the BA premium between 1980 and 2000 and continued to rise through the mid-2000s.

A possible explanation for the rise in relative wages for college-educated workers with a rising share of these workers in the labor force is that their labor services are complementary to the use of information technology.⁶ The most rapid growth of the college premium occurred during the 1995-2000 boom when IT capital made its highest contribution to GDP growth. Our industry-level view of postwar U.S. economic history allows us to consider the role of changing industry composition in determining relative wages.

Table 1 gives characteristics of the work force for each industry for 2010. The industries with the higher share of college-educated workers include the IT-producing industries – computer and electronic products, publishing (including software), information and data processing, and computer systems design. The industries with higher shares of college-educated workers also include those that use IT products and services intensively – securities and commodity contracts, legal services, professional and technical services, and educational services.

After educational attainment the most important determinant of labor quality is experience, captured by the age of the worker. We have noted that the entry of the baby boomers into the labor force contributed negatively to labor quality growth during 1947-1973 and that the aging of these workers contributed positively after 1973. We show the wages of different age groups, relative to the wages of workers aged 25-34, in Figure 10. The wages of the prime age group, 45-54, rose steadily relative to the young from 1970 to 1994. During the Investment Boom of 1995-2000, the wages of the younger workers surged and the prime-age premium fell.

⁶ See Claudia Goldin and Lawrence F. Katz (2008), *The Race between Education and Technology*, Cambridge, MA, Harvard University Press, for more details and historical background.

The wage premium of the 35-44 and 55-64 age groups shows the same pattern as the premium of prime age workers, first rising relative to the 25-34 year olds, then falling or flattening out during the Investment Boom. The wage premium of the oldest workers is the most volatile but showed a general upward trend throughout the Postwar Period, 1947-2014. The share of workers aged 65-plus has been rising steadily since the mid-1990s, during a period of large swings in the wage premium. The relative wages of the very young, 18-24, has been falling steadily since 1970, reflecting the rising demand for education and experience.

Our new industry-level data set provides detailed information for the period 1947-2014 on the growth of outputs, capital, labor, energy, materials and services inputs, and productivity for the 65 industries that make up the U.S. economy. We present new information on educational attainment and the relationship between employment and educational attainment. We also provide detailed information on labor compensation by age and educational attainment. We next consider the application of our new data set to an analysis of the sources of U.S. economic growth. This will be followed by the application of this data set to the projection of the future growth of the U.S. economy.

Sources of U.S. Economic Growth

In analyzing the sources of U.S. economic growth, we first consider the contributions of three major industry groups to the growth of aggregate output. These are the IT-producing industries, the IT-using industries, and Non-IT industries, defined more precisely below. We then consider the contributions of these industry groups to aggregate productivity growth, defined as the difference between the growth rates of output and input. Although the IT-producing industries account for a relatively small proportion of the value of U.S. output, they generate a much larger share of productivity growth.

Finally, we consider the growth of capital and labor inputs, as well as productivity growth, as sources of U.S. economic growth. We divide the growth of capital input among IT equipment and software, intellectual property, and all other capital inputs. In order to emphasize the role of the dramatic increases in educational attainment, we divide the growth of labor input between college and non-college labor inputs. We find that the growth of capital and labor inputs greatly predominates over productivity growth as a source of U.S. economic growth for the Postwar Period, 1947-2014, as well as for the sub-periods we consider.

In *Information Technology and the American Growth Resurgence*, Jorgenson, Ho, and Stiroh (2005) analyze the economic impact of IT at the aggregate level for 1948-2002 and the industry level for 1977-2000. They also provide a concise history of the main technological innovations in information technology during the Postwar Period, beginning with the invention of the transistor in 1947. Jorgenson, Ho, and Samuels (2012) convert the industrial classification to NAICS. They update and extend the data to cover 70 industries for the period 1960-2007.

The NAICS industry classification includes the industries identified by Jorgenson, Ho, and Samuels (2012) as IT-producing industries, namely, computers, electronic products, and software, and the two IT-services industries, information and data processing and computer systems design. Jorgenson, Ho and Samuels (2012) classify industries as IT-using if the IT intensity index is greater than the median for all U.S. industries that do not produce IT equipment, software and services. We classify all other industries as Non-IT.

Value added in the IT-producing industries during 1947-2014 is only 2.5 % of the U.S. economy, while value added in the IT-using industries is 47.5 % with value added in the Non-IT industries accounting for the remaining fifty percent. The IT-using industries are mainly in trade and services. Most manufacturing industries are in the Non-IT sector. The NAICS industry classification provides much more detail on services and trade, especially the industries that are

intensive users of IT. We begin by discussing the results for the IT-producing sectors, now defined to include the two IT-service sectors.

Figure 11 reveals a steady increase in the share of IT-producing industries in the growth of value added since 1947. This corresponds to a decline in the contribution of the Non-IT industries, while the share of IT-using industries remains relatively constant. Figure 12 decomposes the growth of value added for the period 1995-2014. The contributions of the IT-producing and IT-using industries peaked during the Investment Boom of 1995-2000 and have declined since then. However, the contribution of the Non-IT industries also revived during the Investment Boom and declined substantially during the Jobless Recovery and the Great Recession. Figure 13 gives the contributions to value added for the 65 individual industries over the period 1947-2014. The leading contributors are real estate, wholesale and retail trade, and computer and electronic products.

In order to assess the relative importance of productivity growth at the industry level as a source of U.S. economic growth, we express the growth rate of aggregate productivity as a weighted average of industry productivity growth rates, using the ingenious weighting scheme of Evsey Domar (1961)⁷. The Domar weight is the ratio of the industry's gross output to aggregate value added. The Domar weights for all industries sum to more than one. This reflects the fact that an increase in the rate of growth of the industry's productivity has a direct effect on the industry's output and an indirect effect via the output delivered to other industries as intermediate inputs.

The rate of growth of aggregate productivity also depends on the reallocations of capital and labor inputs among industries. The rate of aggregate productivity growth exceeds the weighted sum of industry productivity growth rates when these reallocations are positive. This occurs when

⁷The formula is given in Jorgenson, Ho and Stiroh (2005), equation 8.34

capital and labor inputs are paid different prices in different industries and industries with higher prices have more rapid input growth rates. Aggregate capital and labor inputs then grow more rapidly than weighted averages of industry capital and labor input growth rates, therefore the reallocations are positive. When industries with lower prices for inputs grow more rapidly, the reallocations are negative.

Figure 14 shows that the contributions of IT-producing, IT-using, and Non-IT industries to aggregate productivity growth are similar in magnitude for the period 1947-2014. The Non-IT industries contributed substantially to productivity growth during the Postwar Recovery, 1947-1973, but this contribution became negative during the Long Slump, 1973-1995. The contribution of IT-producing industries was very small during the Postwar Recovery, but became the predominant source of U.S. productivity growth during the Long Slump, 1973-1995. The contribution of IT-producing industries increased considerably during the period of Growth and Recession, 1995-2014.

The IT-using industries contributed substantially to U.S. productivity growth during the Postwar Recovery, but this contribution nearly disappeared during the Long Slump, 1973-1995, before reviving after 1995. The reallocation of capital input made a small but positive contribution to productivity growth during the Postwar Period 1947-2014 and each of the sub-periods. The contribution of reallocation of labor input was negligible for the period as a whole. During the Long Slump and the period of Growth and Recession, the contribution of the reallocation of labor input was slightly negative.

Considering the period of Growth and Recession in more detail in Figure 15, all three industry groups contributed to aggregate productivity growth during the period as a whole. However, the IT-producing industries predominated as a source of productivity growth during the period as a whole and the three sub-periods. The contribution of these industries remained

substantial during each of sub-periods – 1995-2000, 2000-2007, and 2007-2014 – despite the sharp contraction of economic activity during the Great Recession of 2007-2009.

The contribution of the IT-using industries was considerable during the Investment Boom of 1995-2000, remained substantial in the Jobless Recovery of 2000-2007, but became slightly negative during the Great Recession of 2007-2014. The Non-IT industries contributed positively to productivity growth during the Investment Boom. This contribution rose during the Jobless Recovery and then became negative during the Great Recession.

Figure 16 gives the contributions of each of the 65 industries to productivity growth for the Postwar Period. Computer and electronic products, wholesale and retail trade, farms, and broadcasting and telecommunications were among the leading contributors to U.S. productivity growth during the Postwar Period. Many industries made negative contributions to aggregate productivity growth. These included non-market services, such as health and general government, as well as resource industries affected by depletion, such as oil and gas extraction and mining. Other negative contributions reflect the growth of barriers to resource mobility in product and factor markets due, in some cases, to more stringent government regulations.

Finally, we consider the growth of capital and labor inputs, as well as growth in productivity, as sources of growth of the U.S. economy. The contributions of college-educated and non-college-educated workers to U.S. economic growth are given by the relative shares of these workers in the value of output, multiplied by the growth rates of their labor inputs. Workers with a college degree or higher level of education correspond closely with “knowledge workers” who deal with information. Of course, not every knowledge worker is college-educated and not every college graduate is a knowledge worker.

Figure 17 shows that contribution of college-educated workers predominated in the growth of labor input during the Postwar Period 1947-2014. The contribution of non-college-educated

workers was greater during the Postwar Recovery period 1947-1973, but declined substantially during the Long Slump of 1973-1995 and almost disappeared during the period 1995-2014 of Growth and Recession. The contribution of college-educated workers was the dominant source of growth of labor input during the Long Slump and the period of Growth and Recession.

Capital input was the predominant source of U.S. economic growth for the Postwar Period, 1947-2014, as we show in Figure 17. Capital input was also predominant during the Postwar Recovery, the Long Slump, and the period of Growth and Recession. Considering the period of Growth and Recession in greater detail, Figure 18 reveals that the contribution of capital input was about half of U.S. economic growth during the Investment Boom and increased in relative importance as the growth rate fell in the Jobless Recovery and again in the Great Recession.

Figure 17 also provides greater detail on important changes in the composition of the contribution of capital input. For the Postwar Period as a whole the contribution of research and development to U.S. economic growth was considerably less than the contribution of IT. However, the contributions of other forms of capital input predominated over both. While the contribution of research and development exceeded that of IT during the Postwar Recovery, the contribution of IT grew rapidly during the Long Slump and jumped to nearly half the contribution of capital input during the period of Growth and Recession. By contrast the contribution of research and development shrank during both periods and became relatively insignificant. Figure 18 reveals that the contribution of capital input peaked during the Investment Boom, declined during the Jobless Recovery, and collapsed during the Great Recession, but the relative importance of IT remained the same throughout the period of Growth and Recession.

Figure 18 shows that all of the sources of economic growth contributed to the U.S. growth resurgence after 1995, relative to the Long Slump represented in Figure 17. Both IT and Non-IT capital inputs contributed substantially to growth during the Jobless Recovery of 2000-2007, but

the contribution of labor input dropped precipitously and the contribution of non-college workers became slightly negative. The most remarkable feature of the Jobless Recovery was the sustained growth in productivity, indicating an ongoing surge of innovation.

Despite the slowdown of investment during the Great Recession, both IT and Non-IT capital inputs continued to contribute substantially to U.S. economic growth during the period 2007-2014. Productivity growth almost disappeared, reflecting a widening gap between actual and potential growth of output. The contribution of college-educated workers remained positive and substantial, while the contribution of non-college workers became strongly negative. These trends represent increased rates of substitution of capital for labor and college-educated workers for non-college workers.

We have now identified the sources of the growth of the U.S. economy. The predominant source of U.S. economic growth is the growth of capital and labor inputs. This characterizes the Postwar Period 1947-2014 and the sub-periods we have considered. Second, the growth of capital input is considerably more important than the growth of labor input as a source of U.S. economic growth. Finally, investment in information technology equipment and software is the most important component of the growth of capital input as a source of growth of the U.S. economy.

Productivity growth, while a much less important source of U.S. economic growth than the growth of capital and labor inputs, is essential for sustaining economic growth in the long run. We have seen that productivity growth in the IT-producing industries has been the most important source of U.S. productivity growth during the Postwar Period, 1947-2014. The contribution of the IT-producing industries can be traced to developments in technology that were successfully commercialized after the Postwar Recovery 1947-1973.

Future U.S. Economic Growth

Our final objective is to assess the prospects for revival of U.S. economic growth. We present three alternative projections for U.S. economic growth for the period 2014-2024 – Base Case, Low Growth, and High Growth. This enables us to quantify the uncertainty in projections of the growth of capital quality and productivity growth. We present the three alternative projections in Figures 19, 20 and 21. We compare these projections with historical data for the period 1990-2014.

Figure 19 includes three alternative projections of productivity growth for the period 2014-2024. For the Base Case we set future productivity growth rates for IT-producing, IT-using and Non-IT industries equal to growth rates for the period of Growth and Recession, 1995-2014. The Low Growth projection is based on productivity growth rates for the period 1973-2014, including the Long Slump of 1973-1995. The High Growth projection incorporates productivity growth rates for the recent period, 2000-2014, including the Jobless Recovery of 2000-2007 and the Recession and Recovery of 2007-2014.

We use the following assumptions for all three projections: We set the capital share in value added and the share of reproducible capital in total capital stock equal to the averages for the Postwar Period, 1947-2014. We fix the shares of nominal GDP for IT-producing, IT-using, and Non-IT sectors at the averages for the recent period 2000-2014 to reflect changes in the relative importance of information technology. More details about the projections are provided in the Appendix.

We define average labor productivity as output per hour worked. The growth rate of labor productivity is the sum of growth rates of labor quality, capital deepening, and total factor productivity, where capital deepening is defined as capital input per hour worked. We project growth rates of labor productivity and hours worked for the period 2014-2024, which sum to the

growth rate of output for the U.S. economy. Figure 20 gives the growth rates of labor productivity for the Base Case, Low Growth and High Growth projections, while Figure 21 presents the projected growth rates of output.

Base Case

Our projections of U.S. economic growth incorporate trends in employment rates by gender, age, and education. For each gender-age-education category we assume that the employment rate remains equal to the rate in 2014, when the unemployment rate stabilized. We fix weekly hours for each gender-age-education group at the 2014 level, when the U.S. economic reached full employment. Our projections of the growth rates of labor quality for 2014-2024 are considerably below the averages for the period 1990-2014, due to declines in the rates of growth of average educational attainment.

In the Base Case we assume that the growth rates of capital quality and productivity growth for the next ten years will equal average growth rates for the period of Growth and Recession, 1995-2014. The Investment Boom of 1995-2000 combined rapid accumulation of IT capital and robust productivity growth. The Jobless Recovery of 2000-2007 had strong productivity growth but slower growth of IT capital. The Recession and Recovery of 2007-2014 had weak productivity growth and much slower accumulation of IT capital.

The growth rate of capital quality during the period 1995-2014 that is used in the projection is slightly below the growth rate for the period 1990-2014. Capital deepening makes the biggest contribution to labor productivity growth while the growth of productivity in the IT-producing sector will make the second largest contribution during the period 2014-2024. We project that productivity growth in the IT-using sector during the period 2014-2024 will exceed its contribution during 1990-2014, reflecting more rapid productivity growth and the higher value share of this

sector. Finally, TFP of the Non-IT sector of the economy will contribute relatively little to labor productivity growth, even compared to the period 1990-2014.

Our Base Case projection of labor productivity growth over the next ten years, 2014-2024, is markedly lower than growth during the period 1990-2014. Our projection of labor quality growth in the Base Case is also well below growth in 1990-2014. Total hours worked is projected to grow at 0.50% per year compared to 0.71% during 1990-2014, reflecting the future changes in the age-structure and the assumption of fixed annual hours at 2014 levels for each age-gender-education group.

Combining our projected growth rates in hours worked and average labor productivity, we project the GDP growth rate at 1.83% per year over the next ten years. This is a substantial decline from the growth rate of 2.35% per year during the period 1990-2014. The slower growth in hours worked is reinforced by the slower growth of average labor productivity. We conclude by emphasizing that we do not model the determinants of employment, but rely on extrapolations of trends from the historical data.

Low Growth Case.

Our first alternative assumption to the Base Case is that capital quality and productivity growth over the next ten years will equal the averages over 1973-2014, a period that includes the Long Slump and the Recession and Recovery. The period of Recession and Recovery can be subdivided among the IT Boom, the Jobless Recovery, and the Recession and Recovery. By including the Long Slump and the Recession and Recovery periods, we dampen the growth rates in this low scenario. Taking averages over 1973-2014 yields a capital quality growth rate that is nearly equal to the growth rate for the period 1990-2014.

We project that productivity growth in the IT-producing sector will be only slightly below the rate for 1990-2014. Using the 2000-2014 average share of the IT-producing sector in output, we obtain a substantial contribution of productivity growth from the IT-producing sector to growth of labor productivity. We project that the growth of productivity in the IT-using sector will be almost equal to the contribution for the period 1990-2014. Finally, we project that productivity growth from the Non-IT sector will contribute very little to average labor productivity growth, even less than during the period 1990-2014.

In the Low Growth Case our projected labor productivity growth for the next ten years is below the Base Case projection. Both the Base Case and the Low Growth projections are markedly below the growth of labor productivity during the period 1990-2014. The growth of hours worked in both scenarios is below the growth of hours for the period 1990-2014. Summing the growth rates in hours worked and labor productivity, the Low Growth Case projects output growth at 1.63% over the next ten years. This is a marked deceleration from the growth rate of 2.35% for the period 1990-2014.

High Growth Case.

For the High Growth Case we assume that employment rates for each gender-age-education group are the same as in the Base Case for the ten-year period 2014-2024. Hours worked is also assumed to grow at 0.50% over the next decade as in the base case, and the growth rate of labor quality will be substantially lower than during the period 1990-2014. We assume that growth rates of capital quality and productivity for the next ten years will equal their averages over the period 1995-2007. This includes the Investment Boom and the Jobless Growth periods, but excludes the Long Slump and the Great Recession as temporary slowdowns in economic growth. Taking

averages over 1995-2007 yields a capital quality growth rate significantly higher than the growth rate over the period 1990-2014.

In the High Growth Case productivity growth in the IT-producing sector is more rapid than in the Base Case. This translates into a relatively high contribution of growth in total factor productivity to growth in average labor productivity. The growth of total factor productivity in the IT-using sector is also projected at a higher rate than in the Base Case. Finally, we project that productivity growth in the remainder of the economy will contribute more to labor productivity growth than in the Base Case.

Combining projections of growth in labor productivity and hours worked, the High Growth projection of GDP growth is 2.38% per year, only slightly above the growth rate of 2.35% during the period 1990-2014. Higher growth of productivity and capital quality are offset by lower growth of labor quality and slower capital deepening. It is important to recall that our projections of employment rates differ by demographic group, therefore the rapid growth in hours worked reflects the disparate impacts of the Great Recession on different types of workers.

Alternative Projections.

Byrne, Oliner, and Sichel (2013) survey contributions to the debate over prospects for future U.S. economic growth since the Great Recession. Tyler Cowen (2011) presents a pessimistic outlook in his book, *The Great Stagnation: How America Ate All the Low-Hanging Fruit, Got Sick, and Will (Eventually) Feel Better*. Cowen (2013) expresses a more sanguine view in his book, *Average is Over: Powering America Beyond the Age of the Great Stagnation*. Robert Gordon (2016) analyzes headwinds facing the U.S. economy in his book, *The Rise and Fall of American Economic Growth: The U.S. Standard of Living since the Civil War*.

Byrne, Oliner and Sichel provide detailed evidence on the recent behavior of IT prices. This is based on research at the Federal Reserve Board to provide deflators for the Index of Industrial Production. While the size of transistors has continued to shrink, performance of semiconductor devices has improved less rapidly, severing the close link that had characterized Moore's Law as a description of the development of semiconductor technology.⁸ This view is supported by Unni Pillai (2011) and by computer scientists John Hennessey and David Patterson (2012).⁹

Gordon's pessimism about the future development of technology in the IT-producing industries is forcefully rebutted by Erik Brynjolfsson and Andrew McAfee (2014) in the *Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies*.¹⁰ Martin Baily, James Manyika, and Shalabh Gupta (2013) summarize an extensive series of studies of the prospects for technology in American industries, including the IT-producing industries, conducted by the McKinsey Global Institute and summarized by Manyika, *et al.* (2011). These studies also present a more optimistic view of future technological developments.

John Fernald (2016) presents a number of alternative projections and of U.S. GDP growth and chooses a modal forecast of 1.6% per year as the most likely outcome. The Congressional Budget Office (2016) presents GDP projections for 10-30 years. The 30-year projection is 2.1% per year. The projections of Fernald and CBO are compared with our three alternative projections – Low, Base Case, and High – in Table 2. All three sets of projections are based on the analysis of sources of U.S. economic growth.

⁸ Moore's Law is discussed by Jorgenson, Ho, and Stiroh (2005), ch. 1.

⁹ See John Hennessey and David Patterson (2012), Figure 1.16, p. 46. An excellent journalistic account of the slowdown in the development of Intel microprocessors is presented by John Markoff in the *New York Times* for September 27, 2015. See: <http://www.nytimes.com/2015/09/27/technology/smaller-faster-cheaper-over-the-future-of-computer-chips.html>.

¹⁰ Brynjolfsson and Gordon have debated the future of information technology on TED. See: <http://blog.ted.com/2013/02/26/debate-erik-brynjolfsson-and-robert-j-gordon-at-ted2013/>

The methodology employed by CBO is inconsistent with the methodology used in the U.S. National Income and Product Accounts and employed by Fernald, as well as by ourselves. The CBO does not include growth of labor quality in its analysis of the sources of growth. The CBO projections omit the slowdown in the growth of labor quality due to the leveling of average educational attainment for the U.S. population that we have analyzed. Unfortunately, this has a major impact on CBO's long-term projections of the federal government budget and, in particular, CBO's projections of the government deficit, which determine whether the U.S. budget is fiscally sustainable.

CBO's Extended Baseline scenario, which corresponds to our Base Case projection, assumes a growth rate of Total Factor Productivity of 1.3% per year. Under this assumption CBO projects that federal debt held by the public will reach 141% of the U.S. GDP in 2046.¹¹ CBO also presents an alternative projection, based on a growth rate of Total Factor Productivity of 0.8% per year. For this projection federal debt held by the public will reach 173% of the GDP in 2046. In contrast our Base Case estimate of Total Factor Productivity growth is 0.46% per year, outside the range of estimates of productivity growth considered by CBO. This would raise the Base Case estimate of federal debt held by the public in 2046 to 195% of the GDP in 2046. A refinement of this estimate would involve adding our estimate of the contribution of labor quality growth omitted by CBO of 0.12% per year, to our Base Case estimate of Total Factor Productivity growth. This would reduce the 2016 estimate of federal debt held by the public to 187% of the GDP in 2046.

¹¹ Congressional Budget Office (2016), Congressional Budget Office. 2016. *The 2016 Long-Term Budget Outlook*. Washington, DC, Congressional Budget Office, July, Figure 7-3, p. 83.

Conclusions

Our industry-level data set for the Postwar Period shows that the growth of capital and labor inputs, recently through the growth of college-educated workers and investments in both IT and Non-IT capital, explains by far the largest proportion of U.S. economic growth. International productivity comparisons reveal similar patterns for the world economy, its major regions, and leading industrialized, developing, and emerging economies.¹² Studies for more than forty countries have extended these comparisons to individual industries for the countries included in the World KLEMS Initiative. The results are reported in detail in Jorgenson, Fukao, and Timmer (2016).

Conflicting interpretations of the Great Recession can be evaluated from the perspective of our new data set. We do not share the technological pessimism of Cowen (2011) and Gordon (2016), especially for the IT-producing industries. Careful studies of the development of semiconductor and computer technology show that the accelerated pace of innovation that began in 1995 has reverted to lower, but still substantial, rates of innovation. Productivity growth in the IT-producing industries made a substantial positive contribution to aggregate productivity growth during the Great Recession.

Our findings also contribute to an understanding of the future potential for U.S. economic growth. Our new projections are consistent with the perspective of Jorgenson, Ho, and Stiroh (2008), who showed that the peak growth rates of the Investment Boom of 1995-2000 were not sustainable. However, our projections are similar to those we presented earlier in Jorgenson, Ho, and Samuels (2016). While the low productivity growth of the Great Recession will be transitory, productivity growth is unlikely to return to the high growth rates of the Investment Boom and the Jobless Recovery.

¹² See Jorgenson and Vu (2013).

Finally, we conclude that the new findings presented in this paper have important implications for U.S. economic policy. Maintaining the gradual recovery from the Great Recession will require a revival of investment in IT equipment and software and Non-IT capital as well. Enhancing opportunities for employment is also essential. While this is likely to be most successful for highly-educated workers, raising participation rates for the less-educated workers and the young will be needed for a revival of U.S. economic growth.

Appendix: Projections.

We adopt the methodology of Jorgenson, Ho and Stiroh (2008) to utilize data for the 65 industries included in the U.S. National Income and Product Accounts. The growth in aggregate value added (Y) is an index of the growth of capital (K) and labor (L) services and aggregate growth in productivity (A):

$$(A1) \quad \Delta \ln Y = \bar{v}_K \Delta \ln K + \bar{v}_L \Delta \ln L + \Delta \ln A$$

To distinguish between the growth of primary factors and changes in composition, we decompose aggregate capital input into the capital stock (Z) and capital quality (KQ), and labor input into hours (H) and labor quality (LQ). We also decompose the aggregate productivity growth into the contributions from the IT-producing industries, the IT-using industries, and the Non-IT industries. The growth of aggregate output becomes:

$$(A2) \quad \Delta \ln Y = \bar{v}_K \Delta \ln Z + \bar{v}_K \Delta \ln KQ + \bar{v}_L \Delta \ln H + \bar{v}_L \Delta \ln LQ \\ + \bar{u}_{ITP} \Delta \ln A_{ITP} + \bar{u}_{ITU} \Delta \ln A_{ITU} + \bar{u}_{NIT} \Delta \ln A_{NIT}$$

where the $\Delta \ln A_i$'s are productivity growth rates in the IT-producing, IT-using and Non-IT groups and the u 's are the appropriate weights. Labor productivity, defined as value added per hour worked, is expressed as:

$$(A3) \quad \Delta \ln y = \Delta \ln Y - \Delta \ln H$$

We recognize the fact that a significant component of capital income goes to land rent. In our projections we assume that land input is fixed, and thus the growth of aggregate capital stock is:

$$(A4) \quad \Delta \ln Z = \bar{\mu}_R \Delta \ln Z_R + (1 - \bar{\mu}_R) \Delta \ln LAND = \bar{\mu}_R \Delta \ln Z_R$$

where Z_R is the reproducible capital stock and $\bar{\mu}_R$ is the value share of reproducible capital in total capital stock.

We project growth using equation (A2), assuming that the growth of reproducible capital is equal to the growth of output, $\Delta \ln Y^P = \Delta \ln Z_R^P$, where the P superscript denotes projected variables. With this assumption, the projected growth rate of average labor productivity is given by:

$$(A5) \quad \Delta \ln y^P = \frac{1}{1 - \bar{v}_K \bar{\mu}_R} \times [\bar{v}_K \Delta \ln KQ - \bar{v}_K (1 - \bar{\mu}_R) \Delta \ln H + \bar{v}_L \Delta \ln LQ + \bar{u}_{ITP} \Delta \ln A_{ITP} + \bar{u}_{ITU} \Delta \ln A_{ITU} + \bar{u}_{NIT} \Delta \ln A_{NIT}]$$

We emphasize that this is a long-run relationship that removes the transitional dynamics related to capital accumulation.

To employ equation (A5) we first project the growth in hours worked and labor quality. We obtain population projections by age, race and gender from the U.S. Census Bureau¹³ and organize the data to match the classifications in our labor database (8 age groups, 2 genders). We read the 2010 Census of Population to construct the educational attainment distribution by age, based on the 1% sample of individuals. We use the micro-data in the Annual Social and Economic Supplement (ASEC) of the *Current Population Survey* to extrapolate the educational distribution for all years after 2010 and to interpolate between the 2000 and 2010 Censuses. This establishes the actual trends in educational attainment for the sample period.

¹³ The projections made by the U.S. Census Bureau in 2012 are given on their web site: <http://www.census.gov/population/projections/data/national/2012.html>. The resident population is projected to be 420 million in 2060. We make an adjustment to give the total population including Armed Forces overseas.

Educational attainment derived from the 2010 Census shows little improvement for males compared to the 2000 Census with some age groups showing a smaller fraction with professional degrees. However, the proportion of females with BA degrees is higher in 2010 than 2000. Our next step is to project the educational distribution for each gender-age group. For this purpose we use the historical improvements in educational attainment by these groups shown in Figure 6.

Educational attainment of workers at the end of our sample period is dominated by the effects of the Great Recession. Less-educated workers experienced much higher unemployment rates than those with college degrees and had lower rates of participation. Second, improvement in the share of men with BA or MA-plus degrees between 2000 and 2010 is modest, with some age groups falling behind. The improvement in women's education is more pronounced, especially in the older age groups, but there are also certain age groups of women that regressed.

Given these observations, we assume continuing improvement for all ages. We allow a continuing rise in the share of people in each age group with BA's or MA's, based on the observed educational attainment in 2000 and 2010. The gain in the share with BA's and MA's among men during these 10 years was very small, even negative for some age groups. The gain among women is greater but not uniformly positive for all ages.

We establish a long-run target of maximum educational attainment for 2030 e_{saet}^{\max} by assuming that there will be higher shares of people with BA degrees, MA degrees, Professional degrees or PhD degrees, with offsetting lower shares in the other categories (Associate degree, some college, HS diploma, some high school). We impose a target education-age profile that is changing smoothly for two groups of men – those with BA degrees and Professional degrees.

For men we assume that the increase in the share of BA's by 2030 is similar to the change between 2000 and 2010 for those between 24 and 44 years old. Given that the education-age profiles are somewhat erratic, this projection results in a somewhat uneven improvement by age. For the Professional degree target for men, we assume that the future increase in the share is similar to the improvement between 2000 and 2010 for ages 27 to 37. We apply similar rules for the Associate degrees, BA, MA, and PhD categories. We then apply a reverse rule that lowers the share of those with elementary school, some high school without diploma, and HS diploma.

We apply a similar procedure for women. We impose a smooth increase for the share of women with MA degrees that covers both the 2000 and 2010 lines. We also assume higher shares for Professional degrees and PhD's and offset this with shares of BA's and Associate degrees that are very close to the 2010 values, and lower shares for high school diploma and lower categories.

After establishing the e_{saet}^{\max} target for 2030, we interpolate the 2014-2030 projected matrices linearly using the actual 2014 values and the target:

$$(A.6) \quad e_{saet}^p = \omega_t e_{saet}^{2012} + (1 - \omega_t) e_{saet}^{\max} \quad t=2014, \dots, 2030$$

We apply this projected improvement to those aged less than 60, and allow those aged 61-plus to carry their educational attainment as they age:

$$(A.7) \quad e_{saet} = e_{saet}^p \quad a=0, \dots, 60$$

$$e_{saet} = e_{s,a-1,e,t-1}^p \quad a=61, \dots, 90+$$

Given that those aged a (>60) in 2014 has higher educational attainment than those aged $a-1$ in 2014, this assumption generates a rising level of attainment in the population.

We assume that the educational attainment for men aged 39 or younger will be the same as the last year of the sample period, that is, a man who becomes 22 years old in 2024 will have the same chance of having a BA degree as a 22-year old man in 2014. For women, this cut-off age is

set at 33. For men over 39 years old, and women over 33, we assume that they carry their education attainment with them as they age. For example, the educational distribution of 50-year-olds in 2024 is the same as that of 40-year-olds in 2014, assuming that death rates are independent of educational attainment. Since a 50-year-old in 2024 has a slightly higher attainment than a 51-year-old in 2022, these assumptions result in a smooth improvement in educational attainment that is consistent with the observed profile in the 2010 Census.

After projecting the population matrix by gender, age and education for each year our next step is to project the hours worked matrices by these characteristics. We use the weekly hours, weeks per year, and compensation matrices in 2014 described in Jorgenson, Ho and Samuels (2016). We assume there are no further changes in the annual hours worked and relative wages for each age-gender-education cell. We calculate the effective labor input in the projection period by multiplying the 2014 hours per year by the projected population in each cell and weighting the hours per year by the 2014 compensation matrix. The ratio of labor input to hours worked is our labor quality index.

The growth rate of capital input is a weighted average of the stocks of various assets weighted by their shares of capital income. The ratio of total capital input to the total stock is the capital quality index which rises as the composition of the stock moves towards short-lived assets with high rental costs. The growth of capital quality during the period 1995-2000 was clearly unsustainable. For our Base Case projection we assume that capital quality grows at the average rate observed for 1995-2014. For the High Growth case we use the rate for 1995-2007. Finally, we use the rate for 1990-2014 for the Low Growth case.

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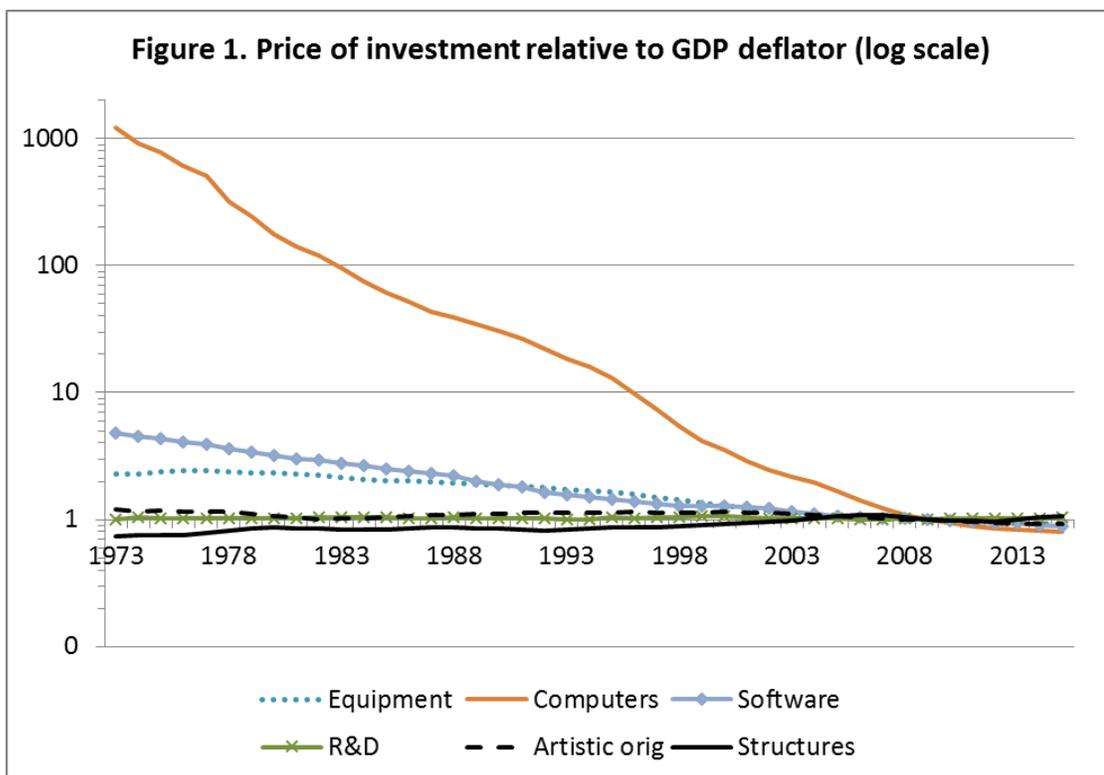
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Table 1: Labor Characteristics by Industry, year 2010.

| | | % workers college educated | compensation (\$/hour) | % of total hours; aged 16-35 | % total hours; females | % Females college educated | % Males college educated |
|----|---|----------------------------|------------------------|------------------------------|------------------------|----------------------------|--------------------------|
| 1 | Farms | 15.1 | 19.5 | 20.3 | 14.7 | 18.6 | 14.3 |
| 2 | Forestry fishing and related activities | 16.4 | 16.6 | 30.8 | 15.3 | 30.6 | 13.3 |
| 3 | Oil and gas extraction | 38.6 | 79.5 | 14.6 | 22.2 | 44.4 | 36.7 |
| 4 | Mining except oil and gas | 11.8 | 39.2 | 20.2 | 8.8 | 28.0 | 10.1 |
| 5 | Support activities for mining | 26.0 | 37.6 | 25.8 | 13.8 | 39.4 | 23.4 |
| 6 | Utilities | 24.0 | 64.0 | 22.0 | 23.4 | 28.6 | 22.6 |
| 7 | Construction | 14.0 | 31.6 | 33.9 | 8.9 | 24.8 | 12.8 |
| 8 | Wood products | 12.2 | 26.0 | 32.9 | 15.1 | 17.3 | 11.1 |
| 9 | Nonmetallic mineral products | 18.1 | 32.3 | 26.0 | 19.7 | 21.6 | 17.2 |
| 10 | Primary metals | 17.7 | 39.7 | 26.0 | 13.5 | 24.8 | 16.6 |
| 11 | Fabricated metal products | 15.2 | 32.2 | 27.7 | 17.7 | 15.9 | 15.0 |
| 12 | Machinery | 24.5 | 38.7 | 25.6 | 19.4 | 24.2 | 24.6 |
| 13 | Computer and electronic products | 62.3 | 56.7 | 31.0 | 30.3 | 54.2 | 66.0 |
| 14 | Electrical equipment appliances | 44.2 | 52.5 | 26.4 | 30.9 | 33.6 | 49.2 |
| 15 | Motor vehicles bodies and parts | 23.6 | 37.9 | 28.4 | 21.8 | 20.8 | 24.4 |
| 16 | Other transportation equipment | 31.4 | 50.6 | 22.6 | 17.3 | 30.9 | 31.7 |
| 17 | Furniture and related products | 15.6 | 26.3 | 31.5 | 24.3 | 17.4 | 15.0 |
| 18 | Miscellaneous manufacturing | 32.1 | 40.7 | 26.8 | 35.6 | 26.3 | 35.7 |
| 19 | Food, beverage and tobacco | 23.8 | 27.2 | 24.3 | 31.5 | 23.2 | 24.2 |
| 20 | Textile mills and textile product mills | 14.0 | 25.6 | 26.5 | 45.2 | 11.9 | 15.8 |
| 21 | Apparel and leather products | 17.6 | 27.0 | 27.4 | 55.9 | 15.4 | 20.9 |
| 22 | Paper products | 18.8 | 37.3 | 23.9 | 20.7 | 18.5 | 18.9 |
| 23 | Printing and related support activities | 22.0 | 29.5 | 28.7 | 32.2 | 23.1 | 21.4 |
| 24 | Petroleum and coal products | 32.9 | 81.5 | 17.7 | 17.4 | 45.2 | 30.0 |
| 25 | Chemical products | 49.5 | 54.1 | 27.4 | 35.2 | 49.1 | 50.3 |
| 26 | Plastics and rubber products | 16.4 | 30.7 | 30.2 | 28.5 | 11.4 | 18.5 |
| 27 | Wholesale Trade | 32.0 | 41.2 | 29.1 | 26.0 | 32.6 | 31.7 |
| 28 | Retail Trade | 15.8 | 23.0 | 35.4 | 42.0 | 14.4 | 17.3 |
| 29 | Air transportation | 38.2 | 49.5 | 28.6 | 35.9 | 36.7 | 39.1 |
| 30 | Rail transportation | 13.2 | 50.7 | 14.0 | 8.3 | 28.7 | 11.7 |
| 31 | Water transportation | 31.1 | 51.6 | 19.1 | 19.6 | 32.6 | 30.6 |
| 32 | Truck transportation | 8.6 | 28.0 | 24.6 | 11.1 | 14.4 | 7.8 |
| 33 | Transit, ground passenger transportation | 16.3 | 22.8 | 18.4 | 23.5 | 11.5 | 18.1 |
| 34 | Pipeline transportation | 32.8 | 65.6 | 17.5 | 18.4 | 45.6 | 29.6 |
| 35 | Other transportation and support | 19.7 | 33.5 | 34.1 | 20.7 | 22.3 | 19.0 |
| 36 | Warehousing and storage | 12.6 | 29.2 | 35.6 | 26.3 | 13.2 | 12.4 |
| 37 | Publishing industries (includes software) | 60.2 | 52.5 | 38.1 | 42.8 | 59.7 | 60.5 |
| 38 | Motion picture and sound recording | 45.9 | 46.4 | 47.9 | 31.6 | 48.8 | 44.3 |
| 39 | Broadcasting and telecommunications | 39.5 | 46.7 | 37.9 | 39.0 | 42.4 | 37.7 |
| 40 | Information and data processing services | 55.4 | 55.0 | 47.7 | 40.8 | 50.8 | 59.1 |
| 41 | Fed Res banks, credit intermediation | 42.4 | 42.1 | 36.5 | 60.1 | 30.3 | 62.8 |
| 42 | Securities, commodity contracts | 71.9 | 120.6 | 38.3 | 35.2 | 58.0 | 80.7 |
| 43 | Insurance carriers | 46.6 | 48.7 | 28.5 | 56.4 | 33.9 | 65.0 |
| 44 | Funds, trusts & other financial vehicles | 71.0 | 99.4 | 40.7 | 37.3 | 57.1 | 80.4 |
| 45 | Real estate | 40.6 | 31.1 | 18.6 | 46.6 | 36.1 | 45.1 |
| 46 | Rental, leasing & lessors of intangibles | 25.4 | 31.1 | 45.0 | 28.8 | 24.1 | 26.0 |
| 47 | Legal services | 65.5 | 57.5 | 29.0 | 53.1 | 46.3 | 90.6 |
| 48 | Computer systems design | 68.6 | 56.7 | 41.1 | 28.5 | 67.0 | 69.3 |
| 49 | Misc. professional and technical services | 65.3 | 46.9 | 31.1 | 42.3 | 58.9 | 70.6 |
| 50 | Management of companies | 53.4 | 62.2 | 28.9 | 51.4 | 39.8 | 69.4 |
| 51 | Administrative and support services | 20.1 | 24.8 | 37.7 | 40.4 | 23.2 | 17.9 |
| 52 | Waste management | 10.2 | 32.5 | 33.9 | 14.3 | 16.1 | 9.2 |
| 53 | Educational services | 64.2 | 28.8 | 27.5 | 65.9 | 64.2 | 64.2 |
| 54 | Ambulatory health care services | 38.8 | 39.2 | 27.5 | 74.2 | 30.8 | 66.6 |
| 55 | Hospitals, Nursing and residential care | 30.4 | 28.4 | 28.1 | 79.5 | 29.4 | 34.4 |
| 56 | Social assistance | 30.0 | 18.8 | 36.1 | 86.7 | 28.9 | 37.4 |
| 57 | Performing arts, spectator sports | 48.7 | 53.8 | 29.1 | 43.8 | 55.1 | 43.1 |
| 58 | Amusements, gambling and recreation | 21.7 | 20.1 | 39.4 | 41.0 | 22.2 | 21.4 |
| 59 | Accommodation | 18.6 | 22.1 | 35.8 | 52.7 | 16.3 | 21.3 |
| 60 | Food services and drinking places | 11.1 | 14.8 | 53.5 | 47.9 | 9.9 | 12.2 |
| 61 | Other services except government | 17.9 | 25.7 | 26.7 | 64.8 | 18.8 | 19.3 |
| 62 | Federal General government | 52.0 | 63.3 | 19.5 | 54.6 | 49.6 | 54.9 |
| 63 | Federal Government enterprises | 19.6 | 42.0 | 14.5 | 34.6 | 20.0 | 19.3 |
| 64 | S&L Government enterprises | 29.9 | 40.9 | 25.4 | 40.2 | 28.9 | 30.7 |
| 65 | S&L General Government | 48.6 | 36.3 | 23.5 | 61.2 | 48.6 | 50.6 |

Notes: "College educated" workers are those with BA or BA+

| Source | Projection period | ALP | Hours | GDP | TFP | Capital Deepening | Labor quality |
|----------------|-------------------|------|-------|------|----------|-------------------|---------------|
| CBO(2015) | 2015-25 | 1.6 | 0.5 | 2.1 | 1.4(NFB) | | |
| Fernald (2016) | 7-10 years | 1.06 | 0.55 | 1.6 | | | 0.20 |
| JHS(2016) | Low case | 1.13 | 0.50 | 1.63 | 0.30 | 0.71 | 0.21 |
| | base case | 1.32 | 0.50 | 1.83 | 0.45 | 0.76 | 0.21 |
| | High case | 1.88 | 0.50 | 2.38 | 0.64 | 1.12 | 0.21 |



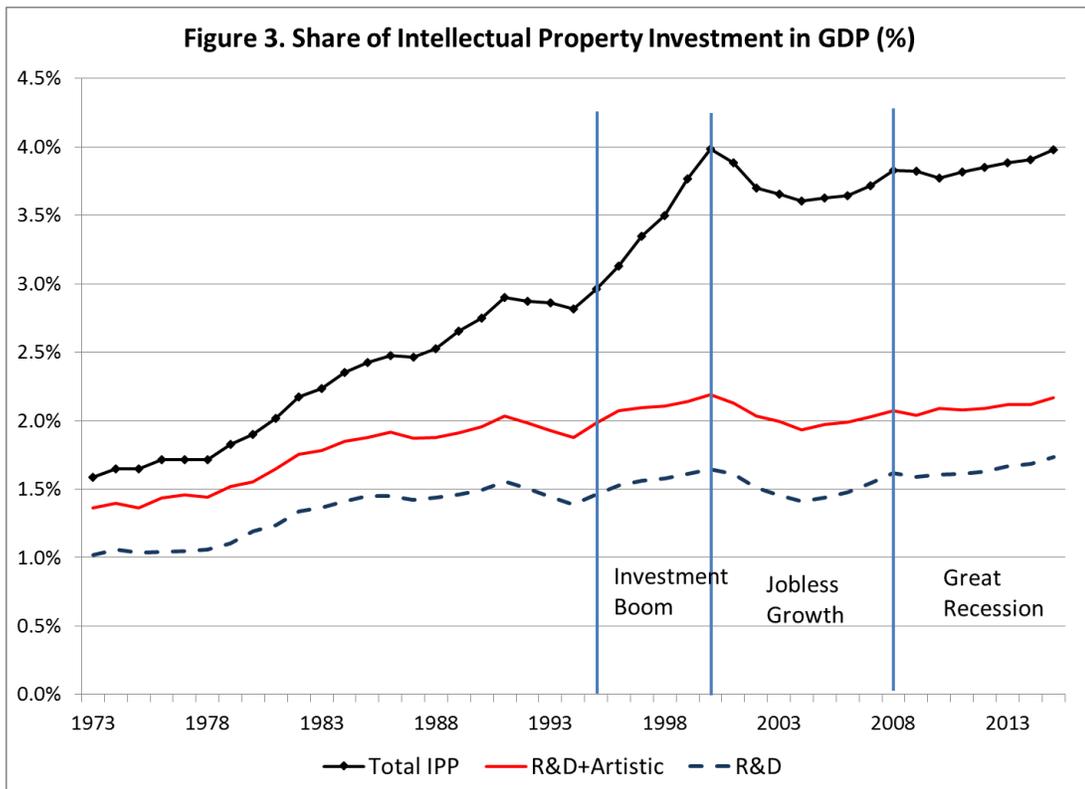
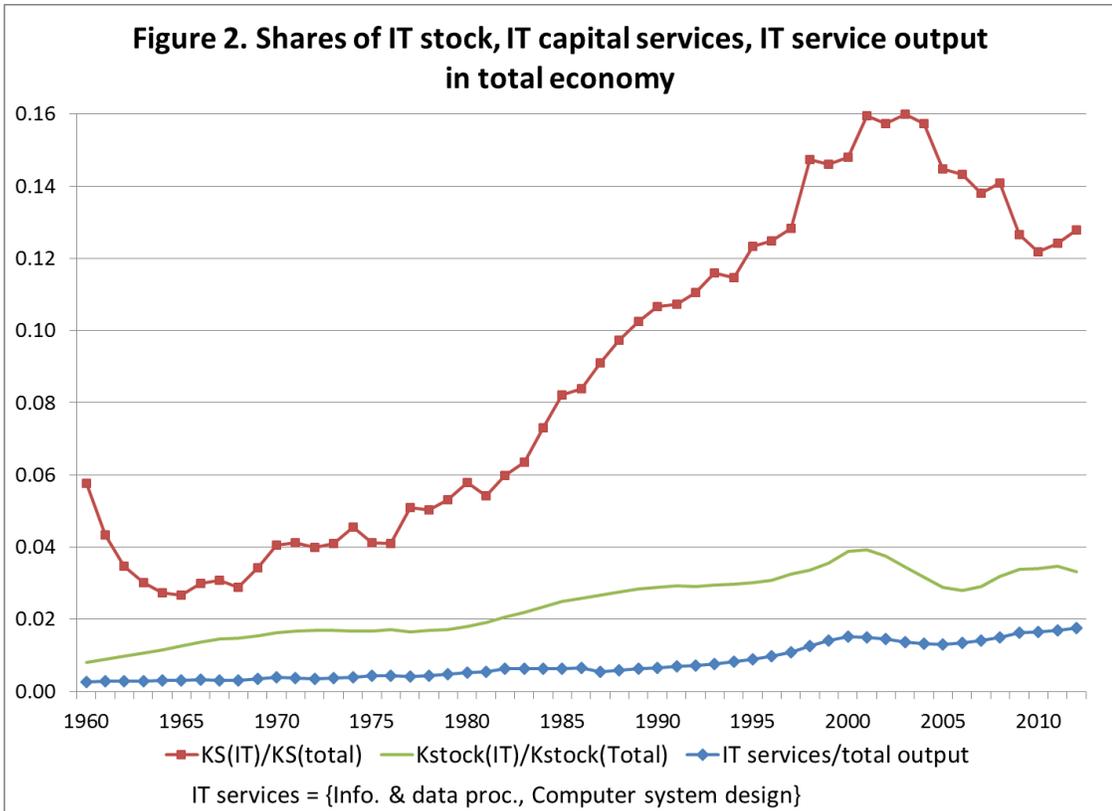


Figure 4. Contribution of education, age and gender to labor quality growth

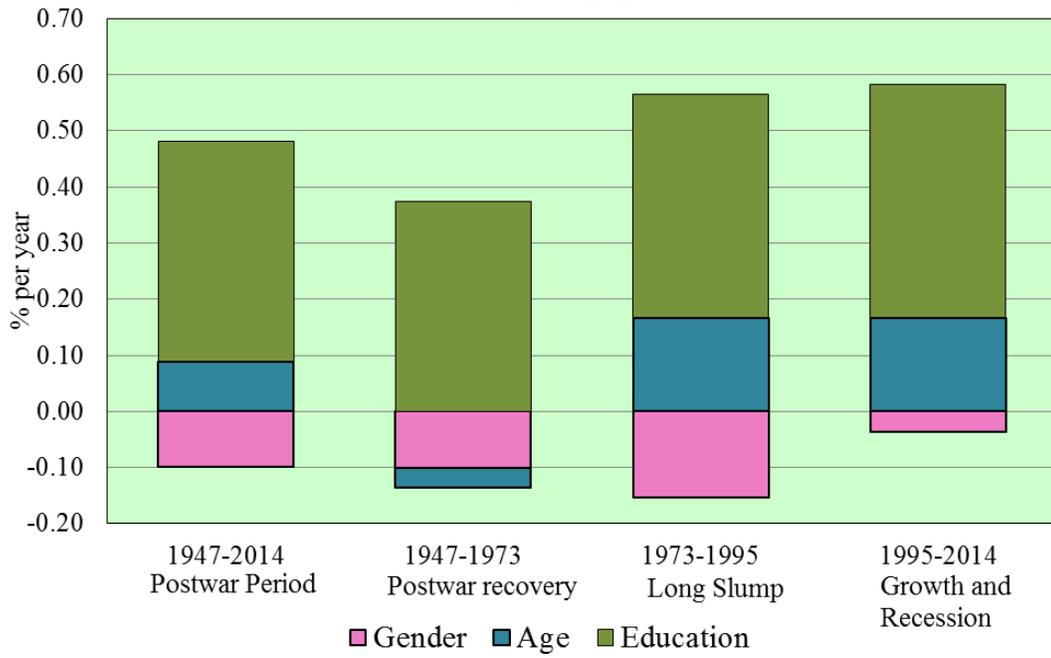


Figure 5. Contribution of education, age and gender to labor quality growth (1995-2014)

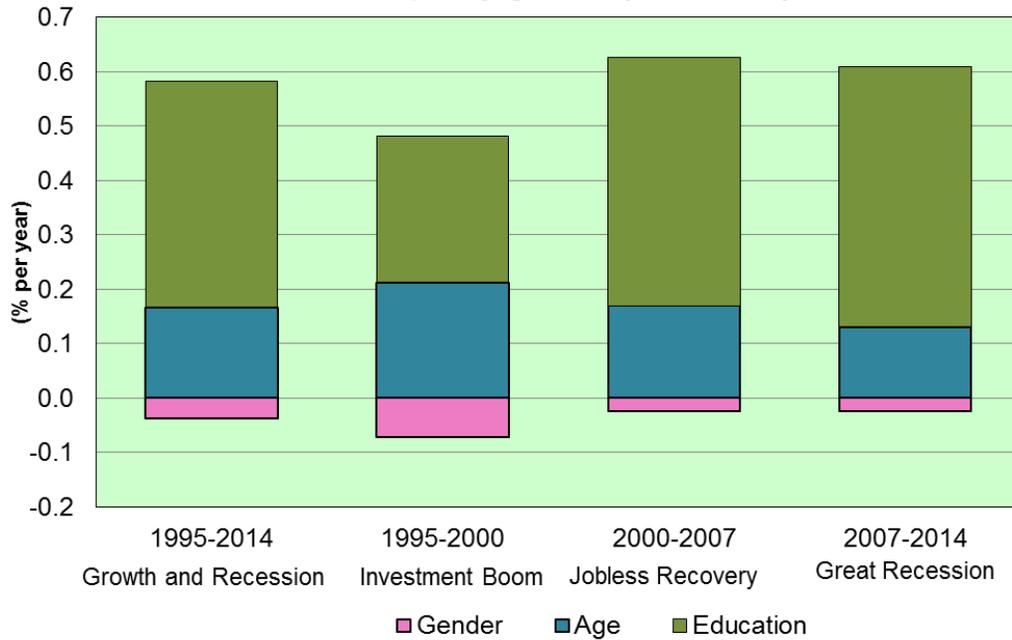


Figure 6. Education attainment of work force

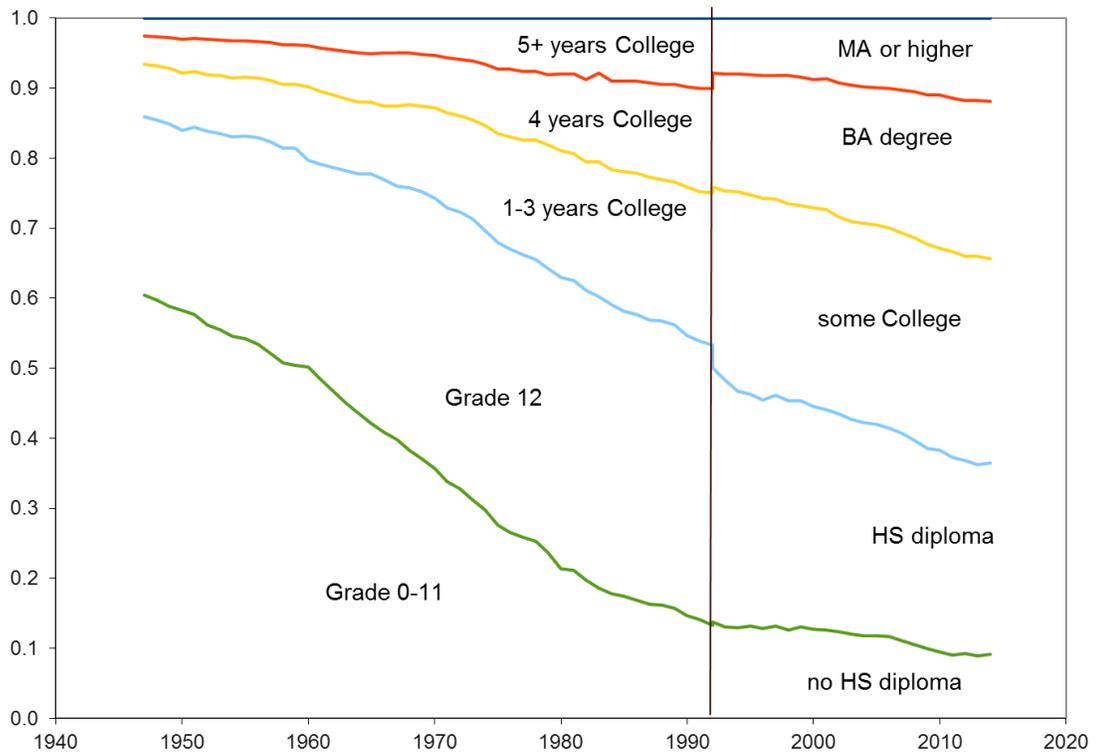


Figure 7. Education attainment of workers aged 25-34

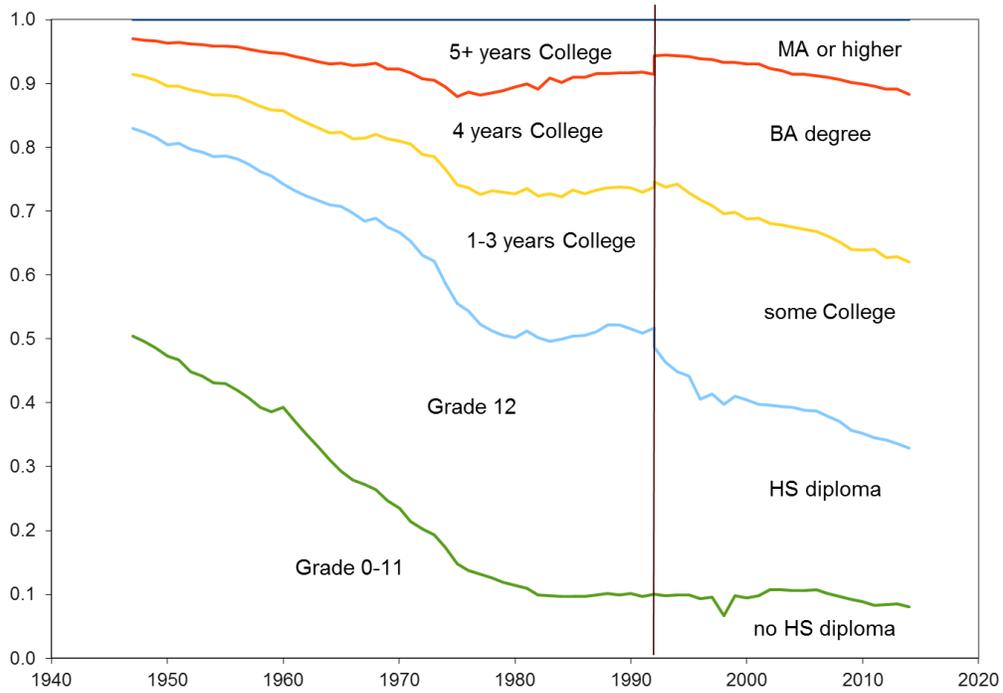
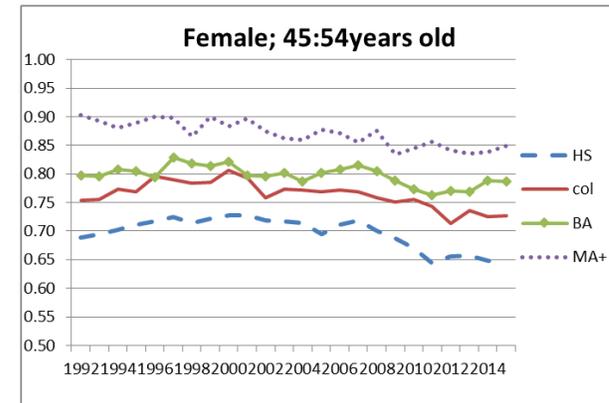
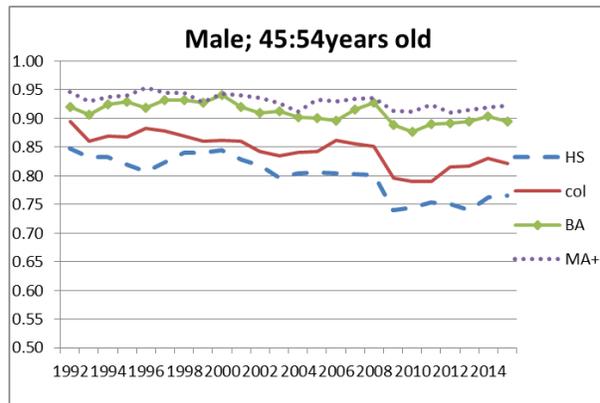
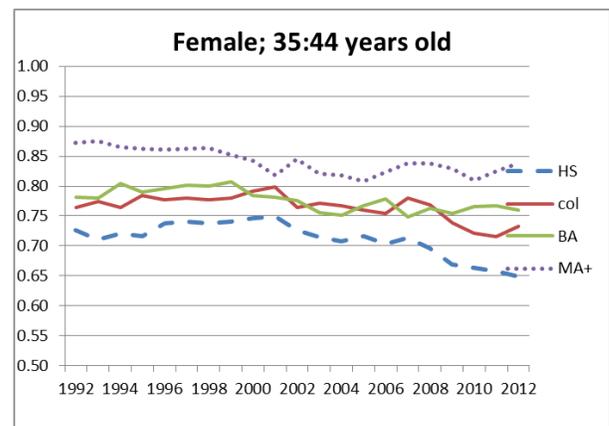
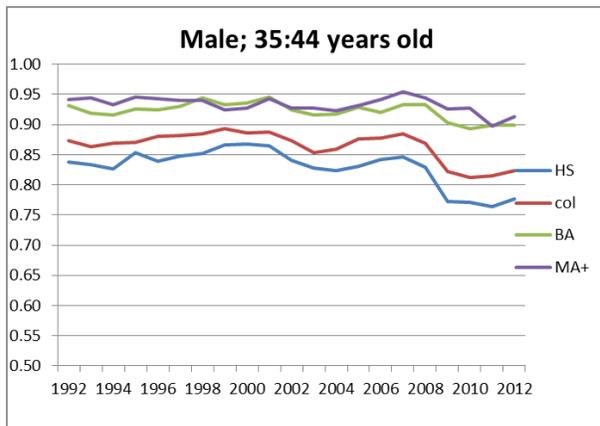
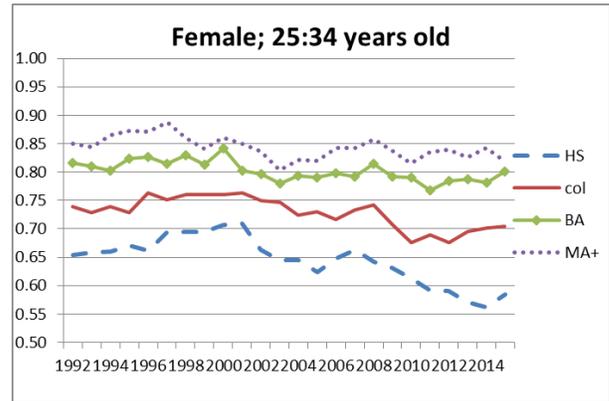
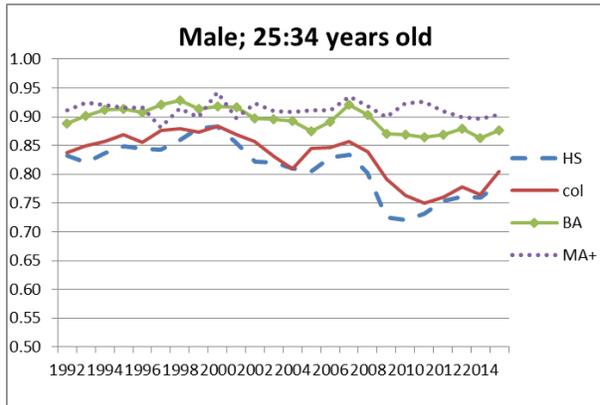


Figure 8. Employment Participation Rates by Gender, Age and Education



**Figure 9. Compensation by education attainment
(relative to those with HS diploma)**

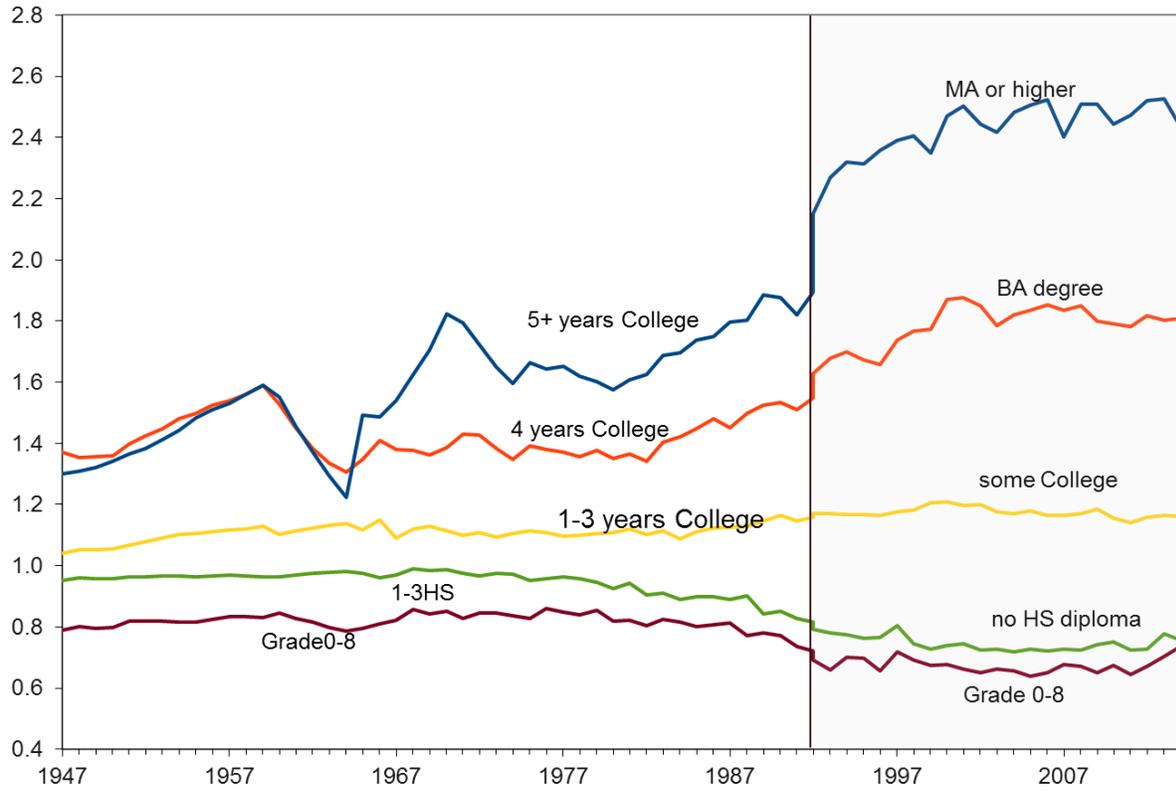


Figure 10. Compensation by age (relative to 25-34 year olds)

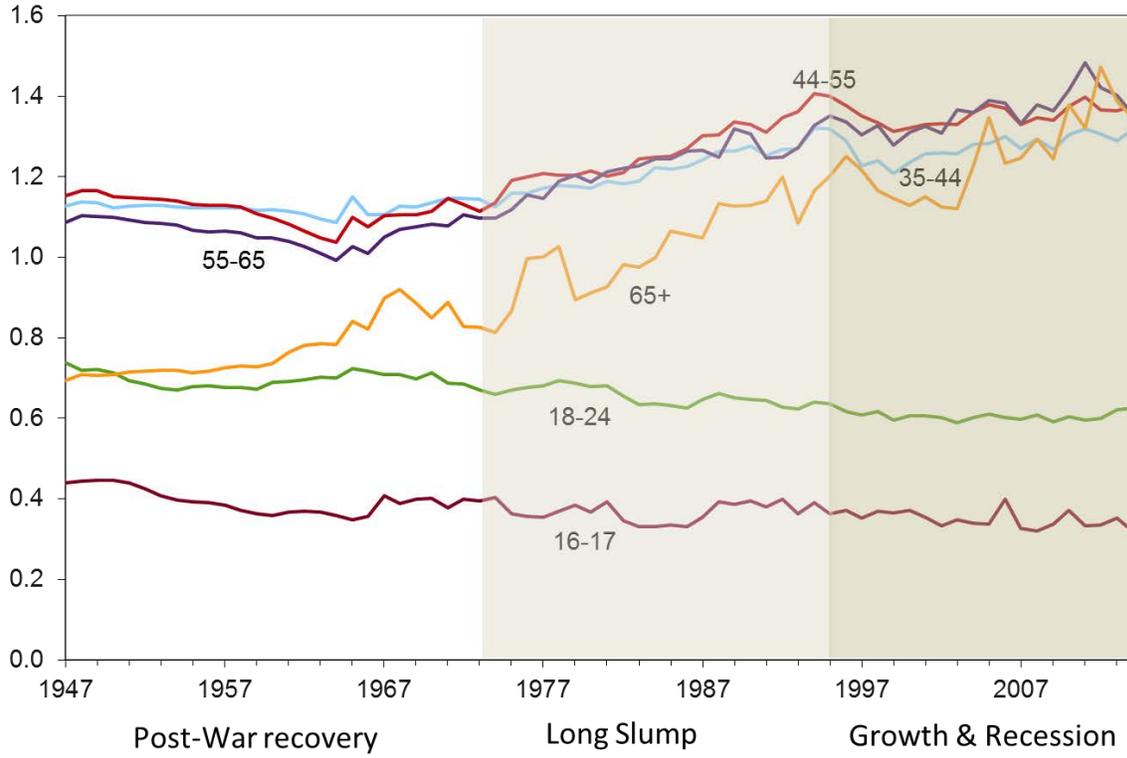


Figure 11. Contributions of Industry Groups to Value Added Growth, 1947-2014

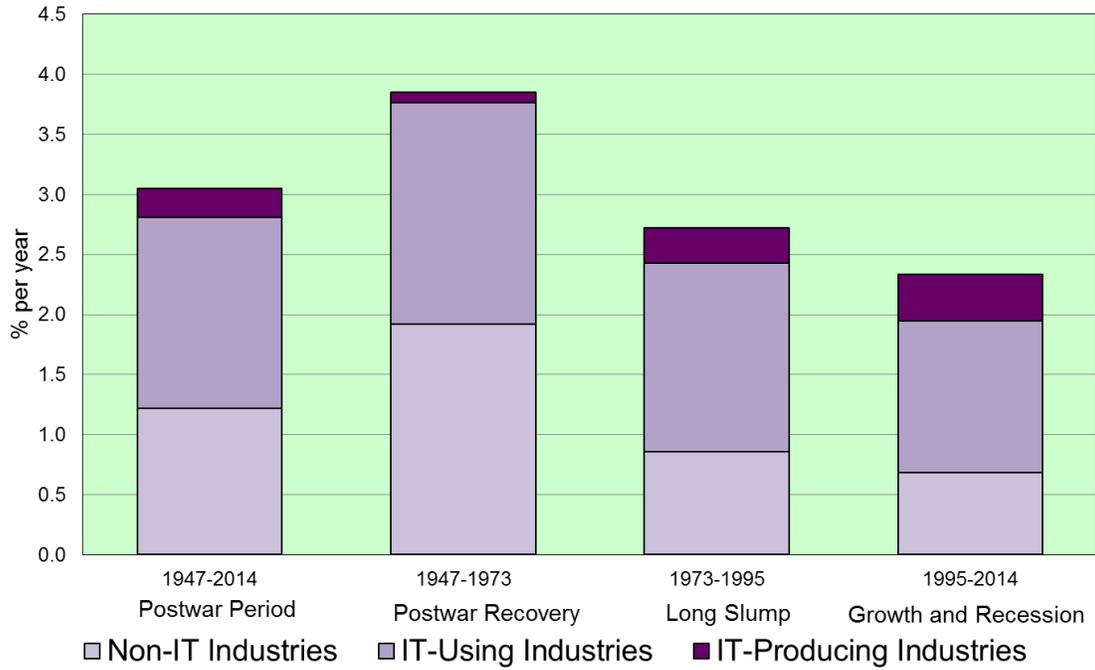


Figure 12. Contributions of Industry Groups to Value Added Growth (1995-2014)

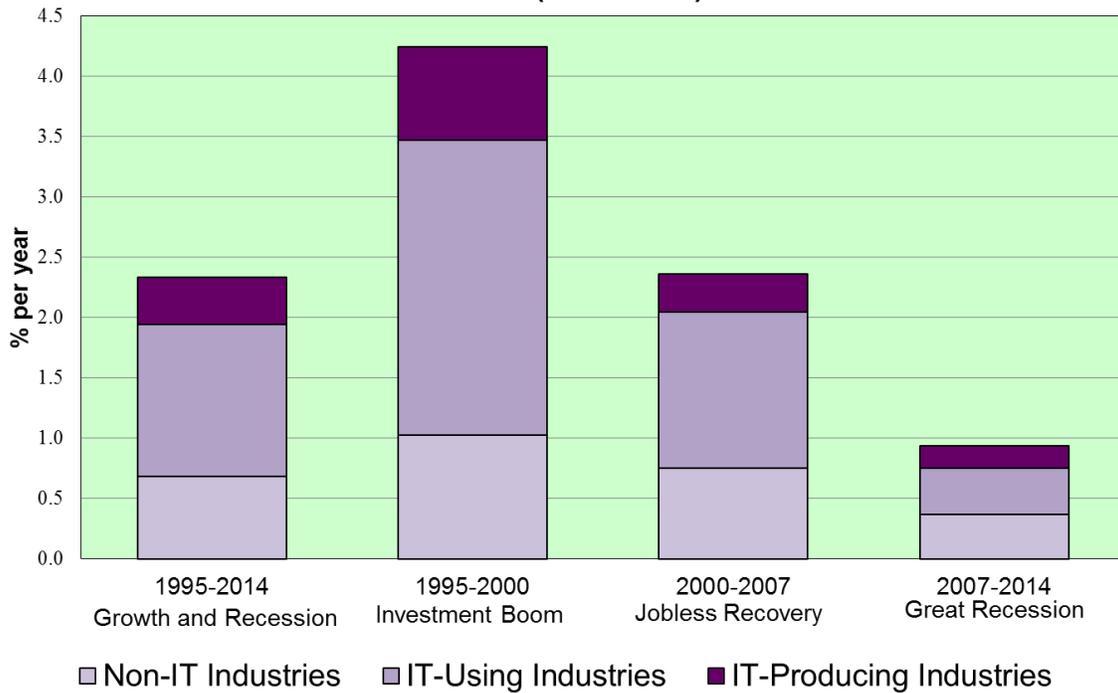


Figure 13. Industry Contributions to Value Added 1947-2014

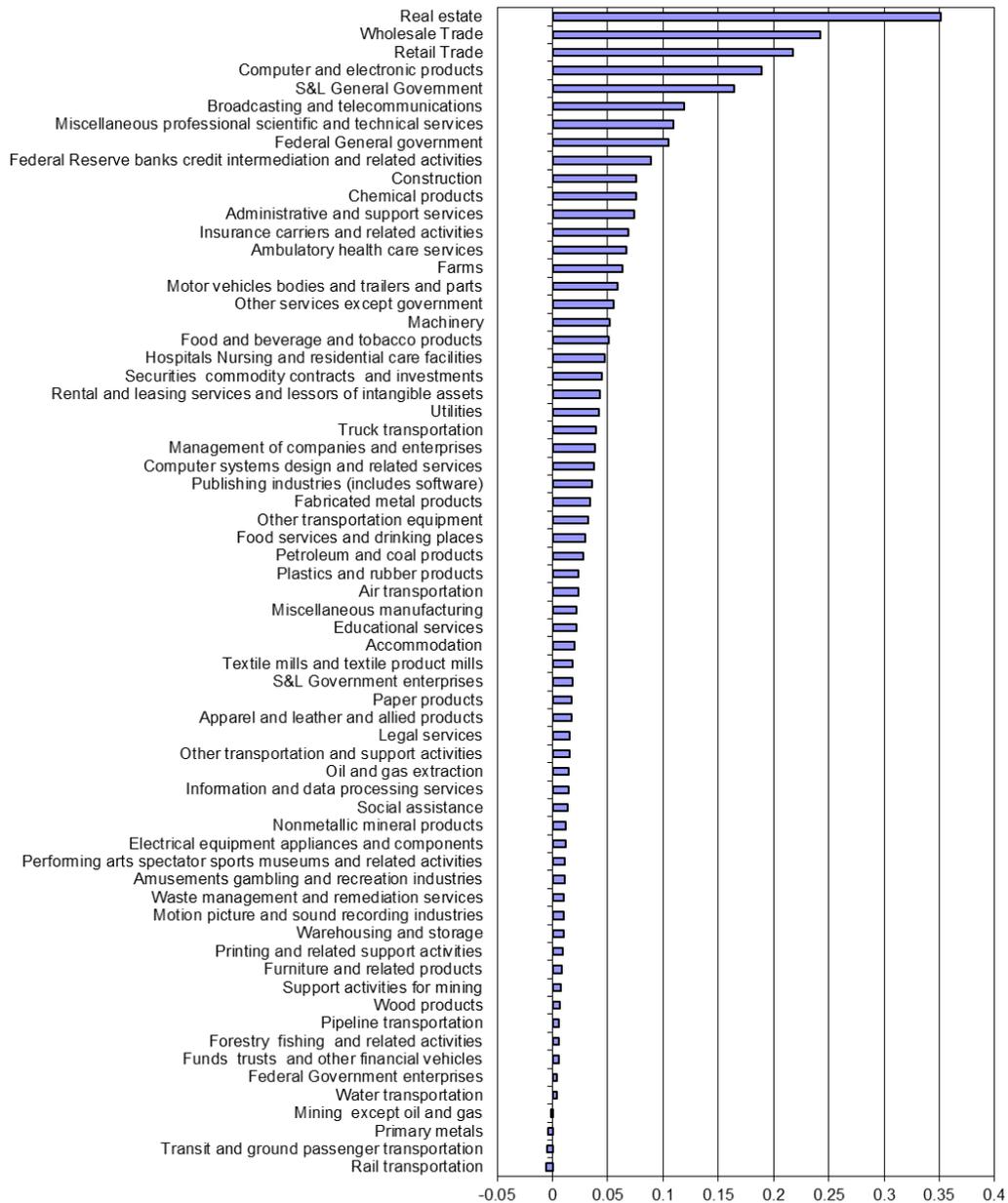


Figure 14. Contribution of Industry Groups to Aggregate Productivity Growth, 1947-2014

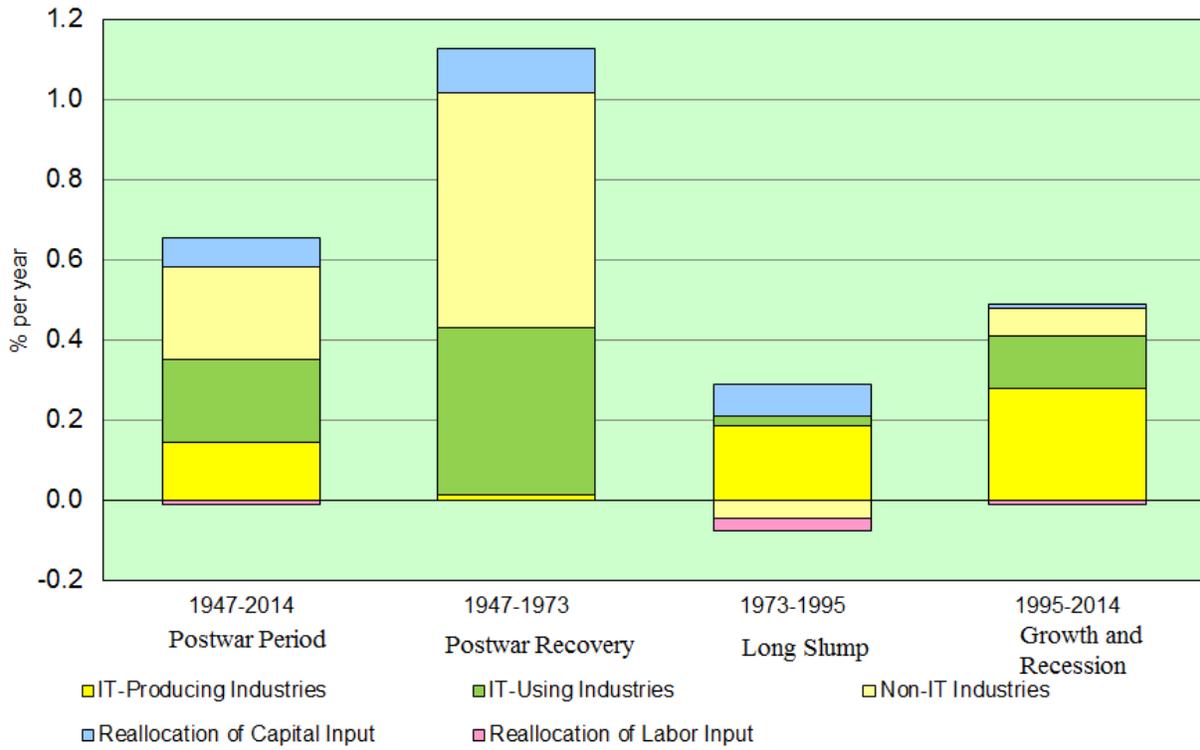


Figure 15. Contribution of Industry Groups to Aggregate Productivity Growth, 1995-2014

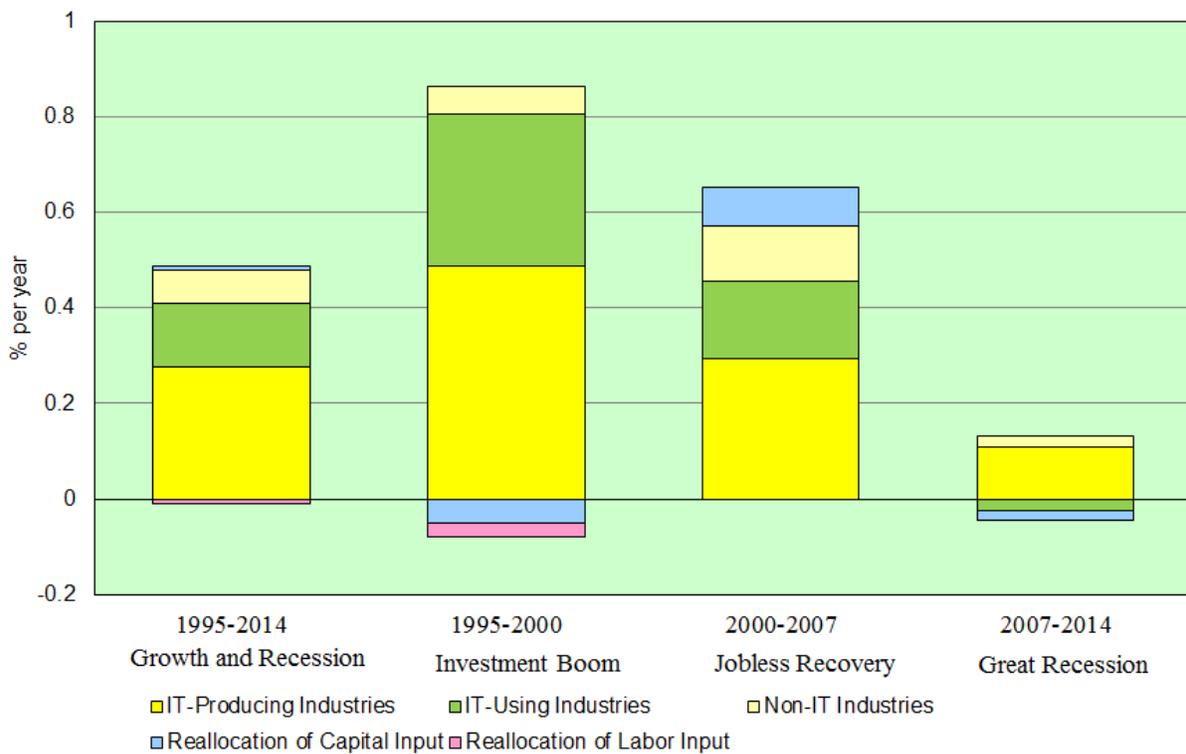


Figure 16. Industry Contributions to Productivity 1947-2014

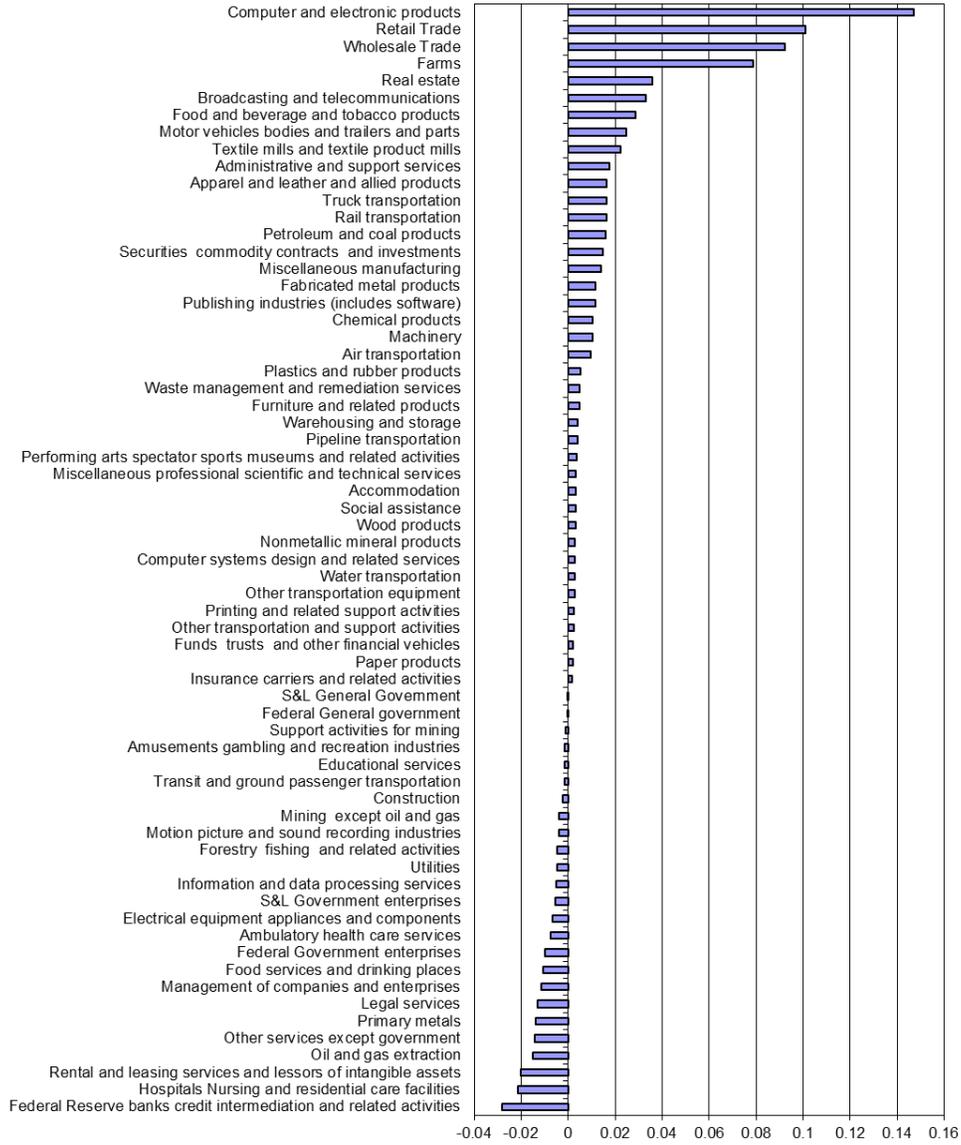


Figure 17. Sources of U.S. Economic Growth, 1947-2014

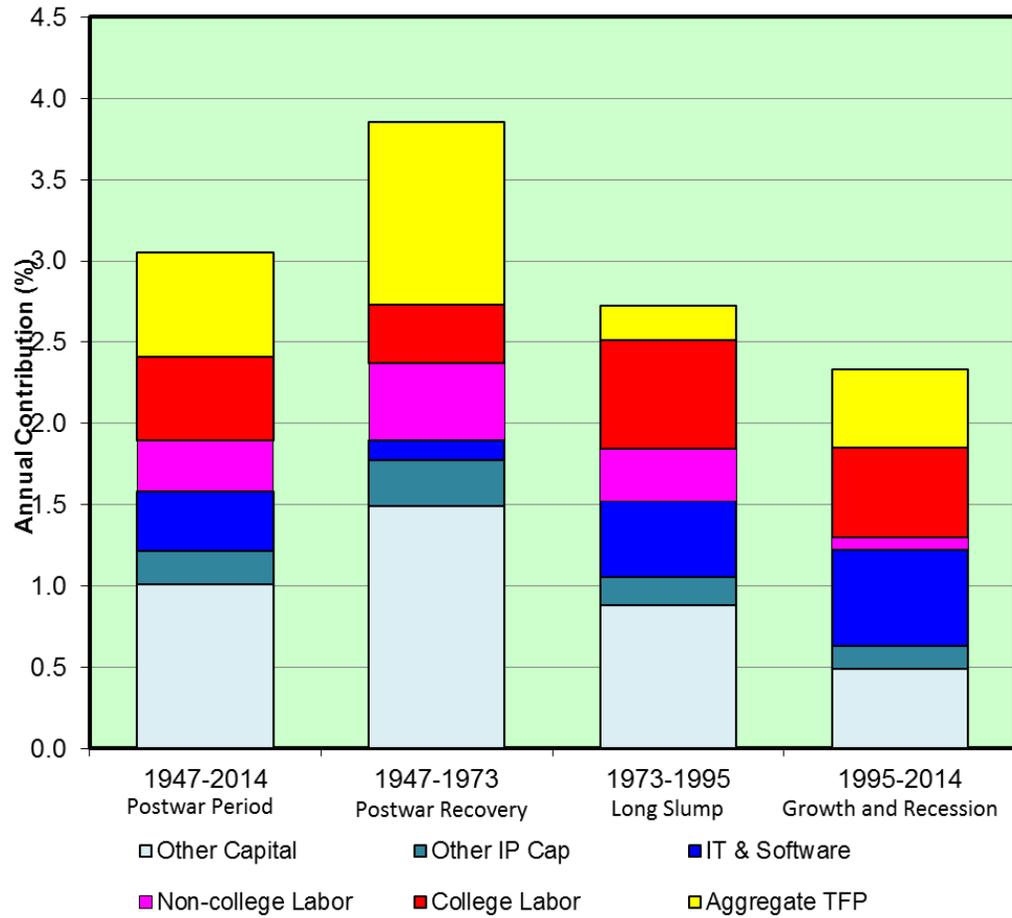


Figure 18. Sources of U.S. Economic Growth, 1995-2014

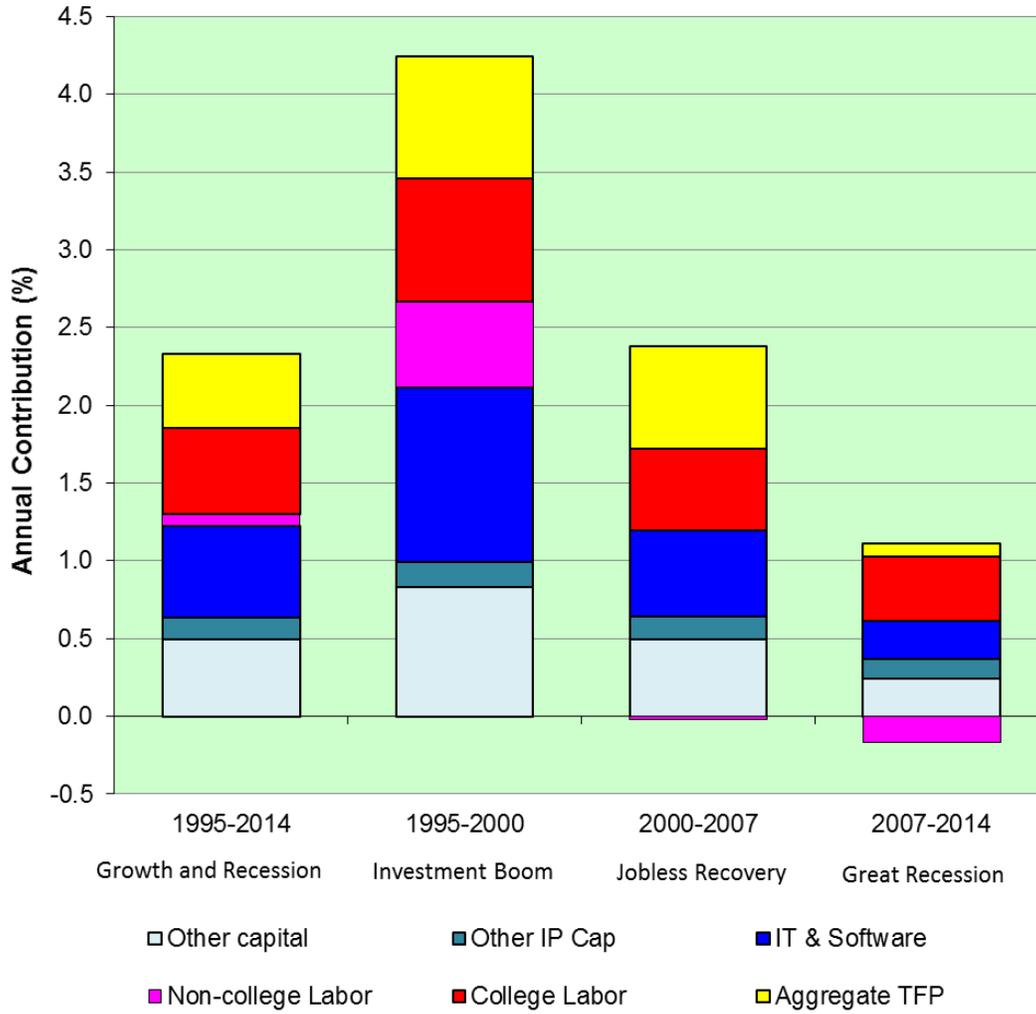


Figure 19. Contribution of Industry Groups to Aggregate Productivity, 2014-2024

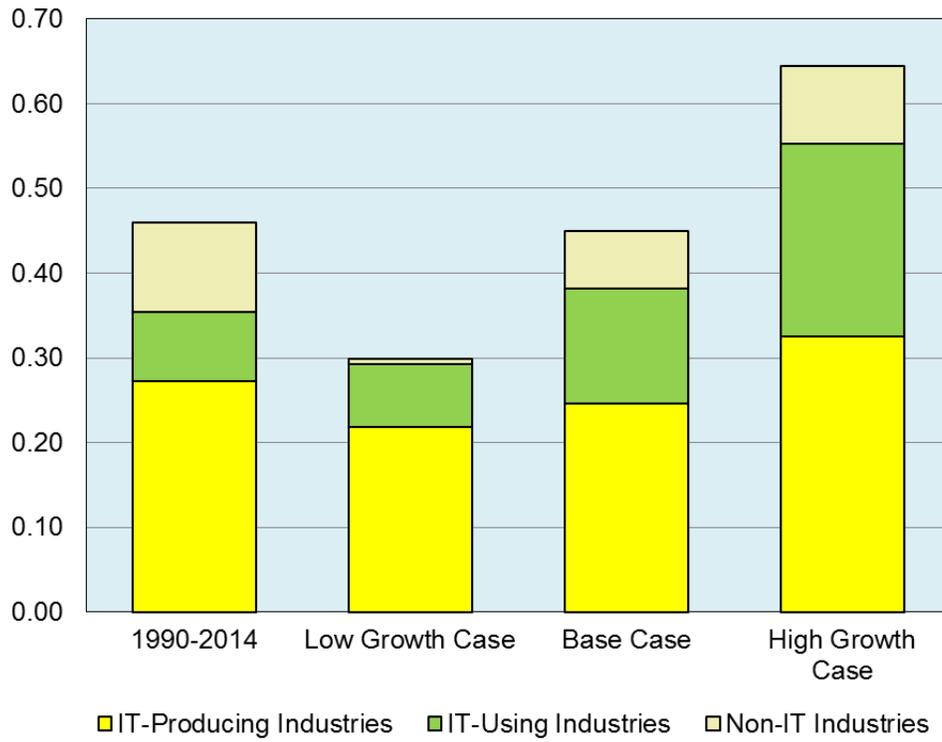


Figure 20. Range of Labor Productivity Projections, 2014-2024

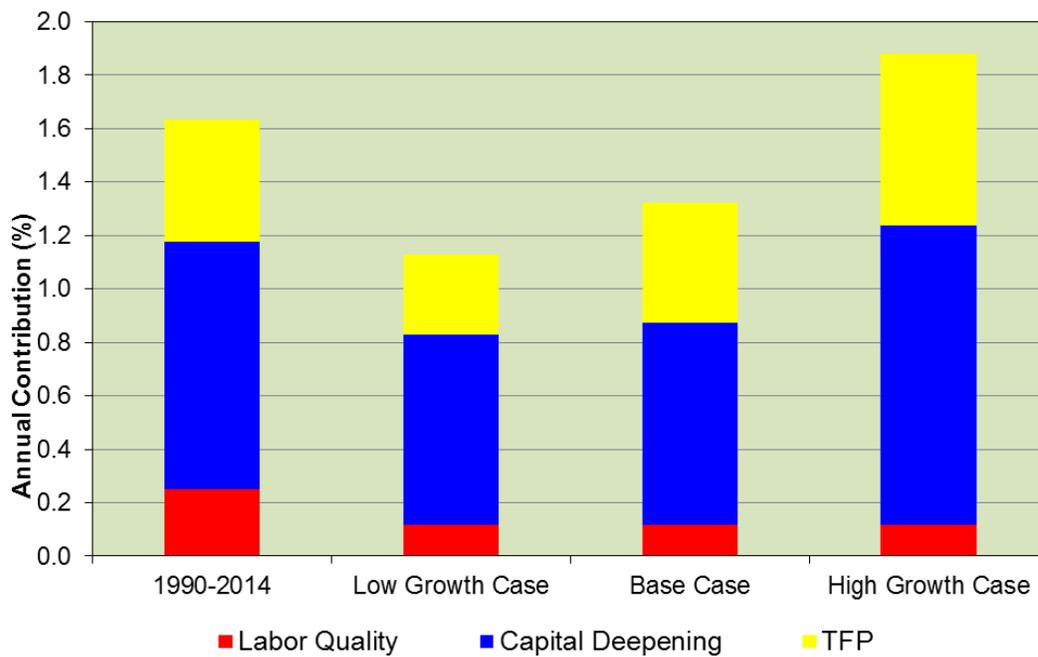


Figure 21. Range of U.S. Potential Output Projections, 2014-2024

