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

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ABSTRACT

Labor quality growth captures the upgrading of the labor force through higher educational attainment and greater experience. Our first finding is that average levels of educational attainment of new entrants will remain high, but will no longer continue to rise, so that growing educational attainment will gradually disappear as a source of U.S. economic growth. Our second finding is that the investment boom of 1995-2000 drew many younger and less-educated workers into employment. Participation rates for these workers declined during the recovery of 2000-2007 and dropped further during the Great Recession of 2007-2009. In order to assess the prospects for recovery of participation as a potential source U.S. economic growth, we project the participation rates of each age-gender-education group. Our third finding is that the recovery of participation rates will provide an important opportunity for the revival of U.S. economic growth. Participation rates for less-educated workers are unlikely to recover the peak levels that followed the investment boom of 1995-2000. However, these rates can achieve the levels that preceded the Great Recession. While labor quality will grow more slowly, hours worked will grow much faster.

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

by

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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 and the ongoing retirement of the baby boomers, the looming plateau in educational attainment has been overlooked. Average levels of educational attainment of the people entering the labor force will remain high, but will no longer continue to rise. Growing educational attainment will gradually disappear as a source of U.S. economic growth.

We define the employment participation rate for males and females of each age category as the number employed as a proportion of the population. We find that the participation 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 participation rates for these workers declined during the recovery of 2000-2007 and dropped further during the Great Recession of 2007-2009.

Are the lower participation rates of the less-educated workers a "new normal" that will persist for some time? Or, will the continuing economic recovery enable these workers to resume the higher rates of participation that preceded the Great Recession? The answers to these questions

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are critical to the future growth of the U. S. economy. In order to assess the prospects for recovery of employment participation as a potential source for the revival in U.S. economic growth, we project the participation rates of each age-gender-education group.

We find that the recovery of participation rates will provide an important opportunity for the revival of U.S. economic growth. The participation rates for less-educated workers are unlikely to recover the peak levels that followed the end of the investment boom of 1995-2000. However, these participation rates can achieve the levels that preceded the Great Recession, beginning in 2007-2009. Labor input will then increase more rapidly than during the period 1990-2014. While labor quality will grow more slowly, hours worked will grow much faster.

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

The distinctive feature of the new data set is that we provide detailed information on employment participation for the U.S. work force. This information covers the period 1947-2014 and makes it possible to characterize the relationship between employment participation and educational attainment. We employ the information on participation rates in assessing the prospects for a revival of U.S. economic growth. This hinges critically on the recovery of participation rates that declined sharply during the Great Recession that began in 2007-2009, especially for less-educated workers.

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

Paul Schreyer's OECD (2001) manual, *Measuring Productivity,* established international standards for economy-wide and industry-level productivity measurement. These standards were 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*. Our new data set is consistent with the OECD standards.

We present a prototype production account within the framework of the U.S. national accounts. This production account combines the newly available estimates from the BEA industry accounts for outputs and intermediate inputs with the results of our research on inputs of capital and labor services, reported 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 to the economy-wide data presented by Michael Harper, Brent R. Moulton, Steven Rosenthal, and David B. Wasshausen (2009).[2]

The first application of our new industry-level data set 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

[2] The most recent data set is available at: http://www.bea.gov/national/integrated_prod.htm. Our data for individual industries could also be linked to firm-level data employed in the micro-economic research reviewed by Chad Syverson (2011).

focus more specifically on the period of Growth and Recession by considering 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 reflects the growth of capital and labor inputs. This growth reflects the expansion and upgrading of the labor force and investment in plant, equipment and software. Contrary to the well-known views of Robert M. Solow (1957) and Simon Kuznets (1971), the innovation indicated by productivity growth accounts for only a relatively modest twenty percent of U.S. economic growth. This is the most important empirical finding from the extensive recent research on productivity summarized by Jorgenson (2009).

The predominant role of investment in plant, equipment, and software, and growth of labor input in U.S. economic growth is crucial to the formulation of economic policy. During the prolonged recovery from the Great Recession of 2007-2009, economic policy should focus on reviving investment and re-establishing the pre-recession participation 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 adapt 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 and capital input that is consistent with the assumption that output and capital stock 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 economic growth in more detail in the Appendix.

[3] Jorgenson and Khuong M. Vu (2013) employ this methodology to project the growth of the U.S. and the world economy.

We first consider the growth of labor input as a determinant of future 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 project future participation rates for each age-gender-education category of the labor force from past trends.

We next consider productivity growth as a determinant of future economic growth. In order to quantify 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 of Growth and Recession. 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.

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 the labor force participation rates that prevailed before the Great Recession. U.S. economic growth during 2014-2024 will be comparable to growth during the period 1990-2014, mainly due to more rapid growth in hours worked. We compare our results with the projections summarized by David Byrne, Steven Oliner and Daniel Sichel (2013). 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 data set for growth and productivity of the U.S. economy at the industry level. This has been 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 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. Investment in intellectual property is treated symmetrically with other capital expenditures. Intellectual property products are included in the Gross Domestic Product and the capital services generated by investments in intellectual property 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 industry accounts 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. Importantly, BEA's historical data set now contains estimates of output and intermediate input in current and constant prices. We incorporate these estimates into our prototype industry-level production account.[4]

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, Matthew Russell, Samuels, Strassner, and Lisa Usher (2016) in their paper, "Integrated Industry-Level Production Account for the United States: Intellectual Property Products and the 2007 NAICS."[5]

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 constant prices for all 65 industries included in the U.S. national accounts.

The 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, beginning in 1998, uses similar methodology. However, our industry-level production account covers the entire postwar period, beginning in 1947, and provides a highly detailed view of the

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[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.

[5] The BEA-BLS data through 2014 are based on a preliminary version of the BEA-BLS integrated industry-level production account that is unpublished at the time of this writing. The data set is in the process of being finalized for release to the public.

evolution of capital and labor inputs for individual industries. We exploit this detail in our projections of future U.S. economic growth.

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. 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 products (IPP) 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. Rapidly increasing female workforce participation also contributed negatively, reflecting the lower average wages of female workers. Rising educational attainment generated substantial growth in labor quality. During the Long Slump of 1973-1995, the increase in participation 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 labor force participation 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 labor force participation 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 change in the educational attainment of 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 participation 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 participation rates for all years except the recessions. Participation 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 participation rates. The participation rates have fallen since 2000 for the less-educated. These rates declined further during the Great Recession.

Although the decline in labor force participation is widely discussed, employment participation rates by gender, age, and educational attainment, like those presented in Figure 8, have not been considered until now. Non-participation has been included in a model of employment and unemployment by Kory Kroft, Fabian Lange, Matthew J. Notowidigo, and

Lawrence F. Katz (2016). This model has been elaborated by Alan B. Krueger, Judd Cramer, and David Cho (2014).

The modeling of non-participation along with employment and unemployment could be extended to include a more detailed breakdown of alternatives to employment for members of the working age population. These might include disability status and increased participation in welfare programs. Both increased as a proportion of the working age population during the Great Recession with relaxation of requirements for eligibility. Labor force participation may have been adversely affected by extended benefit periods for the unemployed, now expired, and lower income requirements for food stamps.[6]

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 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 work force is that their labor services are complementary to the use of information technology.[7] 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.

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

[7] 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.

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 the age of the worker, which captures experience. 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.

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 have presented new information on educational attainment and the relationship between employment participation and educational attainment. We have also provided 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 rate, 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) have analyzed the economic impact of IT at the aggregate level for 1948-2002 and the industry level for 1977-2000. They have also provided 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) converted the industrial classification to NAICS and updated and extended 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) have classified industries as IT-using if the intensity of IT capital input 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 is paralleled by a decline in the contribution of the Non-IT industries, while the share of IT-using industries has remained 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)[8]. 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 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

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[8]The formula is given in Jorgenson, Ho and Stiroh (2005), equation 8.34

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 that began in 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 developmentexceeded 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 developmentshrank 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.

Both IT and Non-IT capital inputs continued to contribute substantially to U.S. economic growth during the Great Recession period 2007-2014, while the contribution of R&D capital input remained small. 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 and have continued up to the present.

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 participation rates and labor quality growth, as well as 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 participation rates by gender, age, and education. For each gender-age-education category we model the trend in participation rates by means of a univariate Kalman filter. We project the trends for the period 2016-2024. We model the sharp drop in participation rates that occurred with the onset of the Great Recession in 2007 by including a dummy variable in the trends and assuming that this reverses by

2024.[9] We also assume that weekly hours for each gender-age-education group revert to 2007 levels after ten years.

We project that hours worked will grow rapidly over the next decade due to the re-entry of the less-educated workers into the work force. However, the growth rates of labor quality will fall substantially as these workers are absorbed into employment. Our projections of the growth rates of labor quality for 2014-2024 are considerably below the averages for the period 1990-2014.

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 projected growth rate of capital quality during the period 1995-2014 is slightly below the growth rate for the period 1990-2014. Growth of productivity in the IT-producing sector will make the largest contribution to the growth in labor productivity 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, the Non-IT sector of the economy will contribute relatively little to labor productivity growth, even compared to the period 1990-2014.

[9] We estimate the Kalman filter model from data for the period 1992-2015. We do not use data before 1992 due to the change in the classification of educational attainment in 1992. We specify that the first difference of the trend is stationary and includes a drift term. To account for the recovery from the Great Recession, we compare the trough in trend participation after 2008 with the estimated trend in 2015. If the participation rate has increased over this period, we reverse the recession effect through 2024 by the difference between the improvement observed through 2015 and the dummy variable estimate of the recession effect. If trend participation has not recovered through 2015, we reverse the entire amount of the recession effect through 2024.

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. By contrast we project strong growth of hours worked for this period. This reflects the re-entry of less-educated workers during the ongoing economic recovery. Rapid growth in hours worked also implies a relatively low contribution from capital deepening to U.S. economic growth.

Combining our projected growth rates in hours worked and average labor productivity, we obtain GDP growth of 2.49% per year over the next ten years. This is a slight increase from the growth rate of 2.34% per year during the period 1990-2014. The rapid growth in hours worked is nearly offset by the slower growth of average labor productivity. We conclude by emphasizing that we do not model the determinants of participation, but rely on extrapolations of trends from the historical data.

Low Growth Case.

Our first alternative assumption to the Base Case is that the participation rates for each gender-age-education group will follow the lower 25% confidence interval bound of the Kalman filter projections for the ten-year period, 2014-2024.[10] This Low Growth Case embodies the "new normal" hypothesis that the Great Recession has had very persistent effects on the labor market. Our projected growth rate of hours worked is higher than during the period 1990-2014, while our projected growth rate of labor quality is lower.

We assume 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

[10] We simulate the confidence intervals by the bootstrap method. We take the smoothed trend and parameters as given and draw errors with replacement from the estimated covariance matrix to simulate each bootstrap sample. For each bootstrap draw, we re-estimate the parameters and trends. To form the confidence interval, we take the α and $1-\alpha$ percentiles of the projected trend in 2024.

Recovery. The period of Recession and Recovery can be sub-divided 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 only slightly below the Base Case projection. However, 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 for the Low Growth projection is below the Base Case projection, but well above 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 2.13% over the next ten years. This is a modest deceleration from the growth rate of 2.34% for the period 1990-2014.

High Growth Case.

For the High Growth Case we assume that participation rates for each gender-age-education group follow the upper 75% confidence interval bound of the Kalman filter projections for the ten-year period 2014-2024. This permits participation rates to recover to the levels of the IT Investment

Boom ending in 2000, a period of high participation rates, especially among young and less-educated workers. Hours worked will grow rapidly over the next decade and the growth rate of labor quality will be substantially lower than during the period 1990-2014.

For the High Growth Case 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 3.20% per year, substantially above the growth rate of 2.34% during the period 1990-2014. This difference can be explained by the sharp rise in hours worked as young and less-educated workers re-enter the labor force. 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 participation 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) provide a recent survey of contributions to the debate over prospects for future U.S. economic growth. 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.*

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.*[11] 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.

John Fernald (2015) analyzes the growth of potential output and productivity before, during, and after the Great Recession and reaches the conclusion that half the shortfall in the rate of growth of output, relative to pre-recession trends, is due to slower growth in potential output. This is consistent with our analysis of the sources of U.S. economic growth during the period of Growth and Recession, 1995-2014. Byrne, Oliner and Sichel present projections of future U.S. productivity growth for the nonfarm business sector and compare their results with others, including Fernald and Gordon. They show that there is substantial agreement among the alternative projections.

[11] 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/

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 semiconductors devices has improved less rapidly, severing the close link that had characterized Moore's Law as a description of the development of semiconductor technology.[12] This view is supported by Unni Pillai (2011) and by computer scientists John Hennessey and David Patterson (2012).[13]

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.[14] Studies are now underway to extend these comparisons to individual industries for the countries included in the World KLEMS Initiative.[15]

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-

[12] Moore's Law is discussed by Jorgenson, Ho, and Stiroh (2005), ch. 1.
[13] 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 .
[14] See Jorgenson and Vu (2013).
[15] See Jorgenson, Fukao, and Timmer, eds., (2016).

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 more optimistic than 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.

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 adapt 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) $$\Delta \ln Y = \bar{v}_K \Delta \ln \mathrm{K} + \bar{v}_L \Delta \ln L + \Delta \ln A$$

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:

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

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:

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

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:

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

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:

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

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 Bureau[16] 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.

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 consider two alternative scenarios for educational improvement. In the first we assume continuing improvement for all ages. In a subsidiary case we assume that the educational attainment of men aged 18-60 has stabilized, so that there is no further

[16] 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.

improvement beyond the end of the sample. Men over 60 years of age carry their educational attainment with them as they age, so that the educational distribution evolves according to:

(A.6) $e_{saet} = e_{sae,t-1}$ a=0,…60, s=male

$e_{saet} = e_{s,a-1,e,t-1}$ a=61,…,90+, s=male

For the women we assume that only those aged 18-35 have reached the maximum level in 2014:

(A.7) $e_{saet} = e_{sae,t-1}$ a=0,…35, s=female

$e_{saet} = e_{s,a-1,e,t-1}$ a=36,…,90+, s=female

In our principal education projection 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.8) $$e_{saet}^{p} = \omega_t e_{saet}^{2012} + (1-\omega_t) e_{saet}^{\max} \qquad t=2014,\ldots,2030$$

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.9) $$e_{saet} = e_{saet}^{p} \qquad a=0,\ldots,60$$

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

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 2010 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 2010 hours per year by the projected population in each cell and weighting the hours per year by the 2010 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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Table 1: Labor Characteristics by Industry, year 2010.

		% workers college educated	compen- sation ($/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+

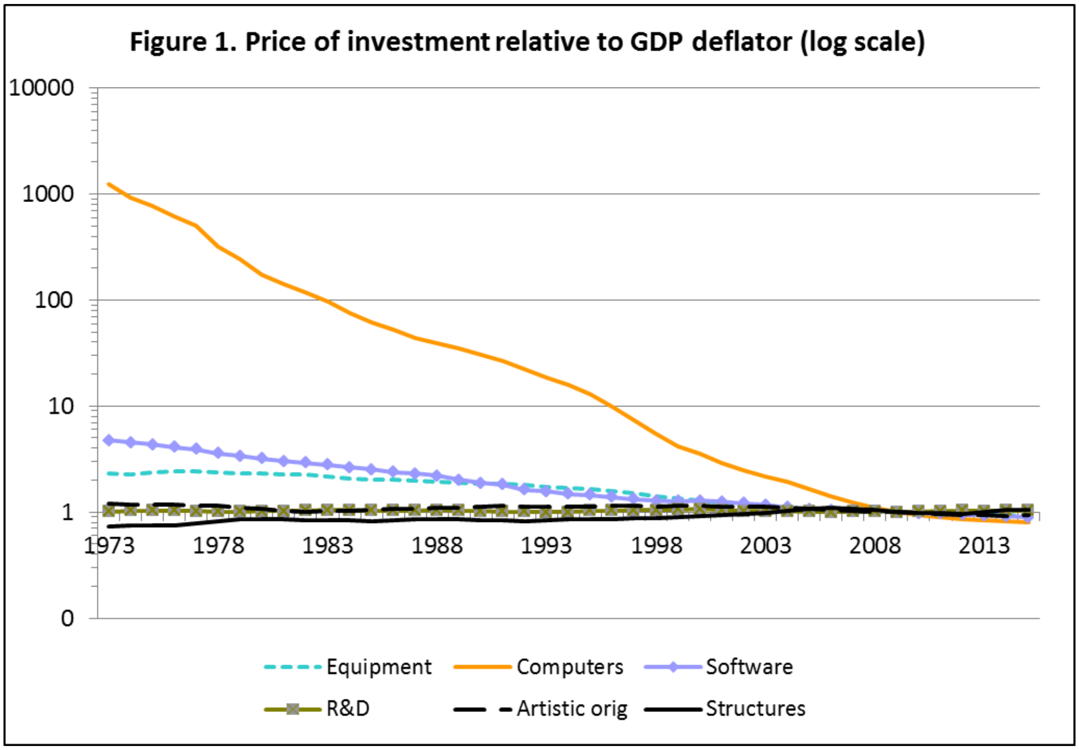


Figure 1. Price of investment relative to GDP deflator (log scale)
10000
1000
100
10
1
0
1973
1978
1983
1988
1993
1998
2003
2008
2013
Equipment
Computers
Software
R&D
Artistic orig
Structures

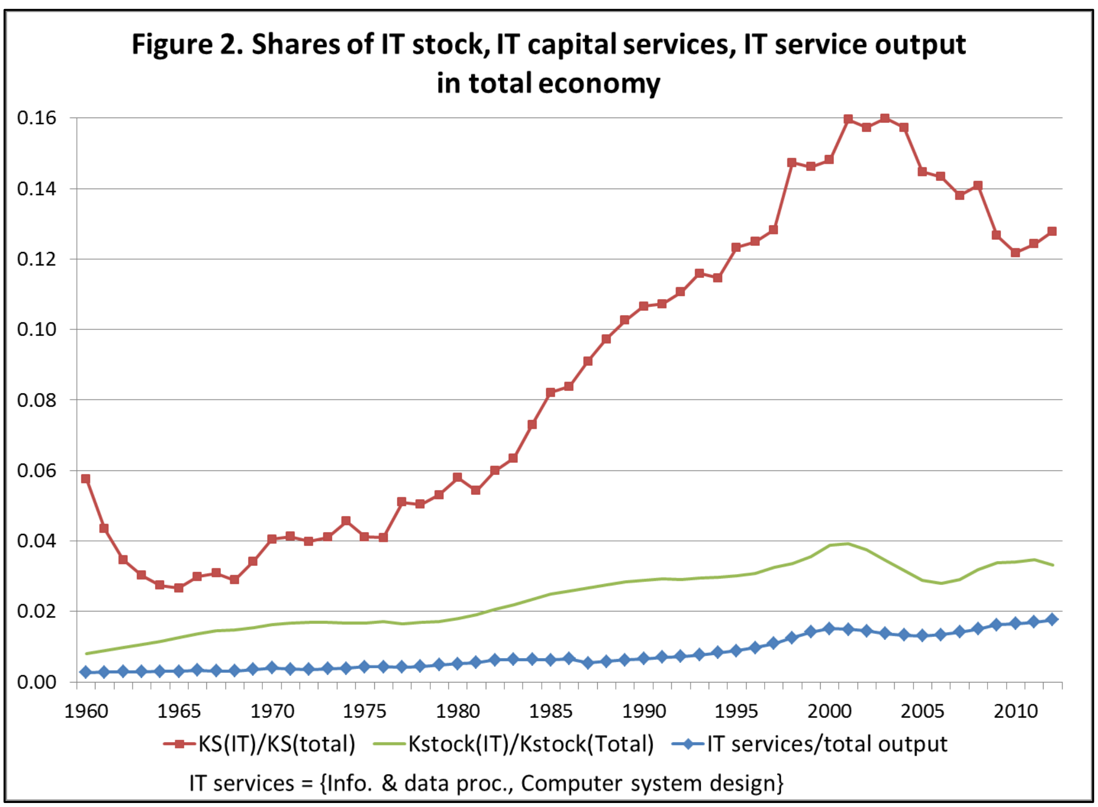


Figure 2. Shares of IT stock, IT capital services, IT service output in total economy
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
KS(IT)/KS(total)
Kstock(IT)/Kstock(Total)
IT services/total output
IT services = {Info. & data proc., Computer system design}

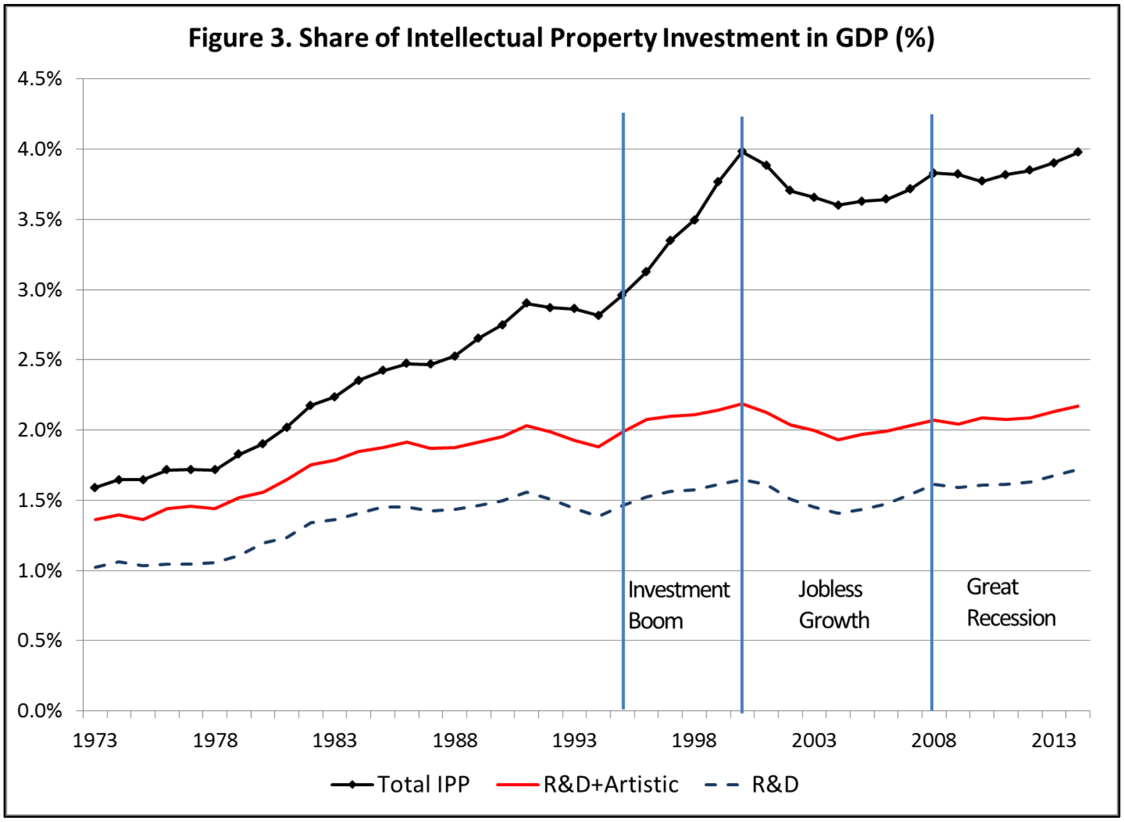


Figure 3. Share of Intellectual Property Investment in GDP (%)
4.5%
4.0%
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
1973
1978
1983
1988
1993
1998
2003
2008
2013
Investment Boom
Jobless Growth
Great Recession
Total IPP
R&D+Artistic
R&D

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

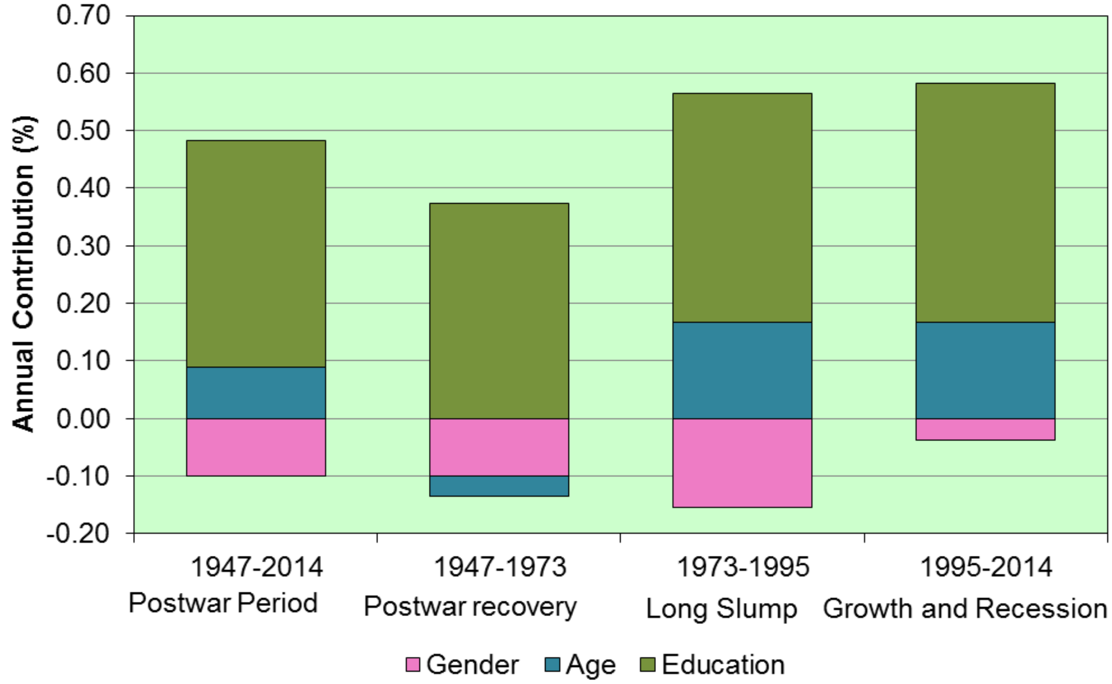


Figure 5. Contribution of education, age and gender to labor quality growth (1995-2014)

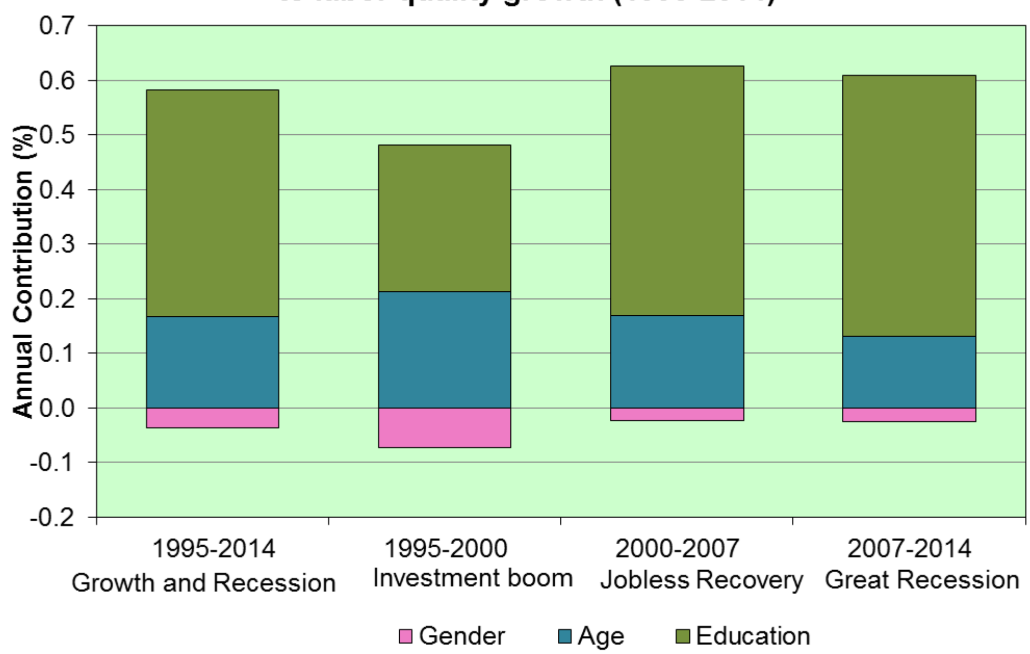


Figure 6. Education attainment of work force

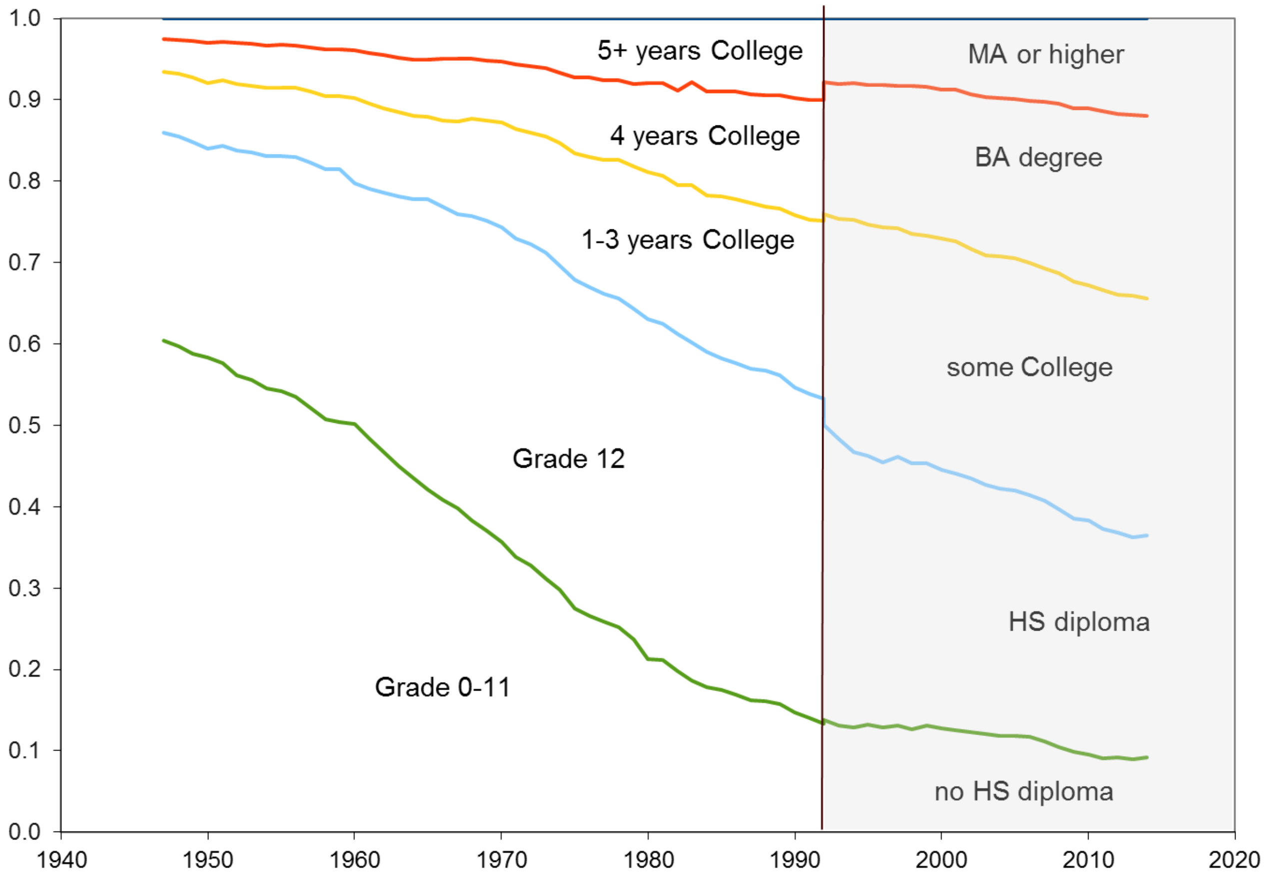


Figure 7. Education attainment of workers aged 25-34

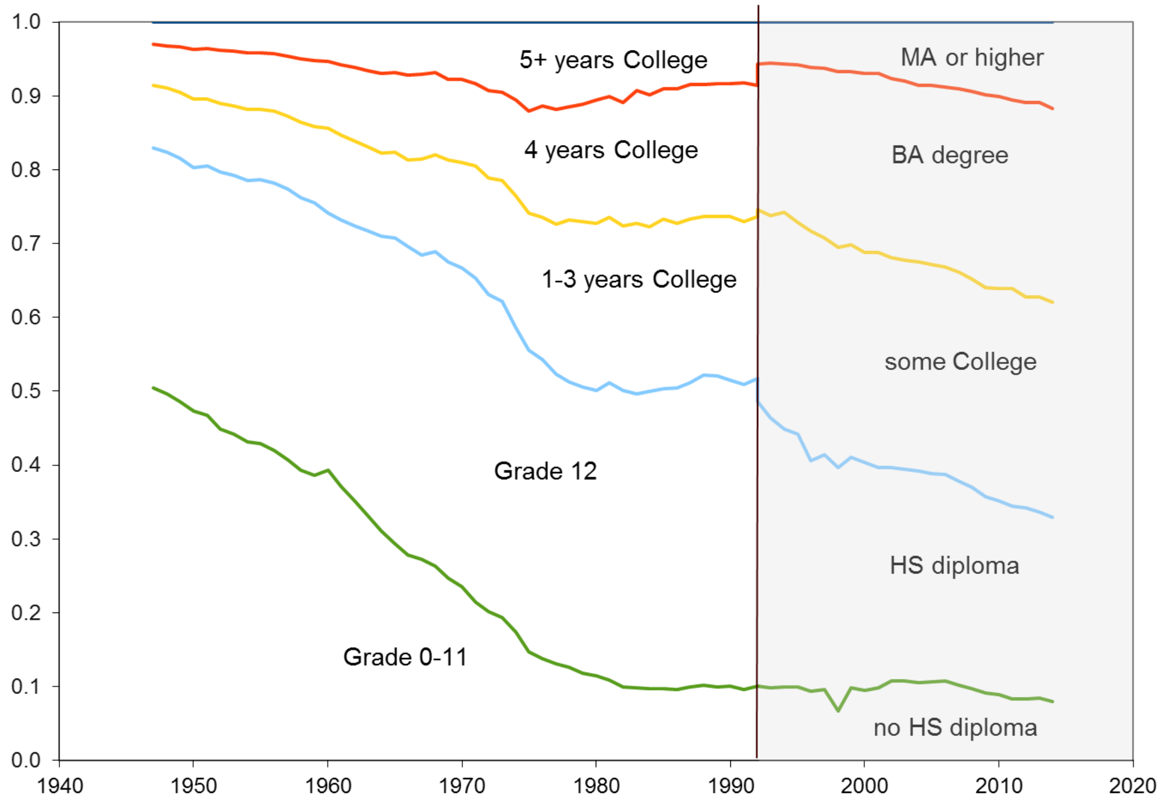


Figure 8. Employment Participation Rates by Gender, Age and Education

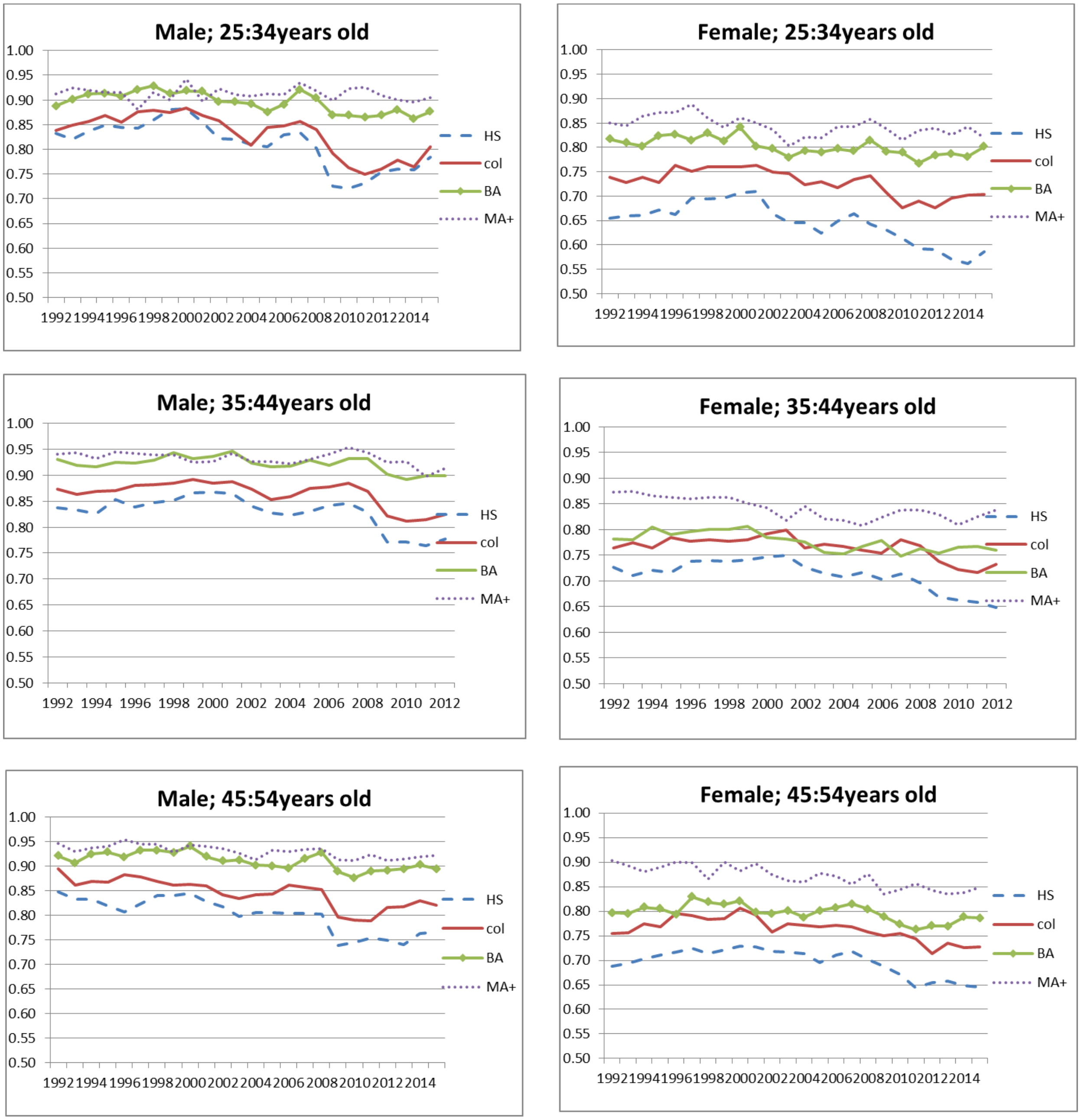


Figure 9. Compensation by education attainment
(relative to those with HS diploma)

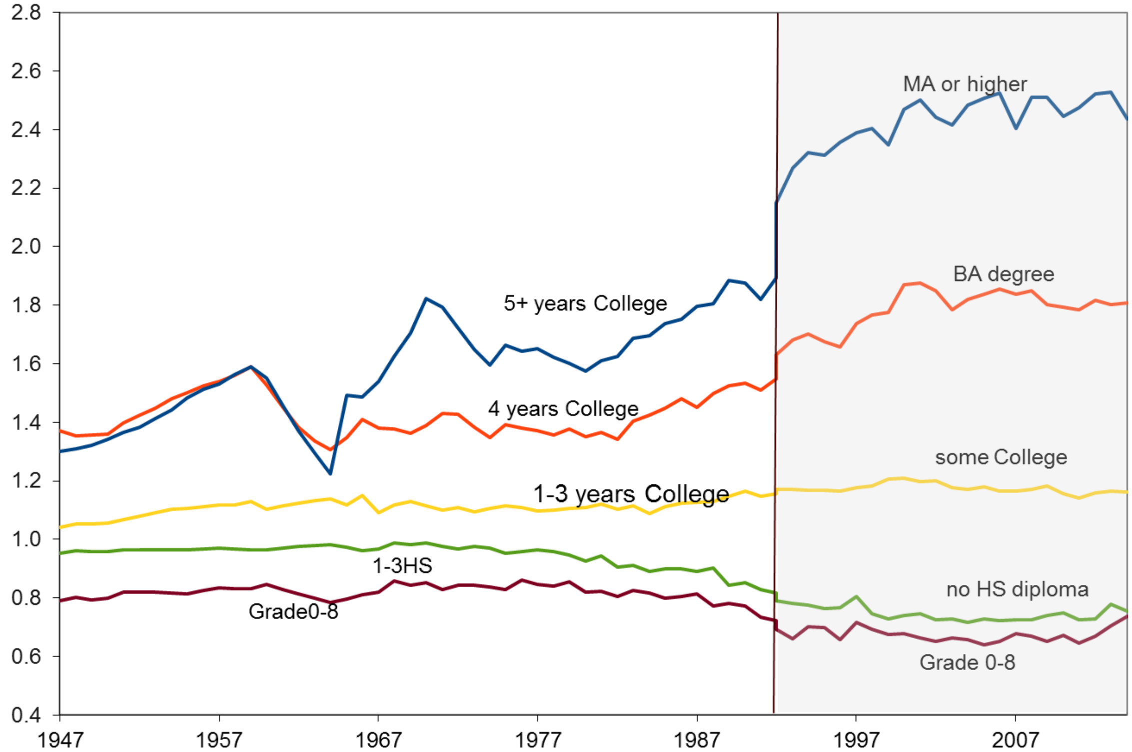


Figure 10. Compensation by age (relative to 25-34 year olds)

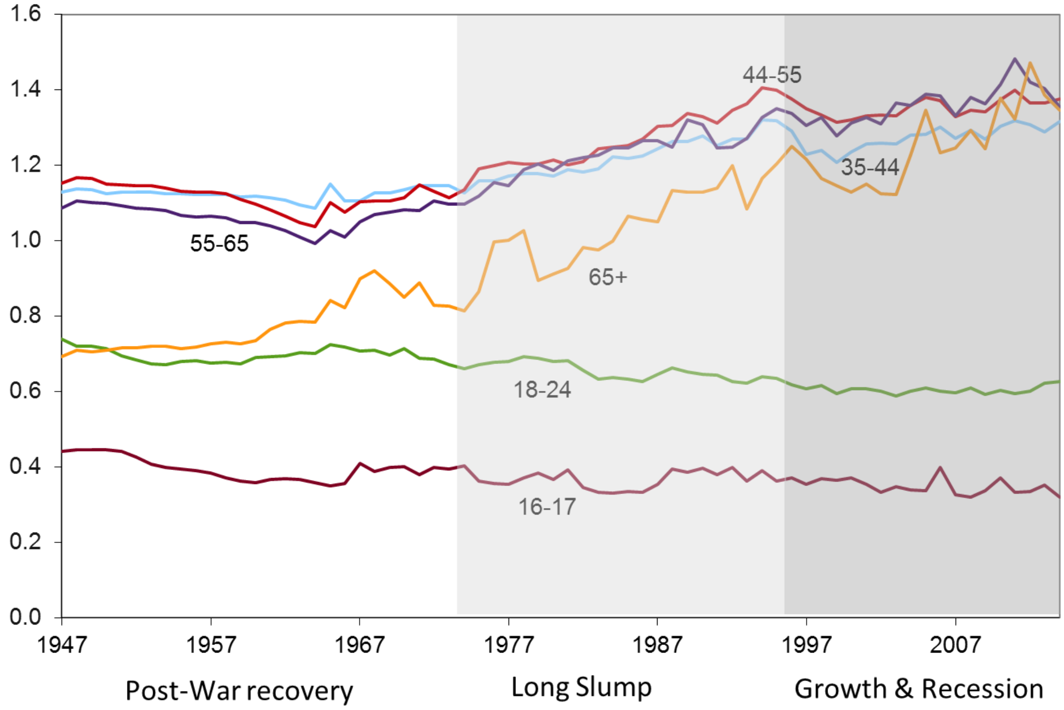


Figure 11. Contributions of Industry Groups to Value Added Growth (1947-2014)

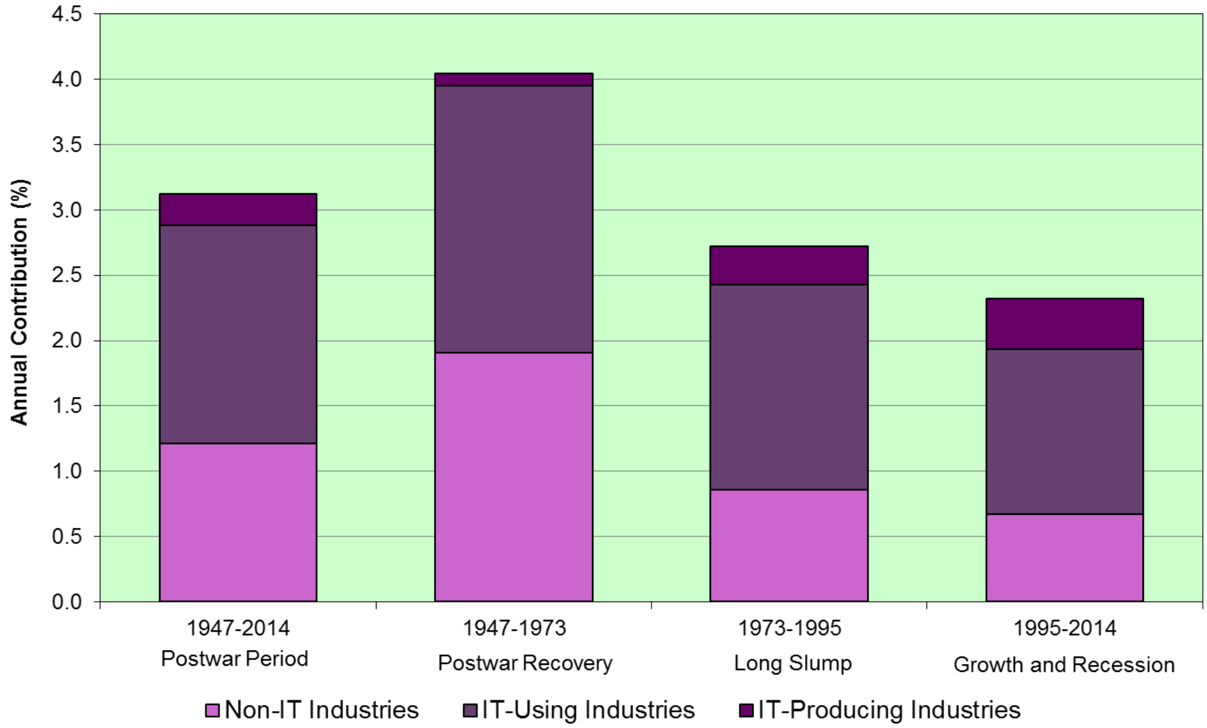


Figure 12. Contributions of Industry Groups to Value Added Growth (1995-2014)

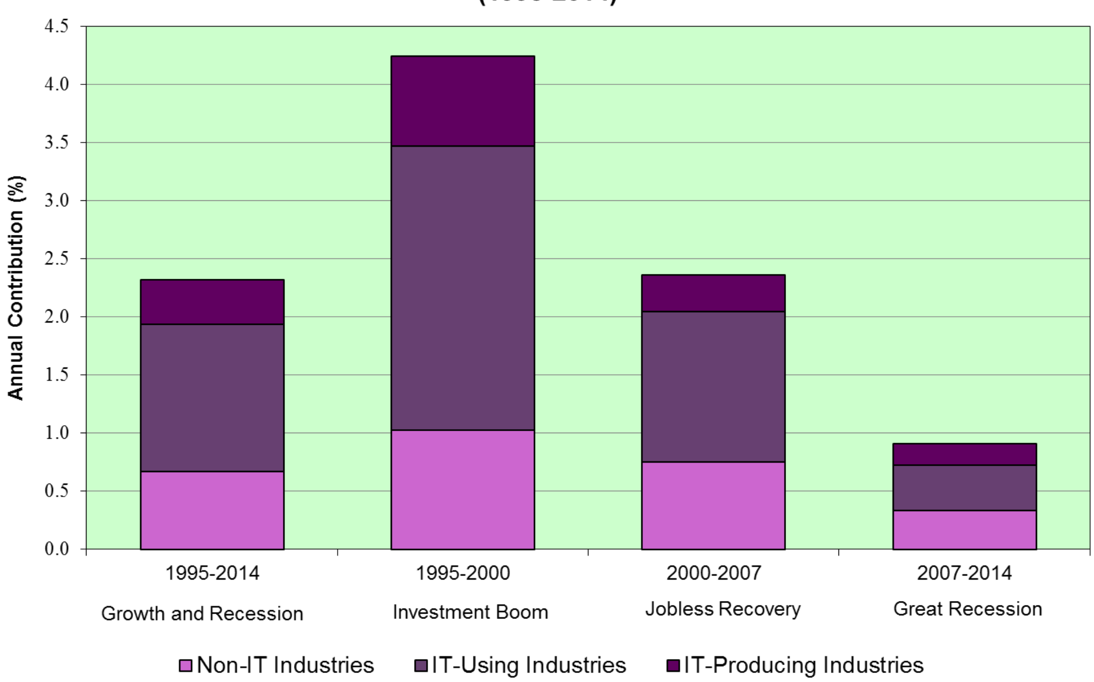


Figure 13. Industry Contributions to Value Added (1947-2014)

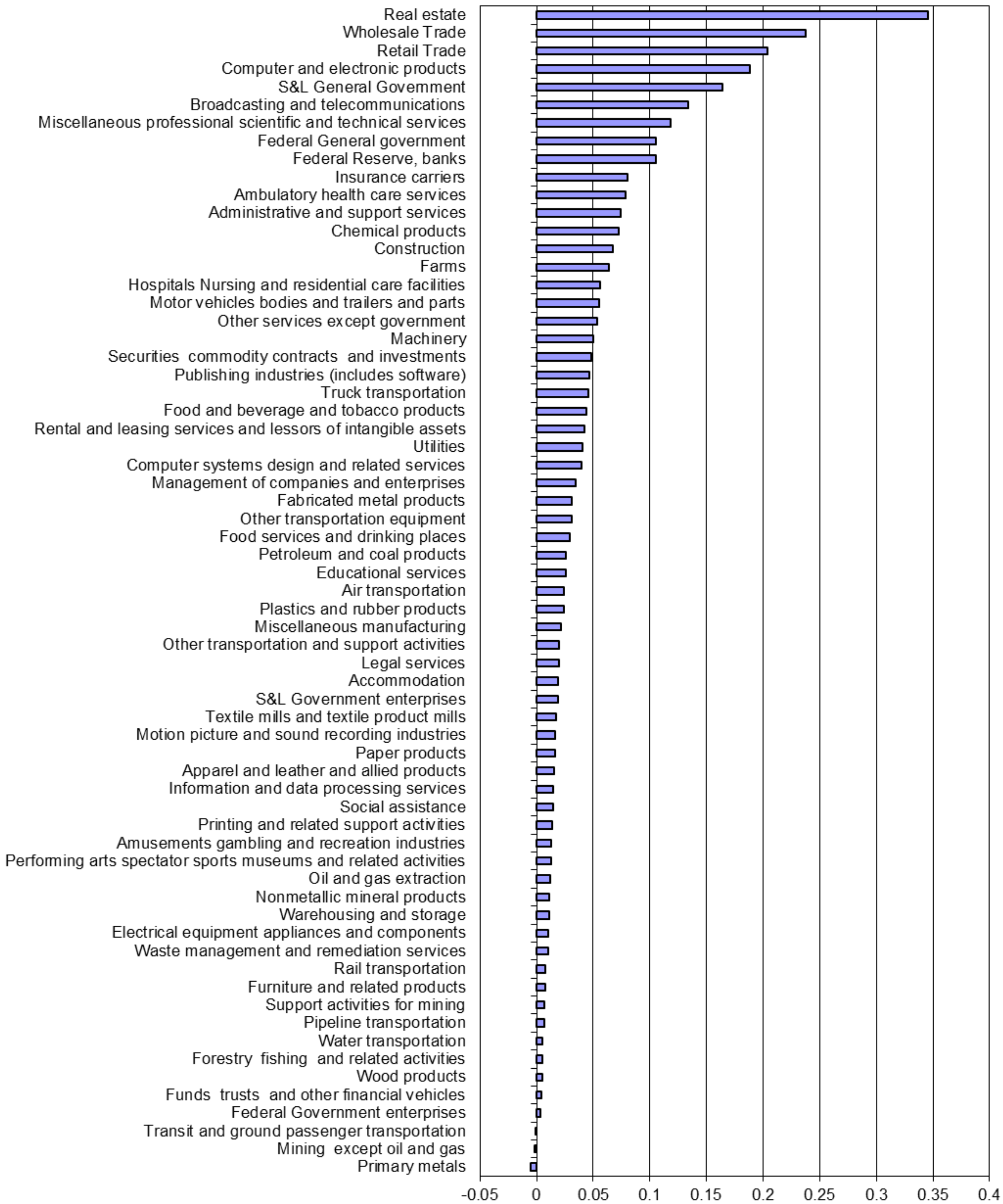


Figure 14. Contribution of Industry Groups to Aggregate Productivity Growth (1947-2014)

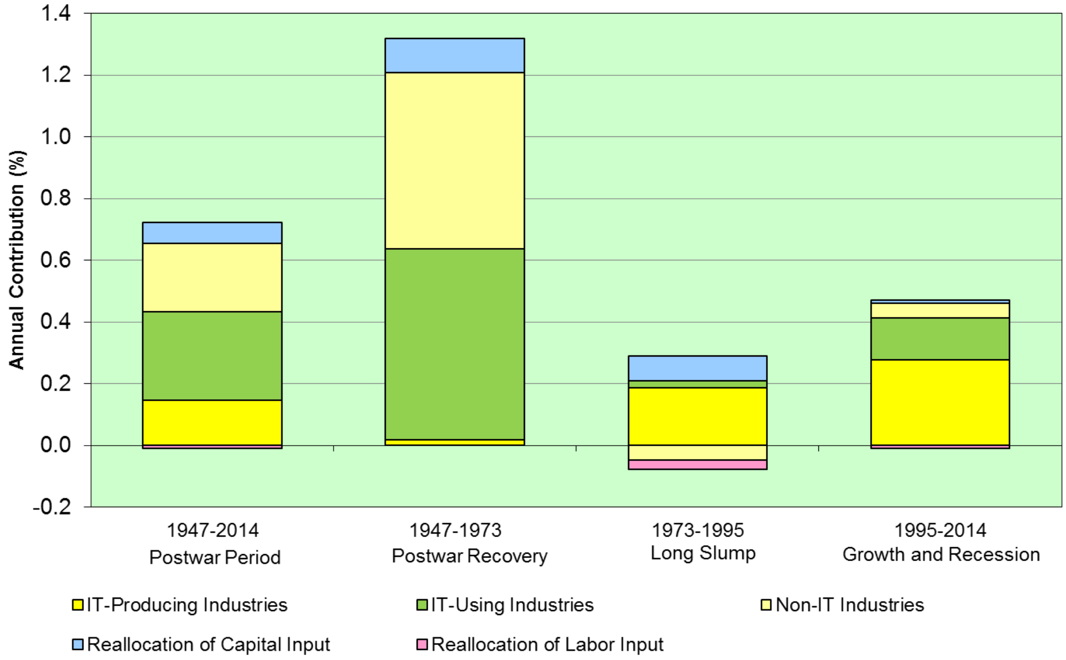


Figure 15. Contribution of Industry Groups to Aggregate Productivity Growth (1995-2014)

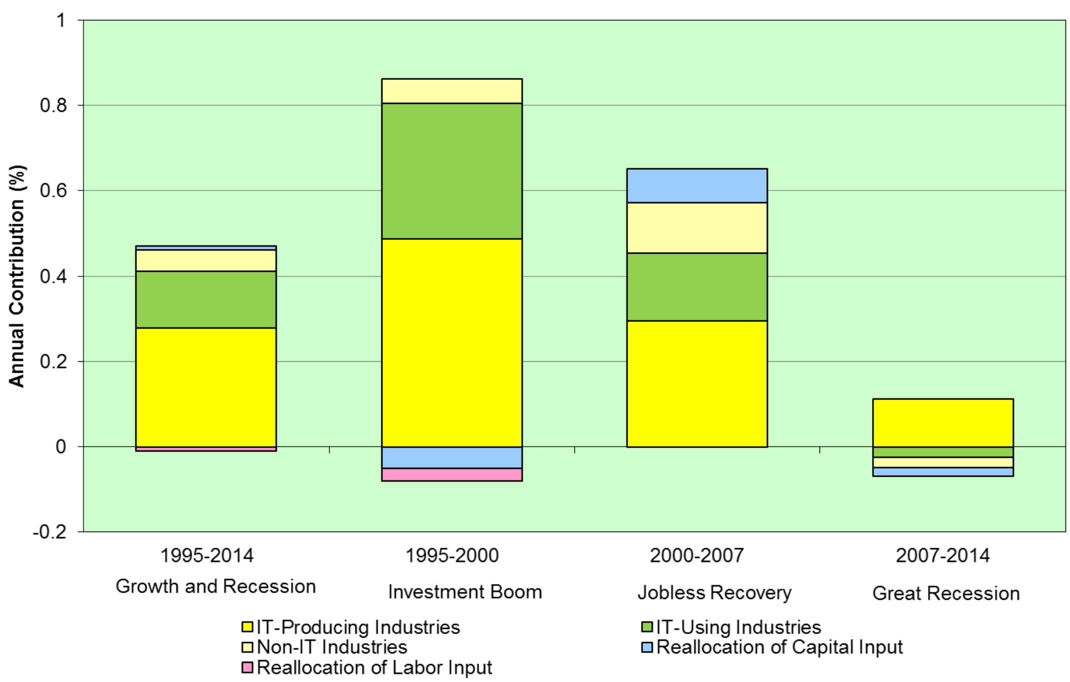
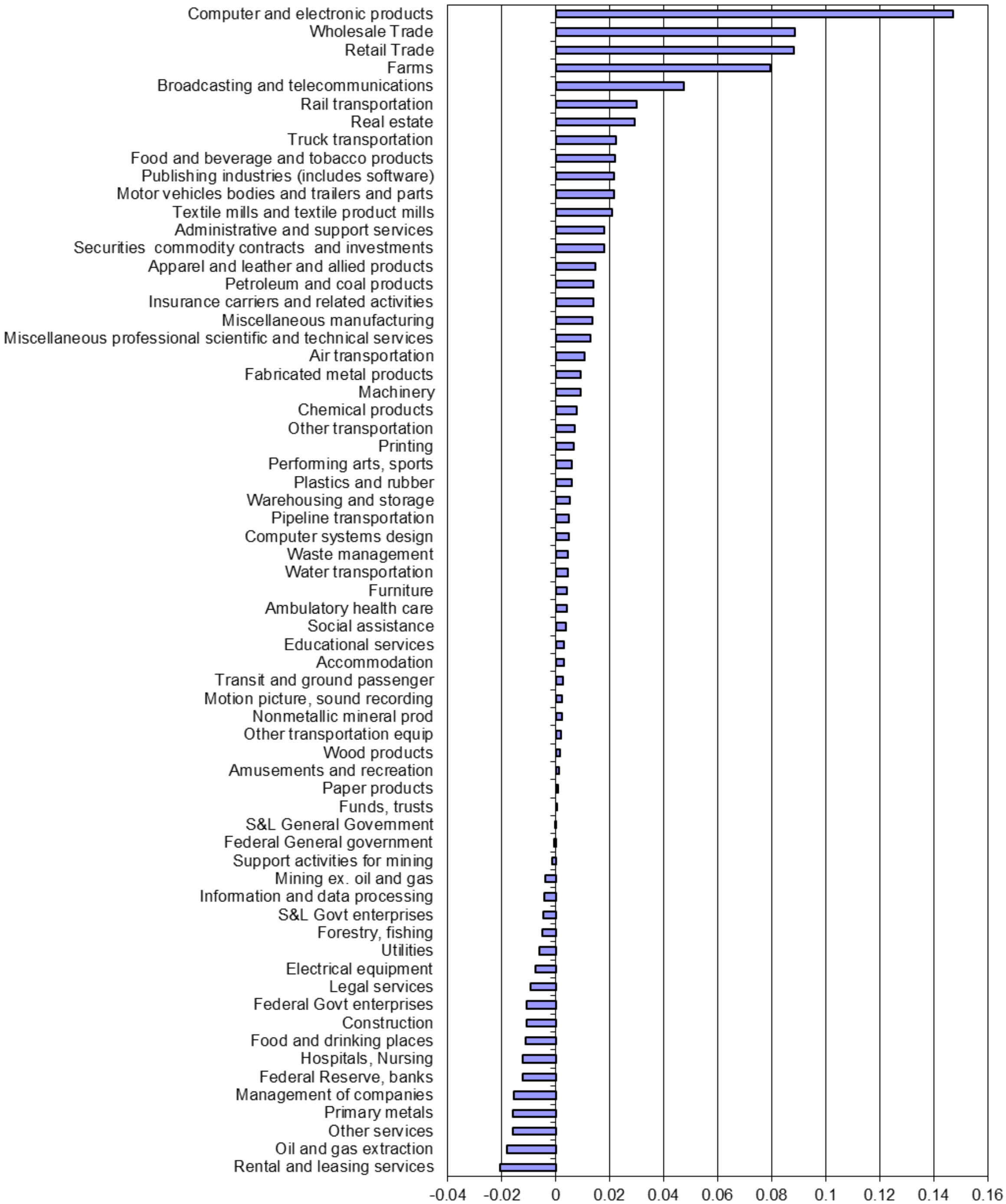


Figure 16. Industry Contributions to Productivity (1947-2014)



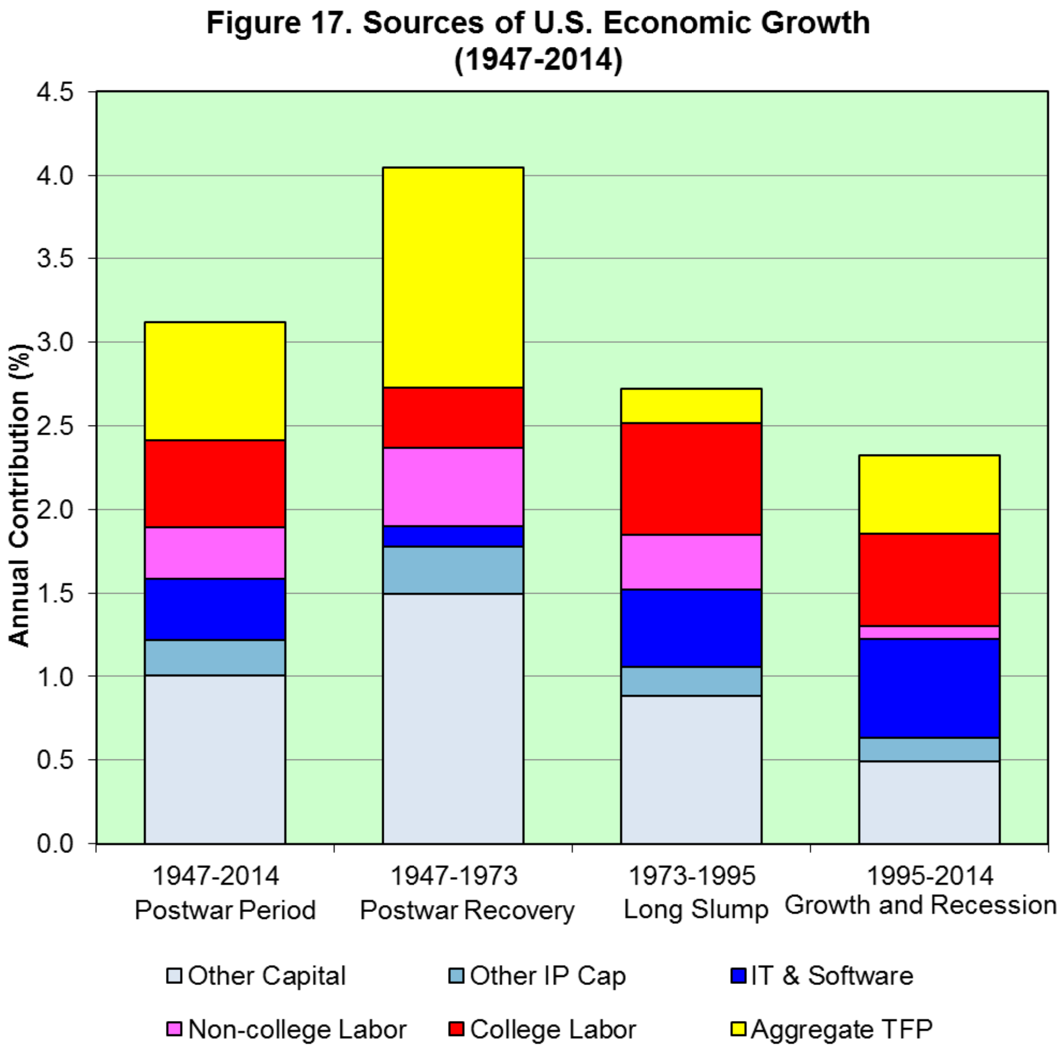


Figure 17. Sources of U.S. Economic Growth
(1947-2014)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Annual Contribution (%)
1947-2014
Postwar Period
1947-1973
Postwar Recovery
1973-1995
Long Slump
1995-2014
Growth and Recession
Other Capital
Other IP Cap
IT & Software
Non-college Labor
College Labor
Aggregate TFP

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

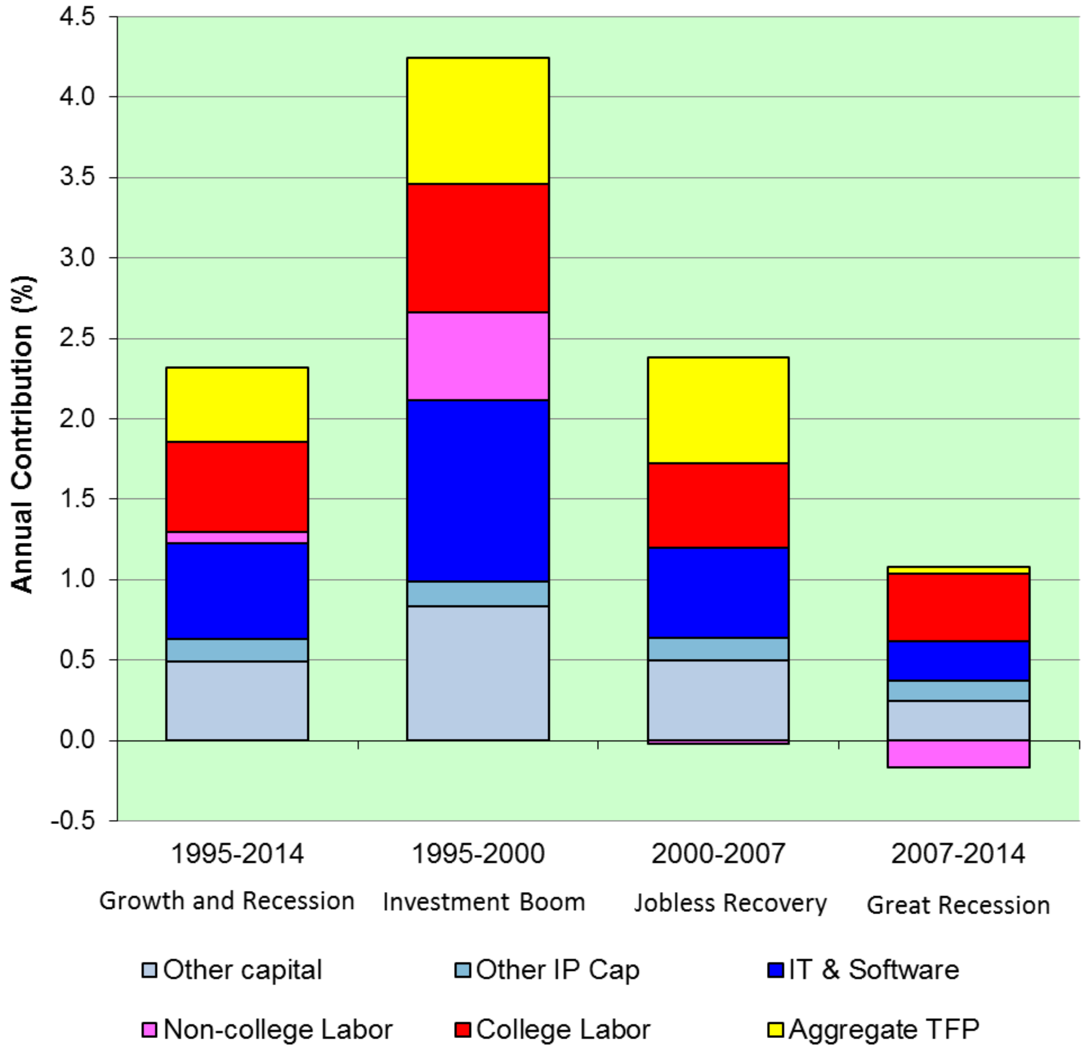


Figure 19. Contribution of Industry Groups to Aggregate Productivity, 2014-2024

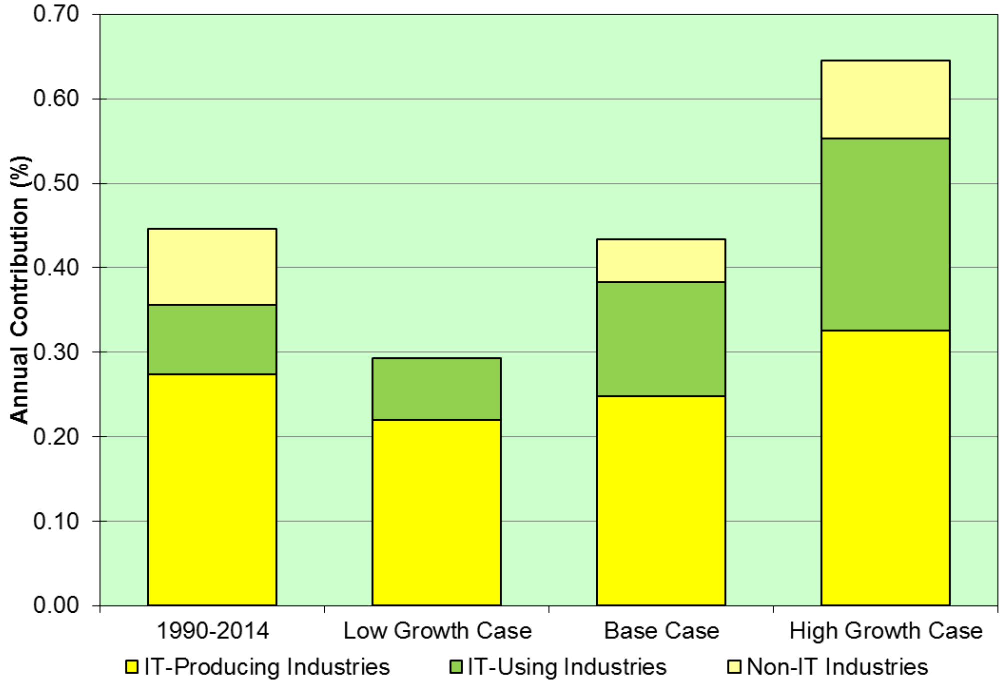


Figure 20. Range of Labor Productivity Projections (2014-2024)

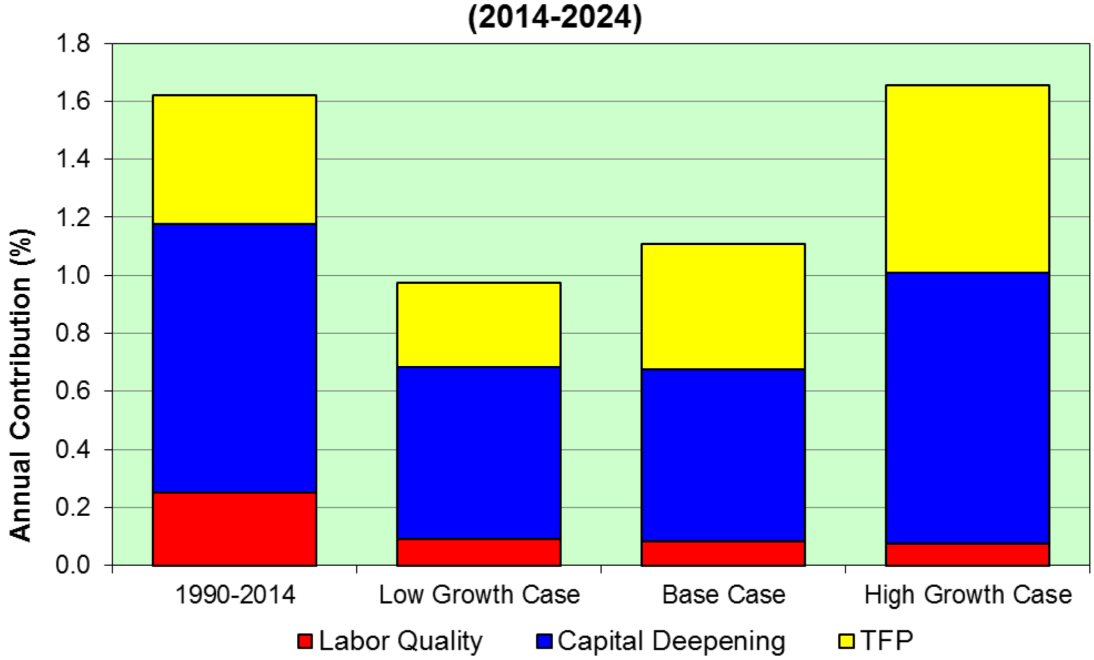


Figure 21. Range of U.S. Potential Output Projections (2014-2024)