U.S. ECONOMIC GROWTH – RETROSPECT AND PROSPECT:

Lessons from a Prototype Industry-Level

Production Account for the United States, 1947-2012

by

Dale W. Jorgenson, Harvard University,

Mun S. Ho, Resources for the Future,

and

Jon D. Samuels, Bureau of Economic Analysis

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Dale W. Jorgenson, Mun S. Ho, and Jon D. Samuels[1]

Introduction

In order to analyze the long-term growth of the U.S. economy we have constructed a new data set on the growth of U.S. output and productivity by industry for 1947-2012. This includes the output for each of the 65 industries represented in the U.S. national accounts, as well as the inputs of capital (K), labor (L), energy (E), materials (M), and services (S). The key indicator of innovation is productivity growth for each industry, where productivity is the ratio of output to input.

We build on the work of Jorgenson, Ho, and Kevin J. Stiroh (2005), who have presented a less detailed industry-level data set for the U.S. economy for 1977-2000. Data for 1947-1977 capture the development of the telecommunications services and equipment industries before the commercialization of semiconductor technology. Data for 2000-2012 highlight the slowdown in productivity growth and the drop in investment during and after the Great Recession of 2007-2009.

[1] 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 project the future growth of the U.S. economy by adapting the methodology of Jorgenson, Ho, and Stiroh (2008).[2] We aggregate over industries to obtain data on the sources of U.S. economic growth and project the future growth of hours worked and labor productivity.

In the next section we incorporate our industry-level data set into the U.S. National Income and Product Accounts (NIPAs). Paul Schreyer's OECD (2001) manual, *Measuring Productivity*, has established international standards for economy-wide and industry-level productivity measurement, exemplified by Jorgenson, Frank M. Gollop, and Barbara M. Fraumeni (1987). The methodology for our new data set is consistent with the OECD standards.

Our data set comprises a prototype production account within the framework of the U.S. national accounts. Over the 1998-2012 period, our industry-level production account is consistent with industry-level production accounts presented by Steven Rosenthal, Matthew Russell, Samuels, Strassner, and Lisa Usher (2015). 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 with the economy-wide data reported by Michael Harper, Brent R. Moulton, Rosenthal, and David B. Wasshausen (2009).[3]

In the following section of the paper we analyze the changing sources of postwar U.S. economic growth. We divide the postwar period into three broad 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, 1995-2012. We focus more narrowly on the period of Growth and

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

[3] 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).

Recession by considering the sub-periods 1995-2000, 2000-2007, and 2007-2012 – the Investment Boom, the Jobless Recovery, and the Great Recession.

We show that the great preponderance of U.S. economic growth since 1947 involves the replication of existing technologies through investment in equipment and software and expansion of the labor force. Contrary to the well-known views of Robert M. Solow (1957) and Simon Kuznets (1971), innovation accounts for a relatively modest twenty percent of U.S. economic growth. This is the most important empirical finding from the extensive recent research on productivity measurement summarized by Jorgenson (2009).

The predominant role of replication of existing technologies in U.S. economic growth is crucial to the formulation of economic policy. During the protracted recovery from the Great Recession of 2007-2009, U.S. economic policy should focus on maintaining the growth of employment and reviving investment. Policies for enhancing the rate of innovation would have a very limited impact in the medium term.

We next consider the future growth of the U.S. economy for the period 2012-2022. We project future growth of the U.S. labor force from demographic projections. We project the future growth of the quality of labor input from the educational attainment of age cohorts that have recently entered the labor force. We find that U.S. economic growth will slow substantially from the period 1990-2012, mainly due to a marked slowdown in labor quality growth.

Labor quality growth represents 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 average educational attainment of U.S. workers has been overlooked. The educational attainment of people emerging from the educational system, while high, has been nearly constant for the past decade. Rising average educational attainment is about to become part of U.S. economic history.

We find that U.S. economic growth will recover from the Great Recession period 2007-2012 through the resumption of productivity growth and the recovery of investment in capital input. However, the long-term growth of the U.S. economy will depend critically on the performance of the relatively small number of sectors where innovation takes place.

A Prototype Industry-Level Production Account for the United States, 1947-2012.

In December 2011 the Bureau of Economic Analysis (BEA) released an integrated industry-level data set. This combines three separate industry programs – benchmark input-output tables released every five years, annual input-output tables, and gross domestic product by industry, also released annually. The input-output tables provide data on the output side of the national accounts along with intermediate inputs in current and constant prices. This account forms the foundation of our industry-level production account. BEA's industry-level data set is described in more detail 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 types of capital expenditures. Intellectual property products are included in the official national product and the capital services generated by these products are included in the national income in our integrated production account. Donald D. Kim, Strassner and Wasshausen (2014) discuss the 2014 benchmark revision of the industry accounts, including the incorporation of intellectual property.

BEA's annual input-output data are employed in the industry-level production accounts presented by Rosenthal, Russell, Samuels, Strassner, and Usher (2015). This covers the period 1998-2012 for the 65 industrial sectors used in the NIPAs. The capital and labor inputs are provided by BLS, while output and intermediate inputs are generated by BEA.[4] Labor quality estimates are based on the methodology in Jorgenson, Ho, Stiroh (2005) and are broadly consistent with the labor quality estimates in our prototype account.

Our estimates of nominal output and intermediate input for 1998-2012 are consistent with the BEA/BLS industry-level production accounts. For the period 1947-1997 we begin with a time series of input-output tables in current prices on a NAICS basis constructed by Mark Planting, former head of the input-output accounts at BEA, and adjust them to reflect the 2013 benchmark revision of the NIPAs and industry accounts. This time series incorporates all earlier benchmark input-output tables for the US, including the first benchmark table for 1947.

The Planting estimates for 1947-62 consisted of only 46 industries and we expanded them to the 65 sectors in the current BEA accounts using the work in Jorgenson, Gollop, and Fraumeni (1987) for 1948-1979. We deflated these nominal data using the BEA industry prices for 1998-2012 and prices estimated in Jorgenson, Gollop and Fraumeni (1987), Jorgenson, Ho, and Stiroh (2005) for 1977-2000, and Jorgenson, Ho, and Samuels (2012) for 1960-2007. We have revised, extended, and updated the data on capital and labor inputs in constant prices from the same

[4] Earlier data are presented by Susan Fleck, Rosenthal, Russell, Strassner, and Usher (2014). For current data, see: http://www.bea.gov/industry/index.htm#integrated.

sources[5]. Finally, we obtain an industry-level production account for the United States, covering the period 1947-2012 in current and constant prices. This KLEMS-type data set is consistent with BEA's annual input-output tables for 1998-2012.

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. Figure 1 presents price indices for 1973-2012 for asset categories included in our measures of capital input – equipment, computers, software, research and development, artistic originals, and residential structures. 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.

The price of an asset is transformed into the price of the corresponding capital input by the *cost of capital*, introduced by Jorgenson (1963). The cost of capital includes the nominal rate of return, the 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 IT capital input relative to the IT asset price is very large by comparison with Non-IT capital input.

Schreyer (2009) provides recommendations for the construction of prices and quantities of capital services. In *SNA 2008* (page 415), estimates of capital services are described as follows:

[5] A detailed description of the data construction is given in "Data Appendix to U.S. Economic Growth: Retrospect and Prospect" which is available at www.worldklems.net/data.htm. We are grateful to the BEA Industry Division for sharing their labor quality estimates for 2010-2012 with us.

“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. Figure 2 gives the share of IT in the value of total capital stock and the share of IT capital services in total capital input. The IT stock share rose from 1.4% in 1960 to 5.3% in 1995 on the eve of the IT boom and reached a high of 6.4% in 2001after the dot-com bubble burst. This share fell to 5.1% during the Jobless Recovery when there was a plunge in IT investment and only a partial recovery.

The share of the IT service flow in total capital input is much higher than the IT share in total capital stock. The share of the IT service flow in total capital input was 5-7% during 1960-84 and rose with the rapid growth in IT investment during 1995-2000, reaching a peak of 15.8% in 2000. The IT service flow then declined with the fall in the IT stock, ending with a sharp plunge in the Great Recession.

By contrast with the production of IT equipment, the IT services industries – information and data processing and computer system design – increased steadily between 2005 and 2012. The share of the gross output of these two industries in the value of total gross output, shown in Figure 2, declined slightly from 1.45% in 2000 to1.29% in 2005 and then continued to rise, hitting a high of 1.60% in 2012. This reflects the displacement of in-house hardware and software by the growth of IT services like cloud computing.

Investment in intellectual property products (IPP) since 1973 is shown in Figure 3. This proportion grew during the Investment Boom of 1995-2000 to four percent of the U.S. GDP and has declined only slightly since the peak around 2000. Investment in research and development also peaked around 2000, but has remained close to two percent through the Great Recession of 2007-2012.

The intensity of the use of IT capital input differs substantially by industry. Figure 4 shows the share of IT in total capital input for each of the 65 industries on the eve of the Great Recession in 2005. There is an enormous range from less than half percent in farms and real estate to about 80% for computer system design and information and data processing. The sectors with the higher-valued added growth have mostly high IT shares – the two IT service industries just noted, as well as publishing (72%), broadcasting and telecommunications (61%), securities (76%), and administrative services (59%). The high growth industries with low IT shares are petroleum products (3.9%), truck transportation (12%), rental and leasing (12%), social assistance (17%).

In Figure 5 we give a scatter plot of TFP growth during 1995-2012 and the 2005 share of IT capital services in total capital. The positive correlation here is weak; the industries with the high IT intensity and high productivity growth are computer products, securities and commodities, computer system design, publishing, broadcasting and telecommunications, and administrative services. Industries with moderate IT intensity and high TFP growth include wholesale trade, water transportation, air transportation, miscellaneous manufacturing. The sectors with moderate IT intensity and negative TFP growth are educational services and legal services.

Changing Structure of Labor Input

Our labor input index recognizes differences in labor compensation for workers of different ages, educational attainment, and gender, as described in detail by Jorgenson, Ho and Stiroh (2005, Chapter 6). Labor quality growth is the difference between the growth of labor input and the growth of hours worked. For example, shifts in the composition of labor input toward more highly educated workers, who receive higher wages, contribute to the growth of labor quality. Of the 1.45% annual growth rate of labor input over 1947-2012, hours worked contributed 1.01 points and labor quality 0.43 points. Figure 6 shows the decomposition of changes in labor quality into age, education, and gender components.

During the Post-War Boom of 1947-1973 the massive entry of young, lower wage, workers contributed -0.04 percent annually to labor quality change, while increasing female workforce participation contributed -0.10 percent, reflecting the lower average wages of female workers. The improvement in labor quality is due to rising educational attainment, which contributed 0.37 percent. During the Long Slump of 1973-1995, the rise of female workers accelerated and the gender composition change contributed -0.15 points, while the aging of the work force contributed 0.17 points and education 0.40.

The contribution of higher educational attainment to labor quality growth accelerated to 0.48 percent during the period of Growth and Recession, 1995-2012. As workers gained in experience, aging of the work force also rose to 0.20, but this was more than offset by the drop in the contribution of gender to -0.22, capturing increased female labor force participation. Considering the period of Growth and Recession in more detail in Figure 7, we see that labor quality growth rose steadily during the period, but declined slightly in 1995-2000 relative to the Long Slump of 1973-1995 as a consequence of a jump in labor force participation. The drastic decline in the gender contribution during the Great Recession period 2007-2012, reflects the fact that unemployment rates rose much more sharply for men than for women.

The change in the educational attainment of workers is the main driver of changes in labor quality and this is plotted in Figure 8. In 1947 only 6.6% of the US work force had four or more years of college. By 1973 this proportion had risen to 14.5% and by 1991 to 24.8%. There was a change in classification in 1992 from years enrolled in school to years of schooling completed. By 2012 32.7% of US workers had a BA degree or higher. The fall in the share of workers with lower educational attainment accelerated during the Great Recession.

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 at about 1.4 in the 1960s and 1970s, but rose to 1.6 in 1995 and 1.8 in 2000. 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 workers with a rising share of these workers is that they are complementary to the use of information technology. 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 post-war U.S. economic history allows us to also consider the role of changing industry composition in determining relative wages.

Table 1 gives the workforce characteristics by industry for 2010. The industries with the higher share of college-educated workers are also those that expanded rapidly –industries that produce computer and electronic products, publishing (including software), information and data processing, and computer systems design, as well as industries that use these IT products and services – securities and commodity contracts, legal services, professional and technical services, and educational services. Not all sectors that expanded faster than average, such as retail trade and truck transportation, are dominated by highly educated workers. However, in declining sectors like mining, primary metals, and textiles the work force consists predominantly of less educated workers.

After educational attainment the most important determinant of labor quality is 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 1947-73 and that the aging of these workers contributed positively after 1973. We show the relative wages of the different age groups, relative to the wages of the 25-34 age group, in Figure 10. The wages the prime age group, 45-54, rose steadily relative to the young from 1.11 in 1970 to 1.41 in 1994. During the peak of the Information Age, the wages of the younger workers surged and the prime-age premium fell to 1.32.

The wage premium of the 35-44 and 55-64 groups show 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 IT boom. The wage premium of the oldest workers is the most volatile but showed a general upward trend throughout the postwar period 1947-2012. The share of workers aged 65+ 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.

Sources of U.S. Economic Growth

In *Information Technology and the American Growth Resurgence* Jorgenson, Ho, and Stiroh (2005) analyzed the economic impact of IT at the (SIC) industry level for 1977-2000 and 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) have 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 (2014) as IT-producing industries, namely, computers and electronic products and two IT-services industries, information and data processing and computer systems design. We have classified industries as IT-using the IT-intensity index of Jorgenson, Ho, Samuels (2014). We classify all other industries as Non-IT.

Value added in the IT-producing industries during 1947-2012 is only 2.5 percent of the US economy, in the IT-using industries about 47.5 percent, and the Non-IT industries the remaining fifty percent. The IT-using industries are mainly in trade and services and 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 1995-2012. 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 1947-2012. In order to assess the relative importance of productivity growth at the industry level as a source of US 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)[6]. The Domar weight is the ratio of the industry's gross output to aggregate value added and they 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 a second 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, so that the reallocations are positive.

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 1947-2012[7]. The Non-IT industries greatly predominated in the growth of value added during the Postwar Recovery, 1947-1973, but this contribution became negative after 1973. The contribution of IT-producing industries was relatively small during the Postwar Recovery, but became the predominant source of U.S. productivity growth during the Long Slump, 1973-1995, and increased considerably during the period of Growth and Recession, 1995-2012.

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

[7] The contribution of an industry is its annual TFP growth multiplied by its Domar weight, and then averaged over the sub-period.

The IT-using industries contributed substantially to U.S. economic growth during the Postwar Recovery, but this contribution disappeared during the Long Slump, 1973-1995, before reviving after 1995. The reallocation of capital input made a small but positive contribution to growth of the U.S. economy for the period 1947-2012 and for 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, the IT-producing industries predominated as a source of productivity growth during the period as a whole. The contribution of these industries remained substantial during each of sub-periods – 1995-2000, 2000-2007, and 2007-2012 – despite the sharp contraction of economic activity during the Great Recession of 2007-2009. The contribution of the IT-using industries was slightly greater than that of the IT-producing industries during the period of Jobless Growth, but dropped to nearly zero during the Great Recession. The Non-IT industries contributed positively to productivity growth during the Investment Boom of 1995-2000, but these contributions were almost negligible during the Jobless Recovery and became substantially negative during the Great Recession.

Figure 16 gives the contributions of each of the 65 industries to productivity growth for the postwar period. Wholesale and retail trade, farms, computer and peripheral equipment, and semiconductors and other electronic components were among the leading contributors to U.S. productivity growth during the postwar period. About half the 65 industries made negative contributions to aggregate productivity. These include non-market services, such as health and education, as well as resource industries, such as oil and gas extraction and mining, affected by resource depletion. 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, but may also reflect measurement challenges.

Figure 17 gives the sources of U.S. growth. 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 input. The contribution of college-educated workers predominated in the growth of labor input during the postwar period 1947-2012. This contribution jumped substantially from the Postwar Recovery period 1947-1973 to the period 1973-1995 of the Long Slump. The contribution of non-college workers predominated during the Postwar Recovery, but declined steadily and almost disappeared during the period 1995-2012 of Growth and Recession.

Capital input was the predominant source of U.S. economic growth for the postwar period 1947-2012, accounting for 1.62 percent of U.S. economic growth of 3.05 percent. Capital input was also predominant during the Postwar Recovery, the Long Slump, 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 provides more detail on important changes in the composition of the contribution of capital input. For the postwar period as a whole the contribution of R&D to U.S. economic growth was considerably less than the contribution of IT, but other forms of capital input greatly predominated. While the contribution of R&D 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 R&D shank during both periods and became relatively insignificant.

Figure 18 reveals that all of the sources of economic growth contributed to the U.S. growth resurgence between 1995 and 2000, relative to the Long Slump represented in Figure 17. Both IT and Non-IT investment 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 continued growth in productivity, indicating an ongoing surge of innovation.

Both IT and Non-IT investment continued to contribute to U.S. economic growth during the Great Recession period 2007-2012, while the contribution of R&D investment remained insignificant. 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.

Future U.S. Economic Growth

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 and his views are supported by Robert Gordon (2012, 2014), who analyzes six headwinds facing the US economy, including the end of productivity growth in IT-producing industries. Cowen (2013), expresses a more sanguine view.

Gordon's pessimism about the future of IT is forcefully countered by Erik Brynjolfsson and Andrew McAfee (2014).[8] Martin Baily, James Manyika, and Shalabh Gupta (2013) summarize an extensive series of studies of technological prospects for American industries, including IT, conducted by the McKinsey Global Institute (Manyika, *et al.* 2011) and also provide a more optimistic view.

John Fernald (2012) 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. Byrne, Oliner and Sichel (2013) present projections of future US 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.

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.[9] This view is supported by Unni Pillai (2011) and by the computer scientists John Hennessey and David Patterson (2012).[10]

We present base case, pessimistic, and optimistic projections of future growth in potential U.S. GDP for the period 2012-2022 in Figures 19, 20 and 21. The Appendix describes our projection methods. Our base case projections are based on the average contributions of total factor

[8] 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/

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

[10] See John Hennessey and David Patterson (2012), Figure 1.16, p. 46. An excellent journalistic account of the turning point in the development of Intel microprocessors is presented by John Markoff in the New York Times for May 17, 2004. See: http://www.nytimes.com/2004/05/17/business/technology-intel-s-big-shift-after-hitting-technical-wall.html

productivity growth for the IT-producing, IT-using, and Non-IT industries for the period 1995-2012. Our optimistic projections omit the Great Recession period of 2007-2012, while our pessimistic projections take account the final five years of the Great Recession and the Long Slump. We compare our projections with actual growth for 1990-2012.

Our base case projection of growth in potential GDP in 2012-2022 is 1.75 percent per year, compared with growth for 1990-2012 of 2.38 percent. The difference is due mainly to the projected slowdown in the growth of labor quality. Labor quality growth is driven mainly by increases in average educational attainment and rising educational attainment has been a major driver of U.S. economic growth throughout the postwar period. However, educational attainment will reach a plateau early in our projection period 2012-2022. Labor quality growth will fall from 0.46 percent per year during 1990-2012 to only 0.087 percent per year in 2012-2022.

Our optimistic projection for potential U.S. GDP growth is 2.20 percent per year during 2012-2022, short of actual growth of 2.38 percent per year in 1990-2012. The contributions of IT-using and Non-IT industries along with more rapid growth in capital quality are mainly responsible higher projected growth. Our pessimistic projection for potential growth is only 1.56 percent per year. The difference from our base case is due mainly to a reduction in the projected growth of productivity in IT-producing and IT-using sectors and slower improvement in capital quality.[11]

Conclusions

Our industry-level data set reveals that replication of established technologies through growth of capital and labor inputs, recently through the growth of college-educated workers and investments

[11] These projections are not directly comparable with those summarized by Byrne, Oliner and Sichel (2013), which are limited to nonfarm business.

in both IT and Non-IT capital, explains by far the largest proportion of US economic growth. International productivity comparisons reveal similar patterns for the world economy, its major regions, and leading industrialized, developing, and emerging economies.[12] Studies are now underway to extend these comparisons to individual industries for the countries included in the World KLEMS Initiative.[13]

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 (2014), especially for the IT-producing industries. Careful studies of developments of semiconductor and computer technology show that the accelerated pace of innovation that began in 1995 reverted to the lower, but still substantial, rates of innovation in IT. This accounted for almost all of productivity growth during the Great Recession.

Our findings also contribute to an understanding of the future potential for US economic growth. Our new projections corroborate the perspective of Jorgenson, Ho, and Stiroh (2008), who showed that the peak growth rates of the US Investment Boom of 1995-2000 were not sustainable. However, our projections are less optimistic, due mainly to the slowing growth of the US labor force and the virtual disappearance of improvements in labor quality. Low productivity growth during the Great Recession is transitory, but productivity growth is unlikely to return to the high rates of the Investment Boom and the Jobless Recovery.

Finally, we conclude that the new findings presented in this paper have important implications for US 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, but this is likely to be most successful

[12] See Jorgenson and Vu (2013).
[13] See Jorgenson (2012), "The World KLEMS Initiative," *International Productivity Monitor,* Fall, pp. 5-19.

for college-educated workers. These measures will contribute to closing the substantial remaining gap between potential and actual output.

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:

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

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:

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

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

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:

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

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 sex from the U.S. Census Bureau[14] and organize the data to match the classifications in our labor database (8 age groups, 2 sexes). We read the 2010 Census of Population to construct the educational attainment distribution by age, based on the 1% sample of individuals. We then 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. There was a higher fraction with BA degrees for females.

[14] 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. In that projection the Resident population is projected to be 420 million in 2060. We make an adjustment to give the total population including Armed Forces overseas.

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 2022 will have the same chance of having a BA degree as a 22-year old man in 2012. 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 2022 is the same as that of 40 year olds in 2012, assuming that death rates are independent of educational attainment. Since a 50-year-old in 2022 has a slightly higher attainment than and 51 year-old in 2020, these assumptions result in a smooth improvement in educational attainment that is consistent with the observed profile in the 2010 Census.

The next step after constructing the population matrix by sex, age and education for each year in the projection period is to calculate the employment and hours worked matrices by these dimensions. The employment rate fell significantly during the Great Recession and we assume that the employment rate rises gradually from the observed 2010 levels back to the 2007 rates. We also assume that the annual hours worked per worker gradually recover to 2007 levels.. We assume there are no further changes in the relative wages for each age-sex-education cell and thus calculate the effective labor input in the projection period by multiplying these projected hours per year by the projected population in each cell, and then weighting by the 2010 compensation matrix. The ratio of labor input to hours worked is the 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 1995-2012. For the optimistic case we use the rate for 1995-2007. Finally, we use the rate for 1990-2012 for the pessimistic 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	`	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+

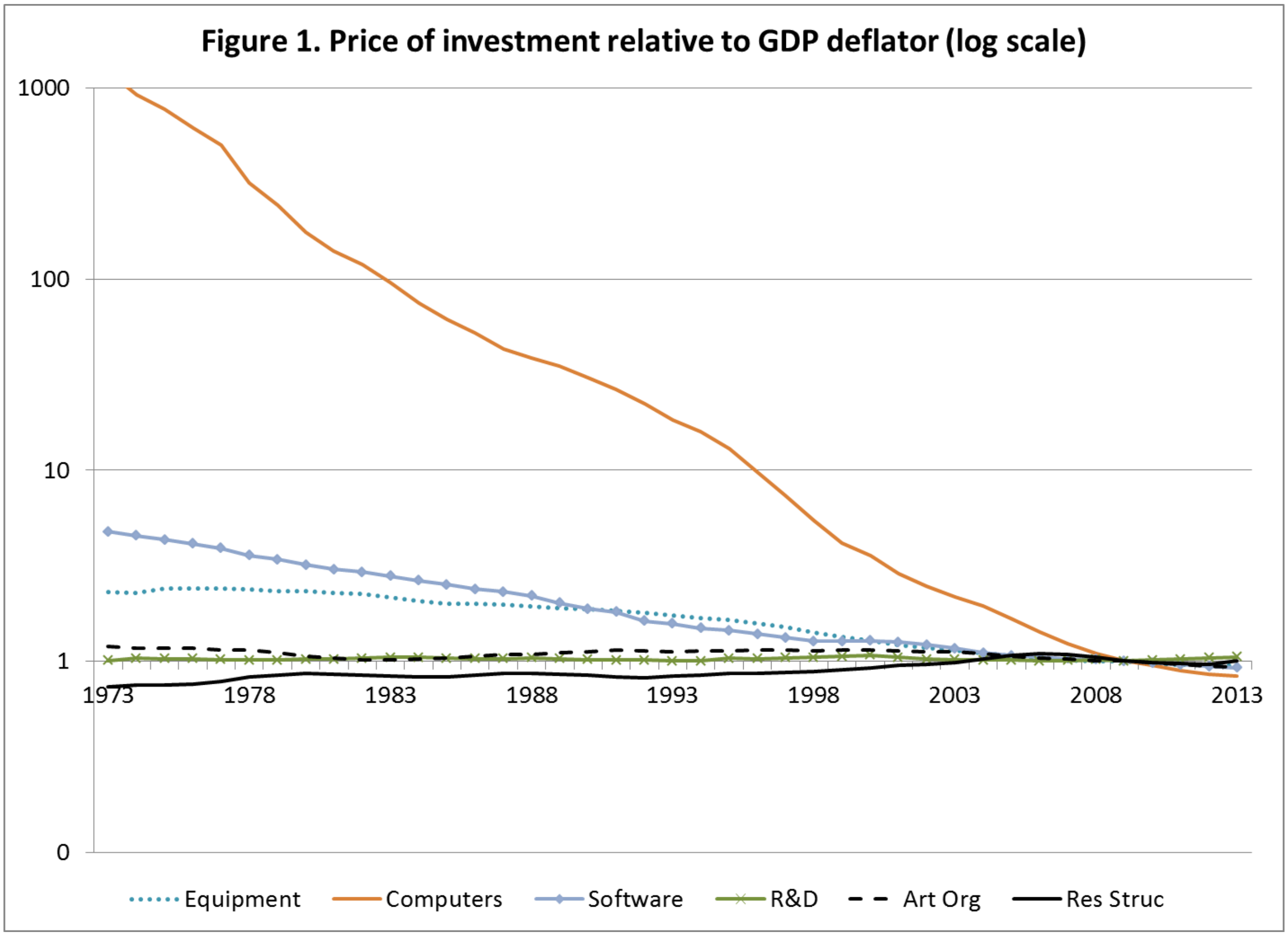
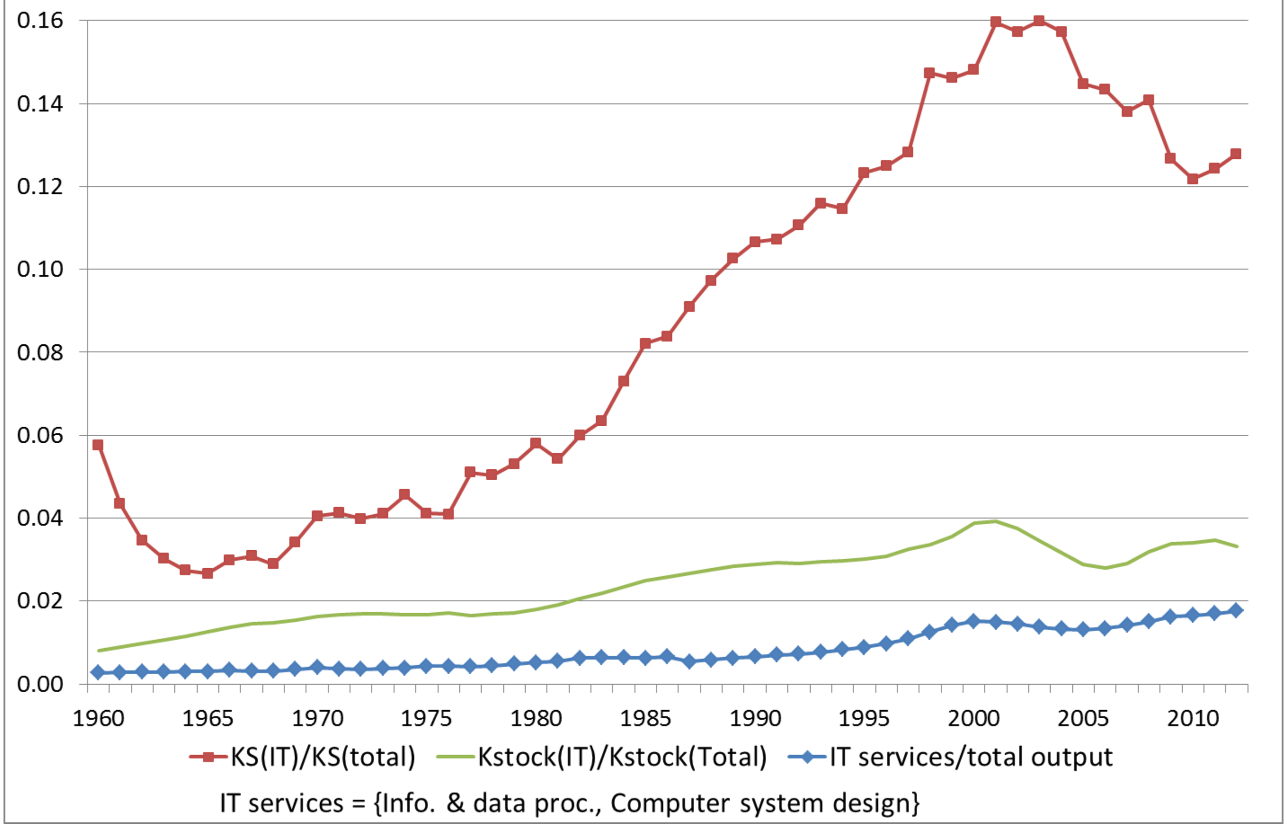


Figure 1. Price of investment relative to GDP deflator (log scale)
1000
100
10
1
0
1973
1978
1983
1988
1993
1998
2003
2008
2013
Equipment
Computers
Software
R&D
Art Org
Res Struc

Figure 2. Shares of IT stock, IT capital services, IT service output in total economy



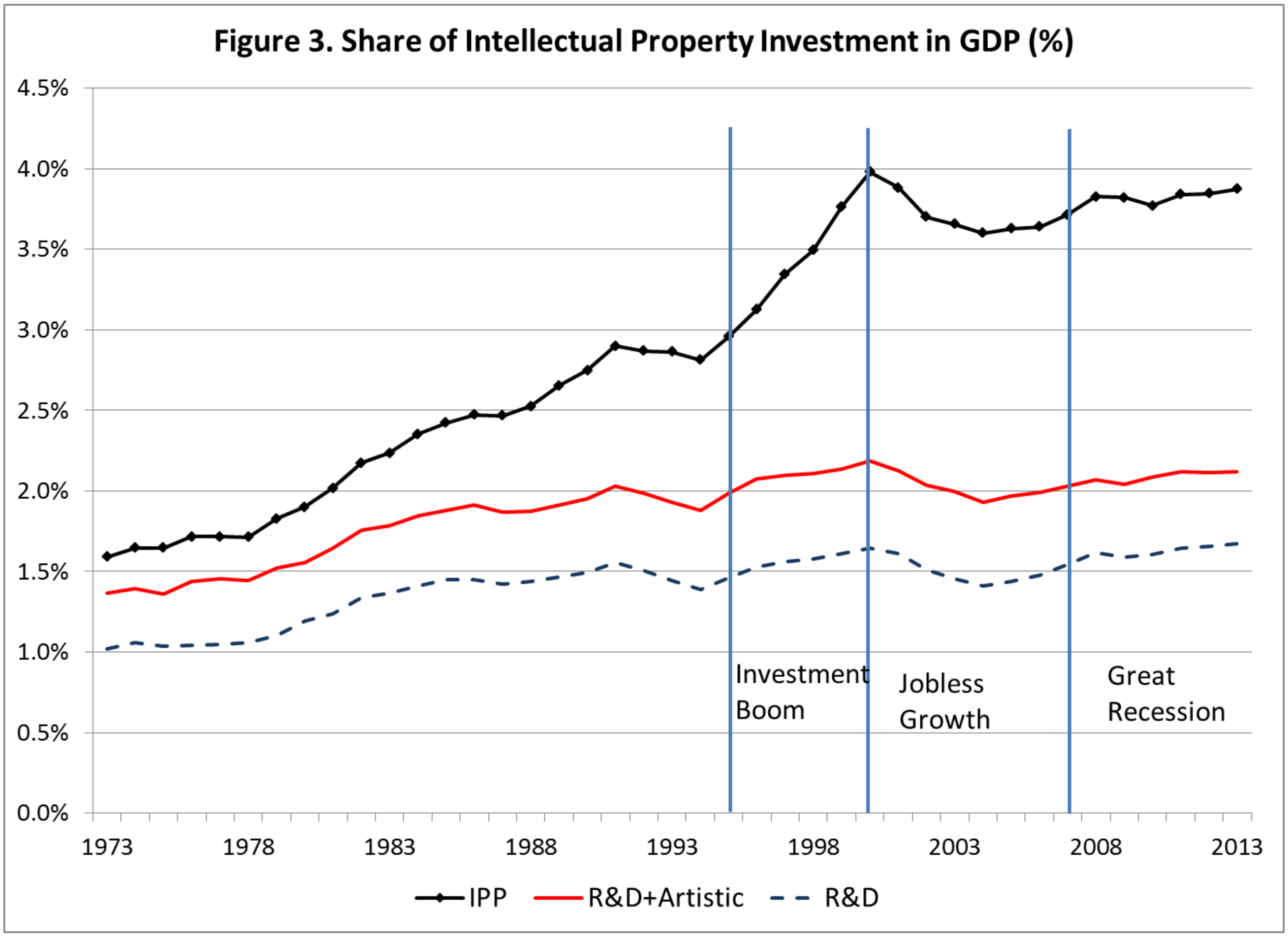


Figure 3. Share of Intellectual Property Investment in GDP (%)
4.5%
4.0%
3.5%
3.0%
2.5%
2.0%
1.5%
1.0%
0.5%
0.0%
1973
1978
1983
1988
1993
1998
2003
2008
2013
Investment Boom
Jobless Growth
Great Recession
IPP
R&D+Artistic
R&D

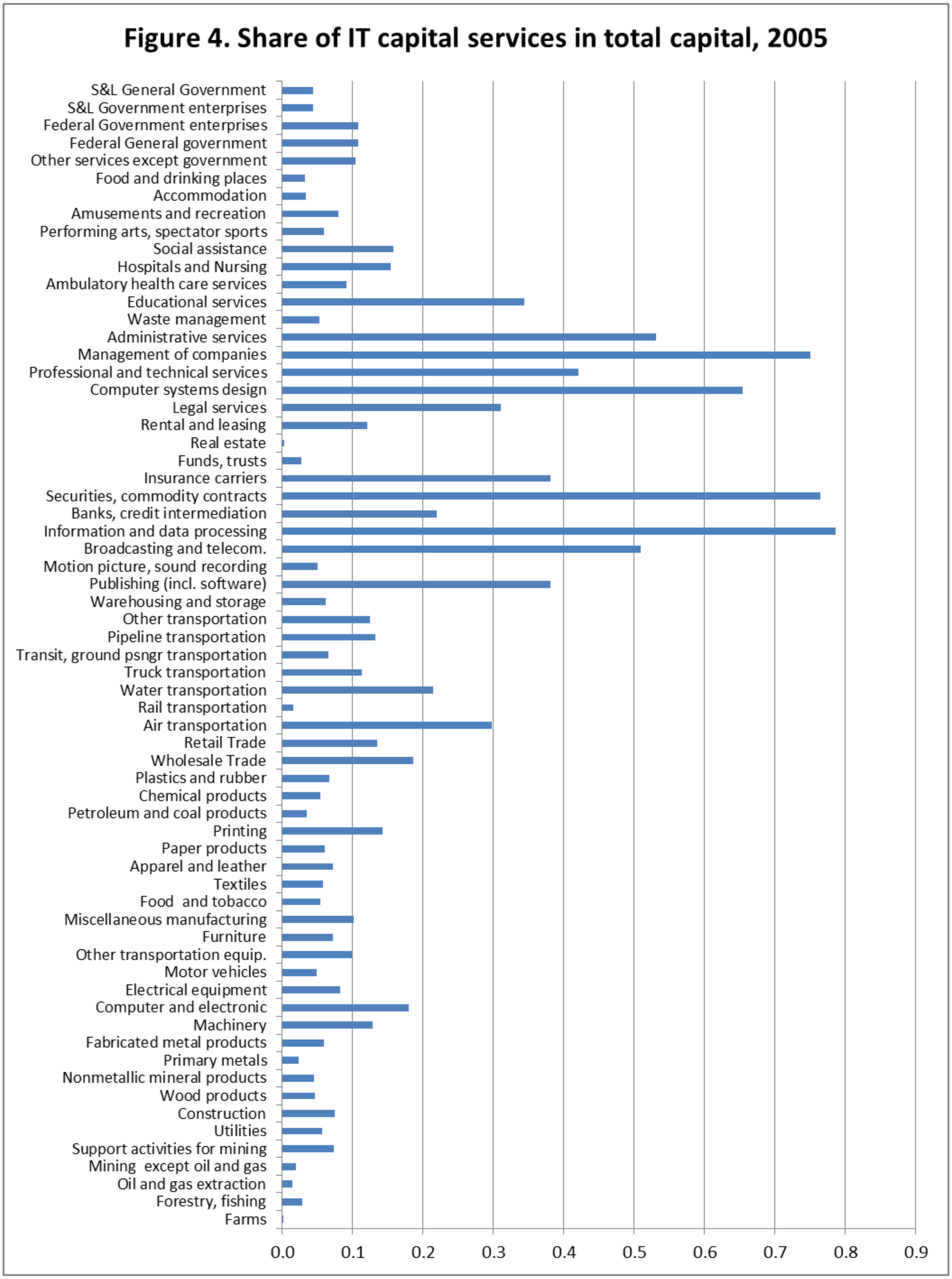


Figure 4. Share of IT capital services in total capital, 2005
S&L General Government
S&L Government enterprises
Federal Government enterprises
Federal General government
Other services except government
Food and drinking places
Accommodation
Amusements and recreation
Performing arts, spectator sports
Social assistance
Hospitals and Nursing
Ambulatory health care services
Educational services
Waste management
Administrative services
Management of companies
Professional and technical services
Computer systems design
Legal services
Rental and leasing
Real estate
Funds, trusts
Insurance carriers
Securities, commodity contracts
Banks, credit intermediation
Information and data processing
Broadcasting and telecom.
Motion picture, sound recording
Publishing (incl. software)
Warehousing and storage
Other transportation
Pipeline transportation
Transit, ground psngr transportation
Truck transportation
Water transportation
Rail transportation
Air transportation
Retail Trade
Wholesale Trade
Plastics and rubber
Chemical products
Petroleum and coal products
Printing
Paper products
Apparel and leather
Textiles
Food and tobacco
Miscellaneous manufacturing
Furniture
Other transportation equip.
Motor vehicles
Electrical equipment
Computer and electronic
Machinery
Fabricated metal products
Primary metals
Nonmetallic mineral products
Wood products
Construction
Utilities
Support activities for mining
Mining except oil and gas
Oil and gas extraction
Forestry, fishing
Farms
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

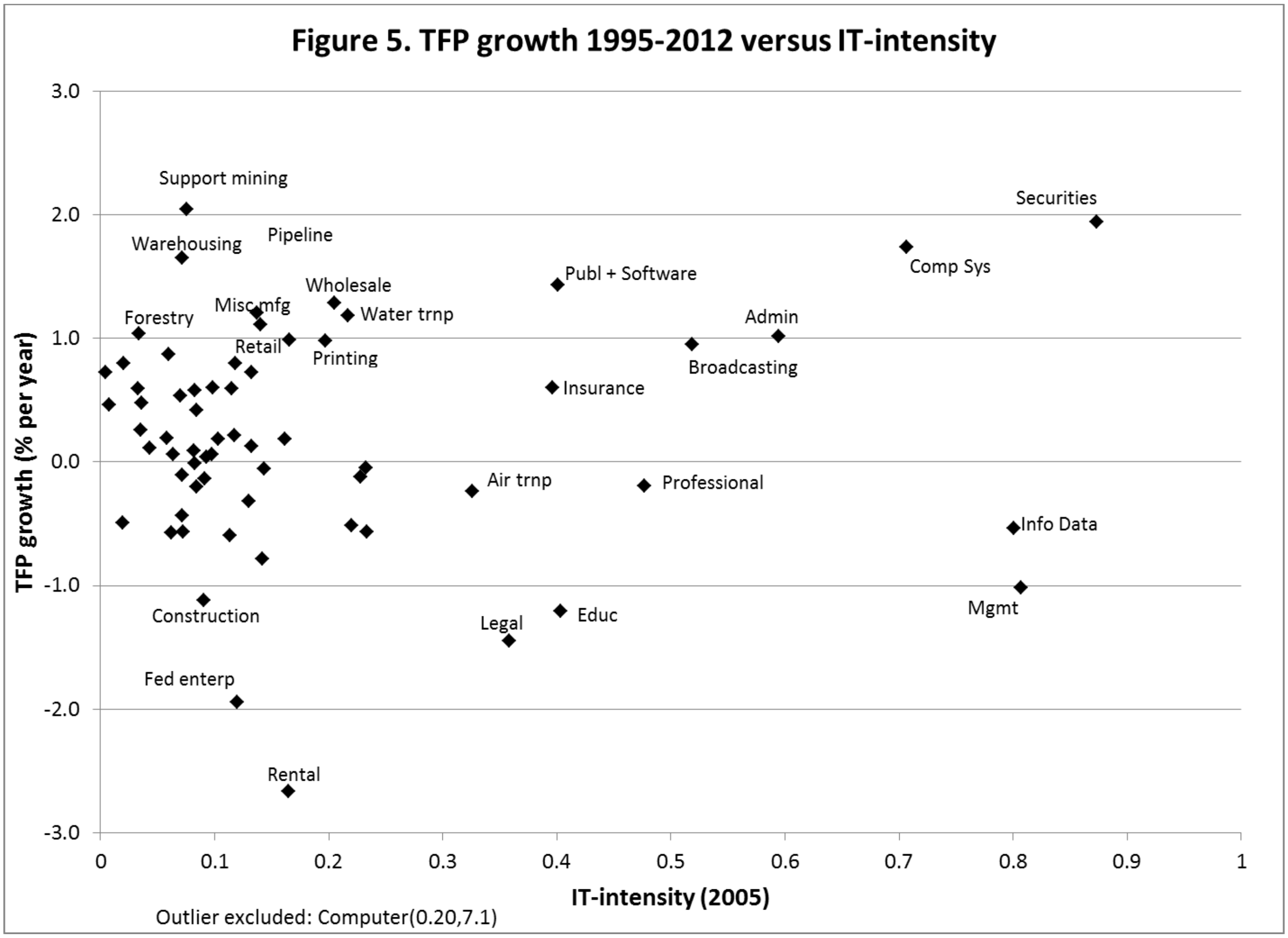


Figure 5. TFP growth 1995-2012 versus IT-intensity
TFP growth (% per year)
IT-intensity (2005)
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Support mining
Warehousing
Pipeline
Wholesale
Misc mfg
Water trnp
Forestry
Retail
Printing
Publ + Software
Insurance
Broadcasting
Admin
Securities
Comp Sys
Air trnp
Professional
Info Data
Mgmt
Construction
Legal
Educ
Fed enterp
Rental
Outlier excluded: Computer(0.20,7.1)

Figure 6. Contribution of education, age and gender to labor quality

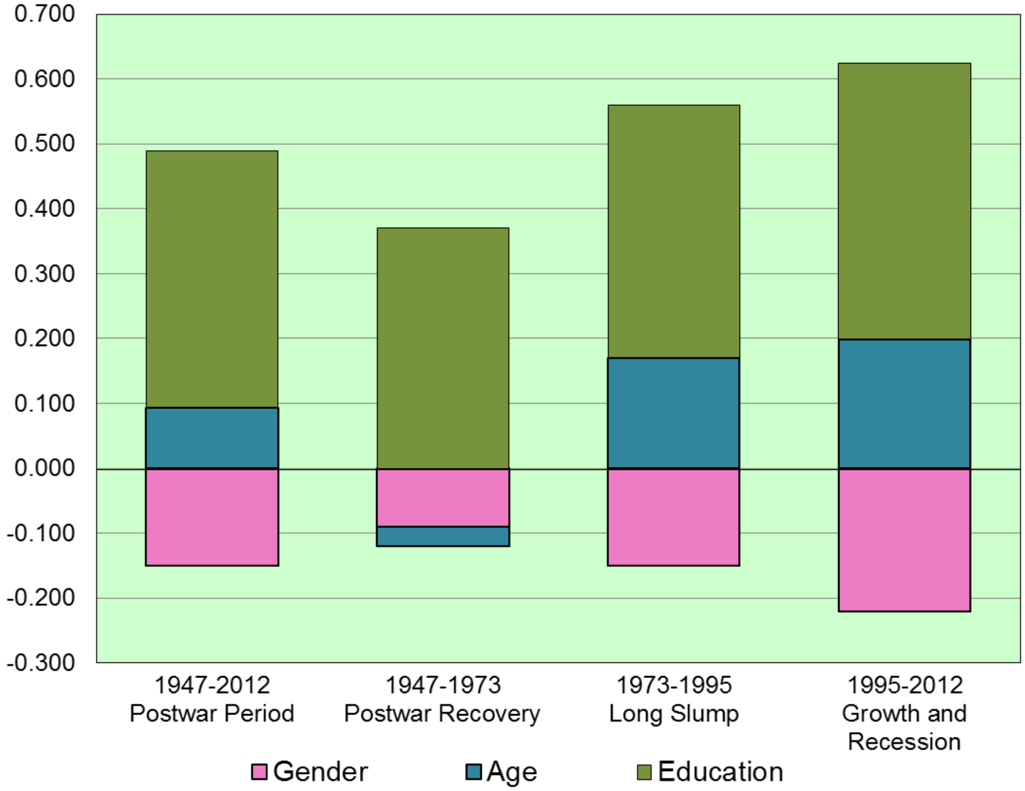


Figure 7. Contribution of education, age and gender to projected labor quality

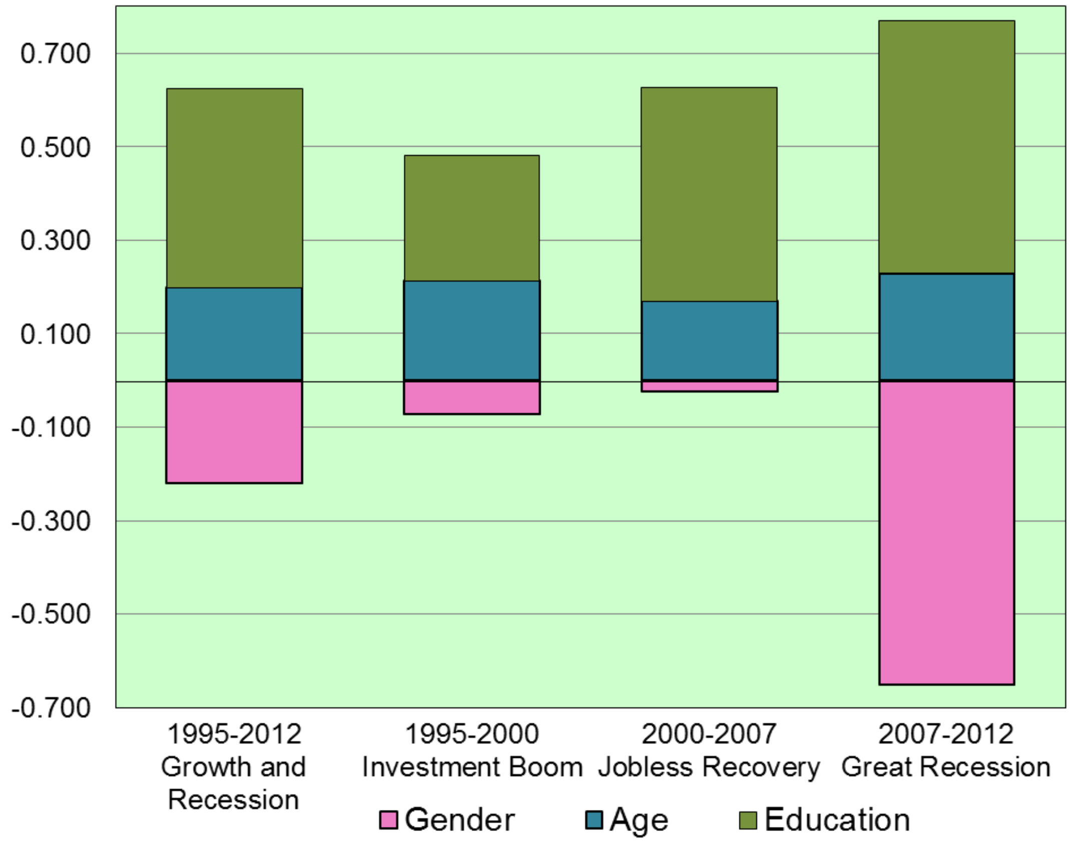


Figure 8. Distribution of education attainment of work force

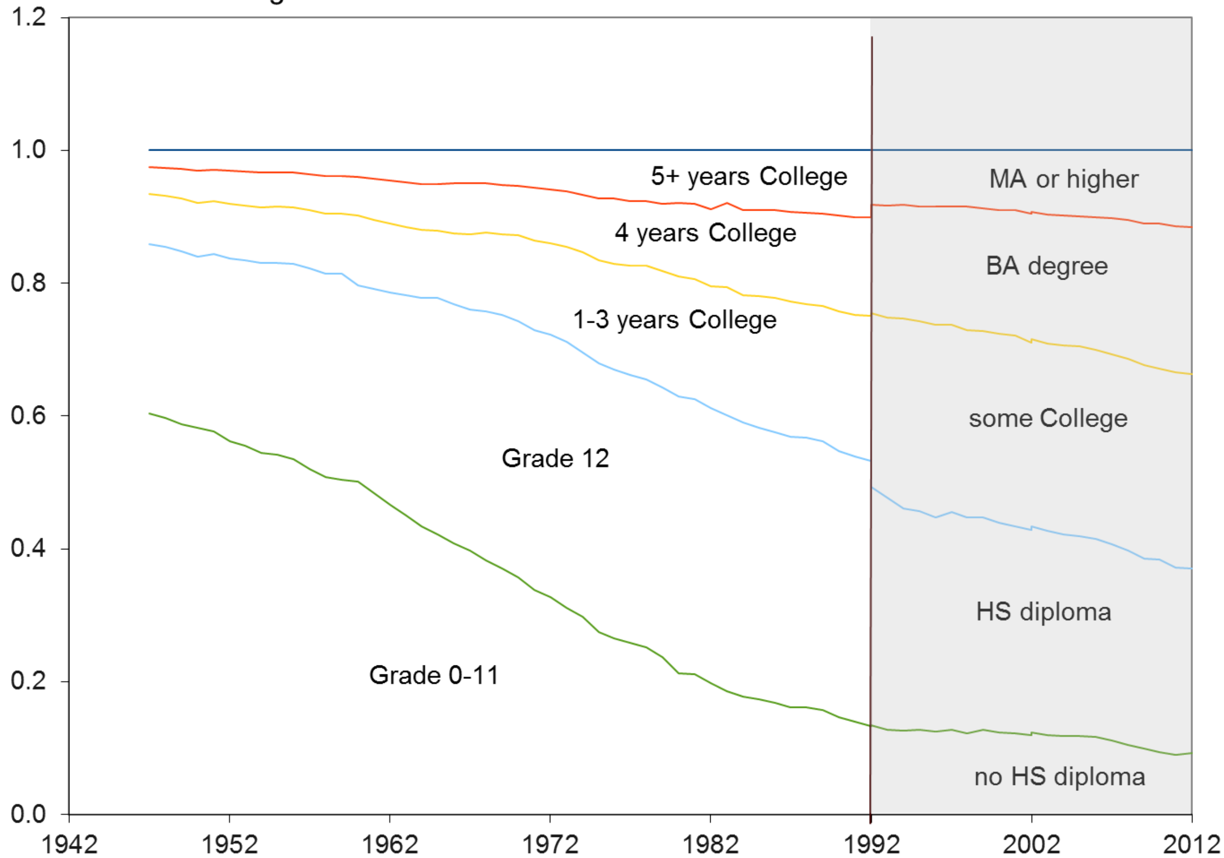


Figure 9. Compensation by education attainment (relative to those with HS diploma)

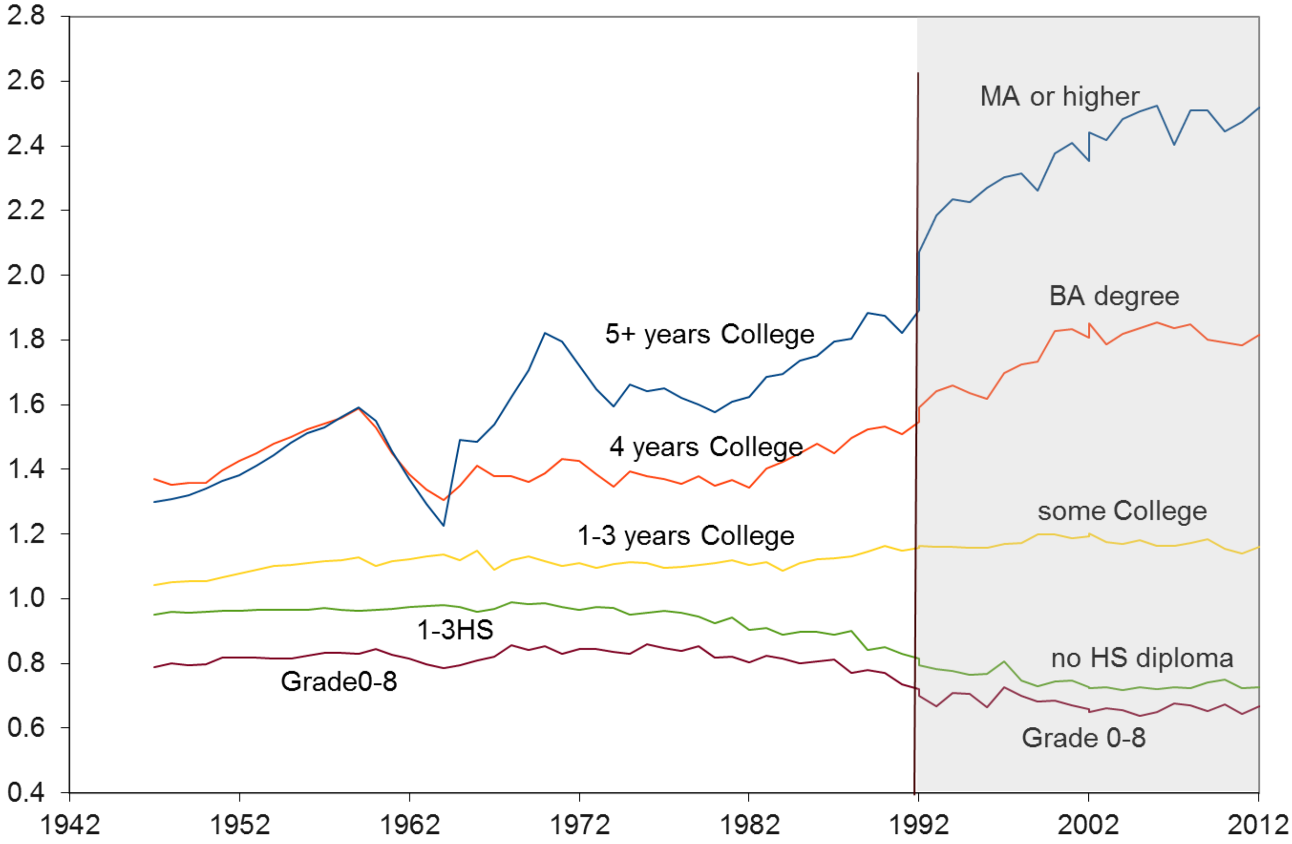


Figure 10. Compensation by age relative to 25-34 year olds

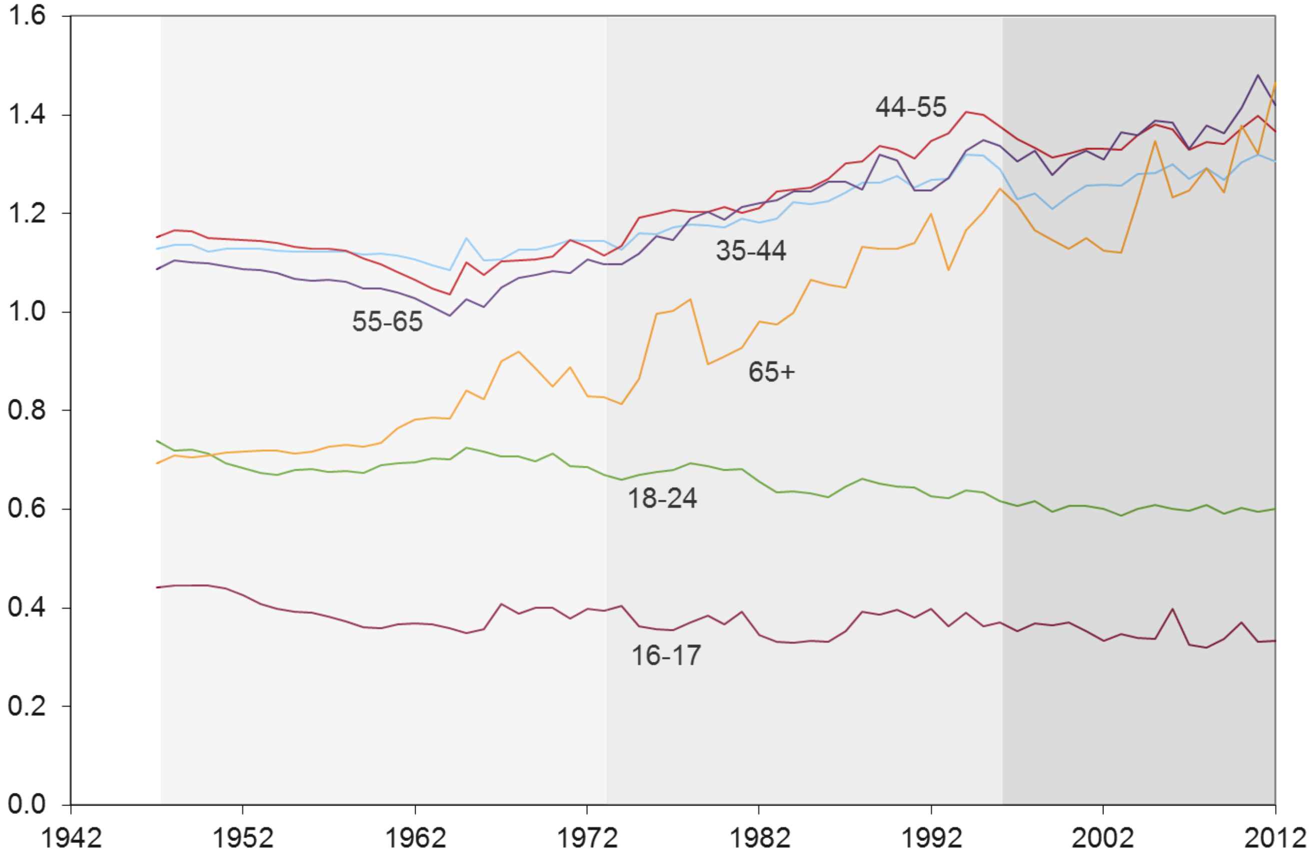


Figure 11. Contributions of Industry Groups to Value Added Growth, 1947-2012

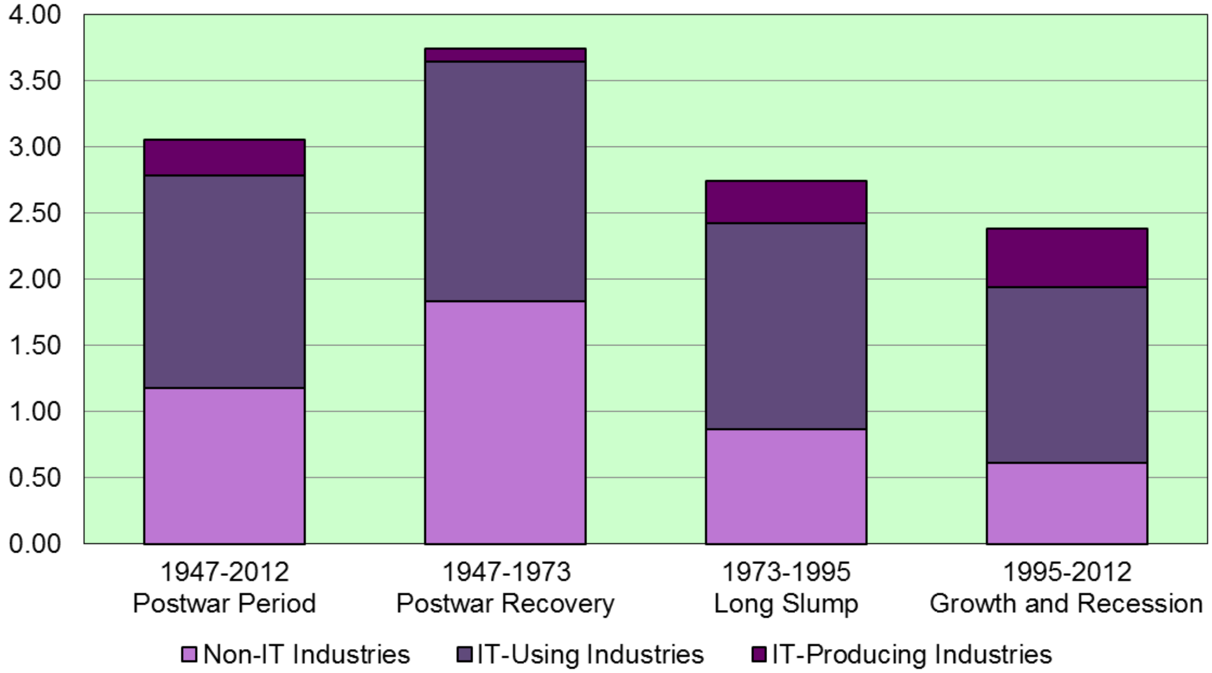


Figure 12. Contributions of Industry Groups to Value Added Growth, 1995-2012

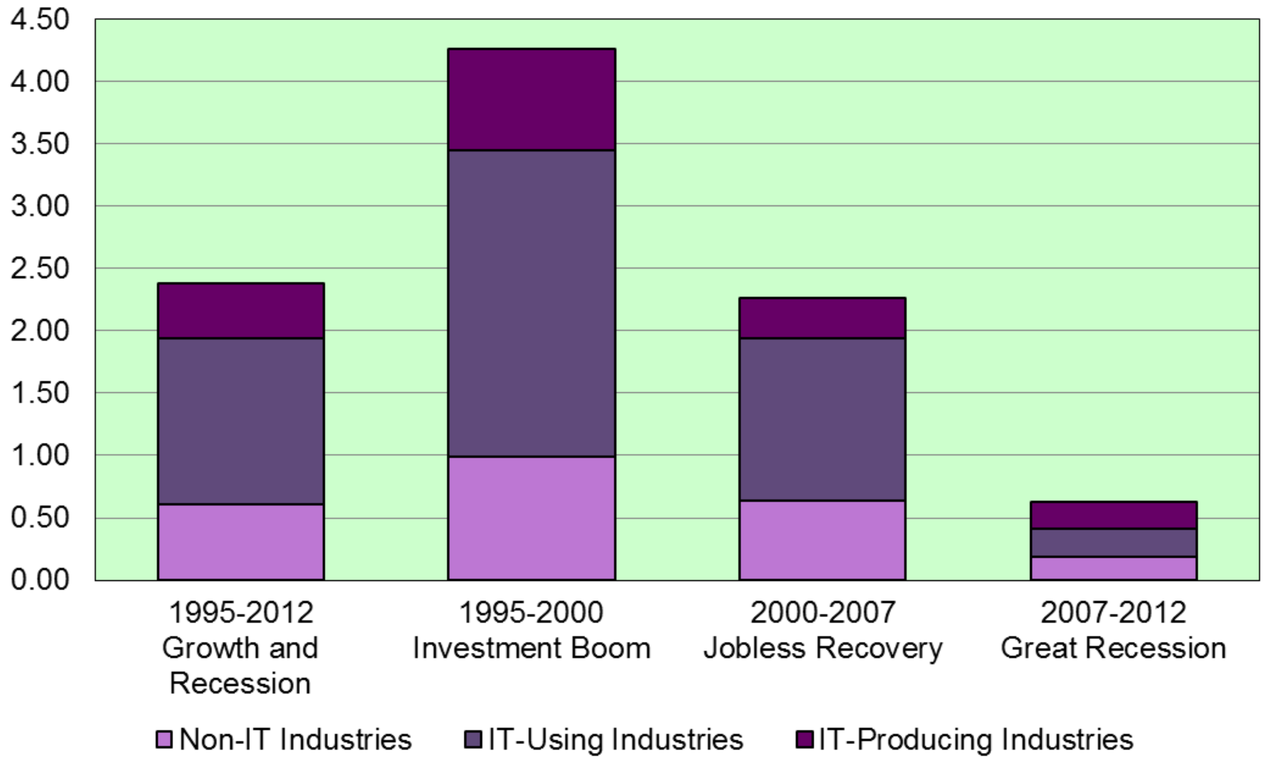


Figure 13. Industry Contributions to Value Added 1947-2012

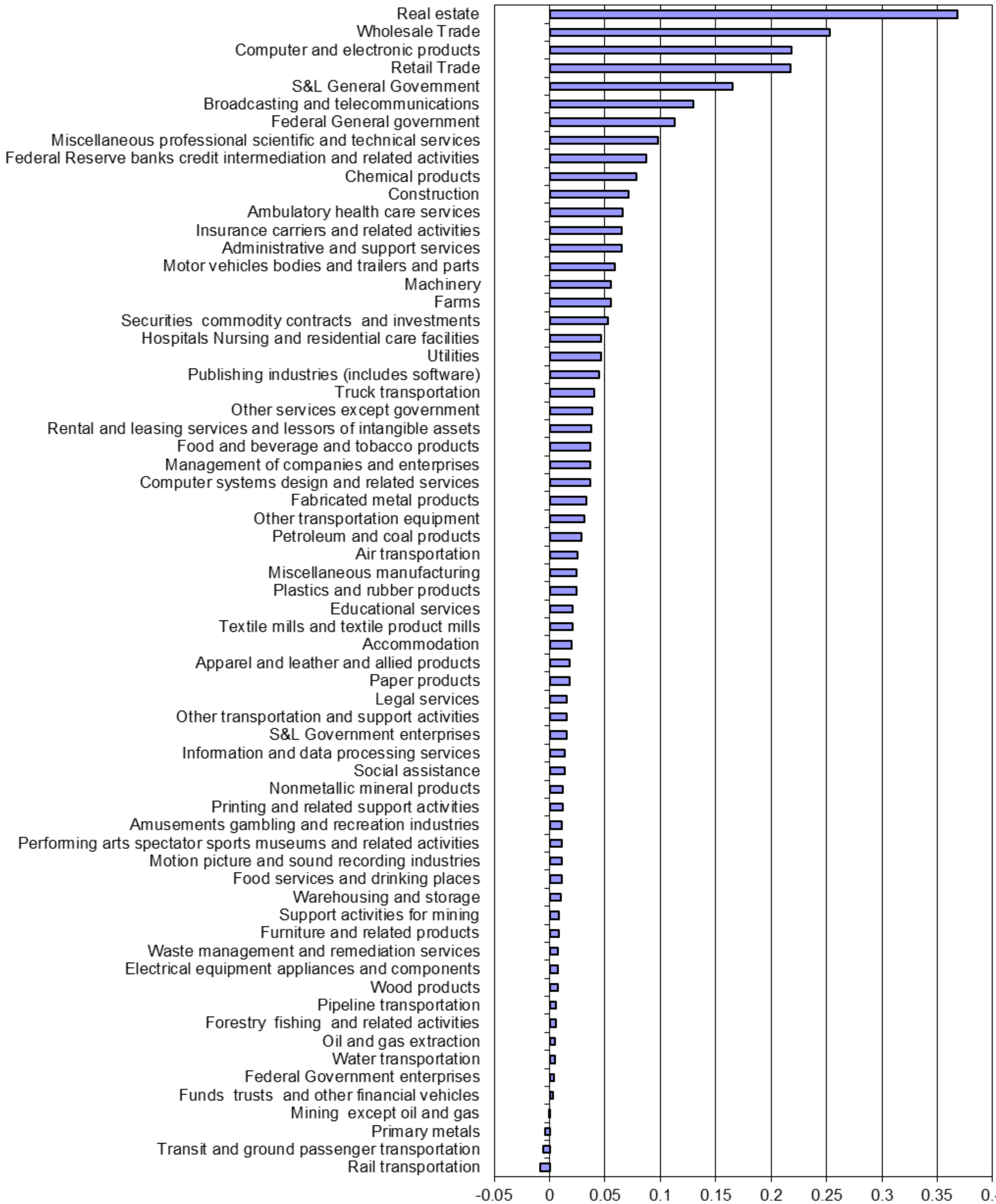


Figure 14. Contribution of Industry Groups to Productivity Growth, 1947-2012

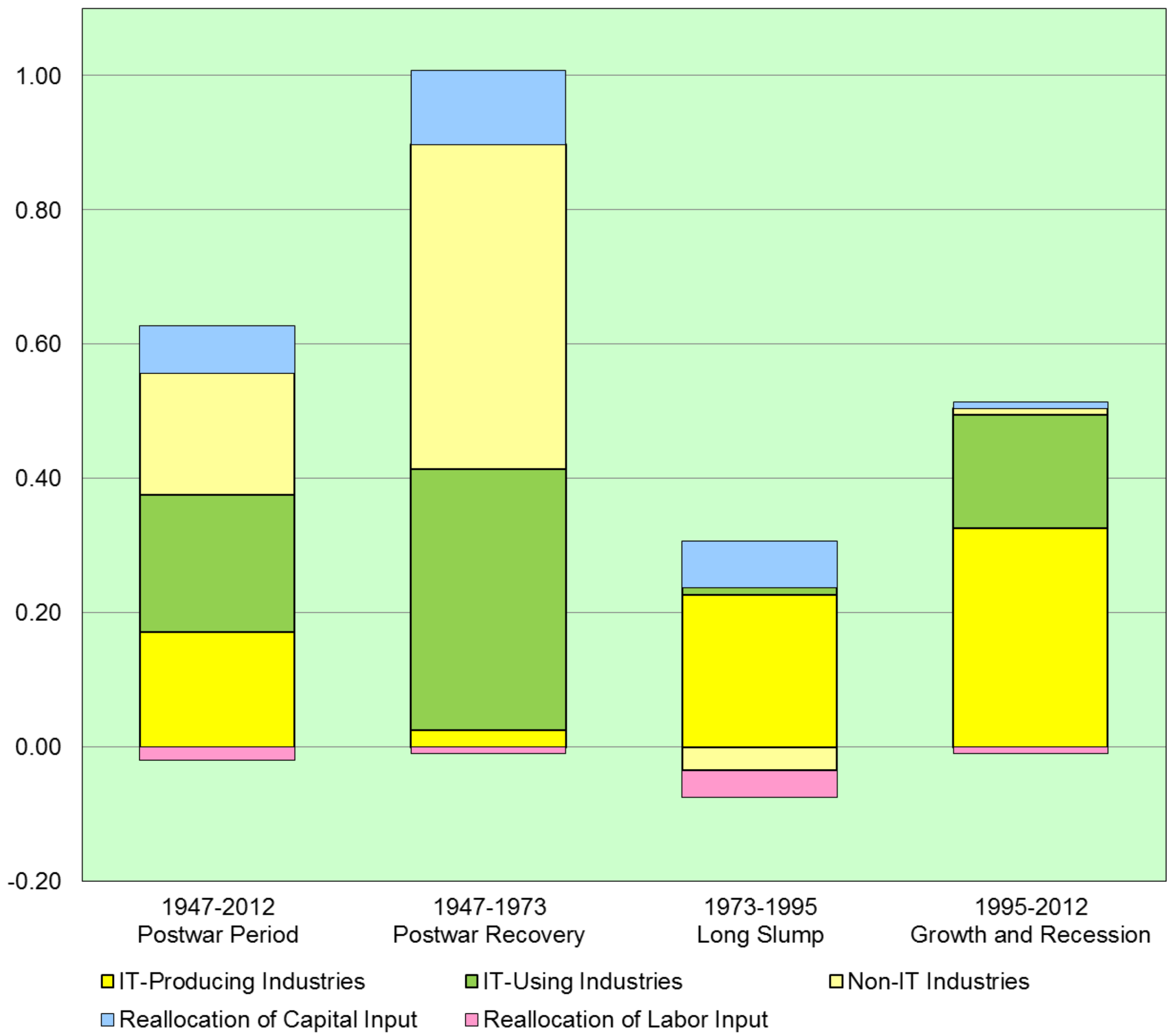


Figure 15. Contribution of Industry Groups to Productivity Growth, 1995-2012

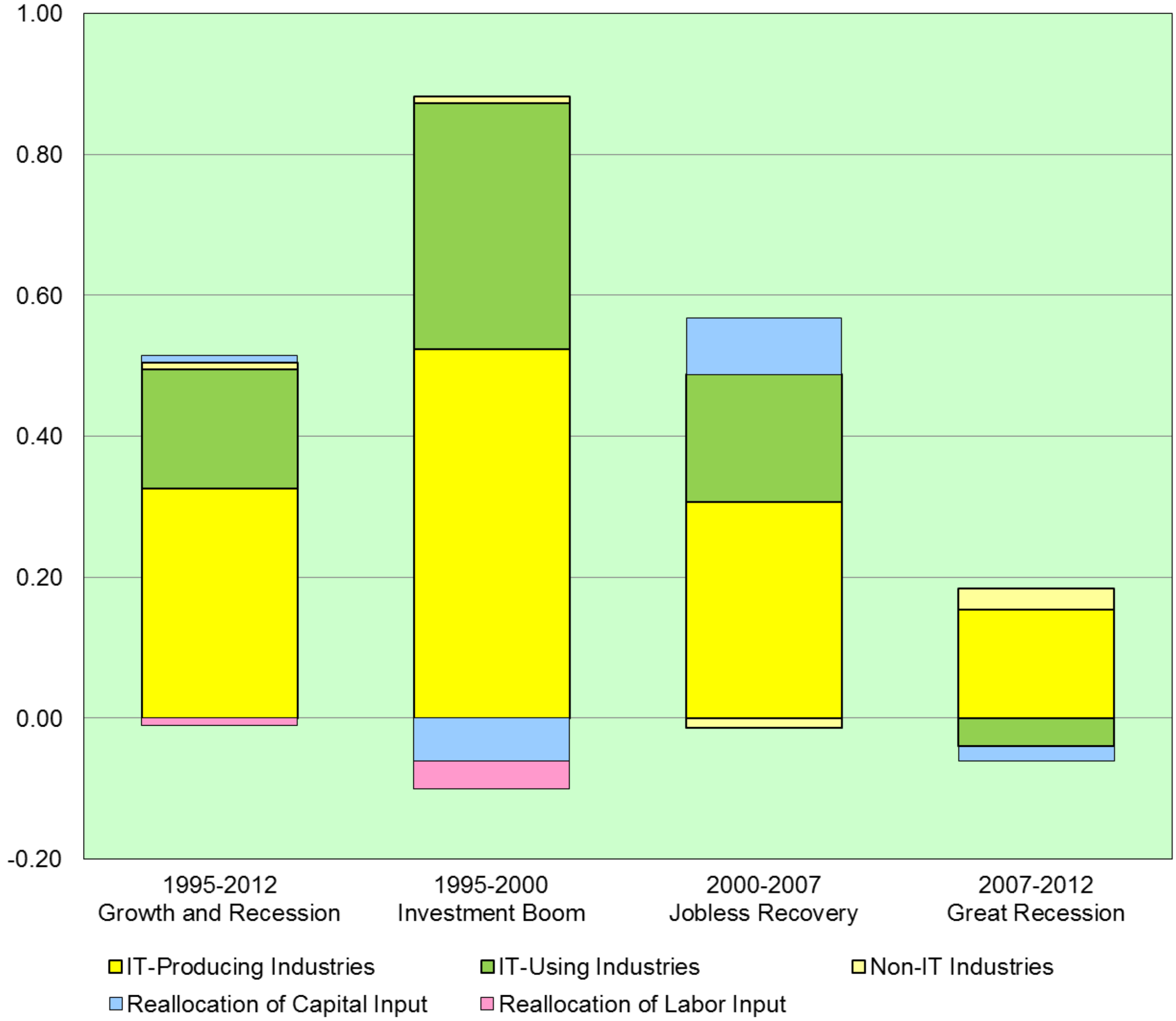


Figure 16. Industry Contributions to Productivity 1947-2012

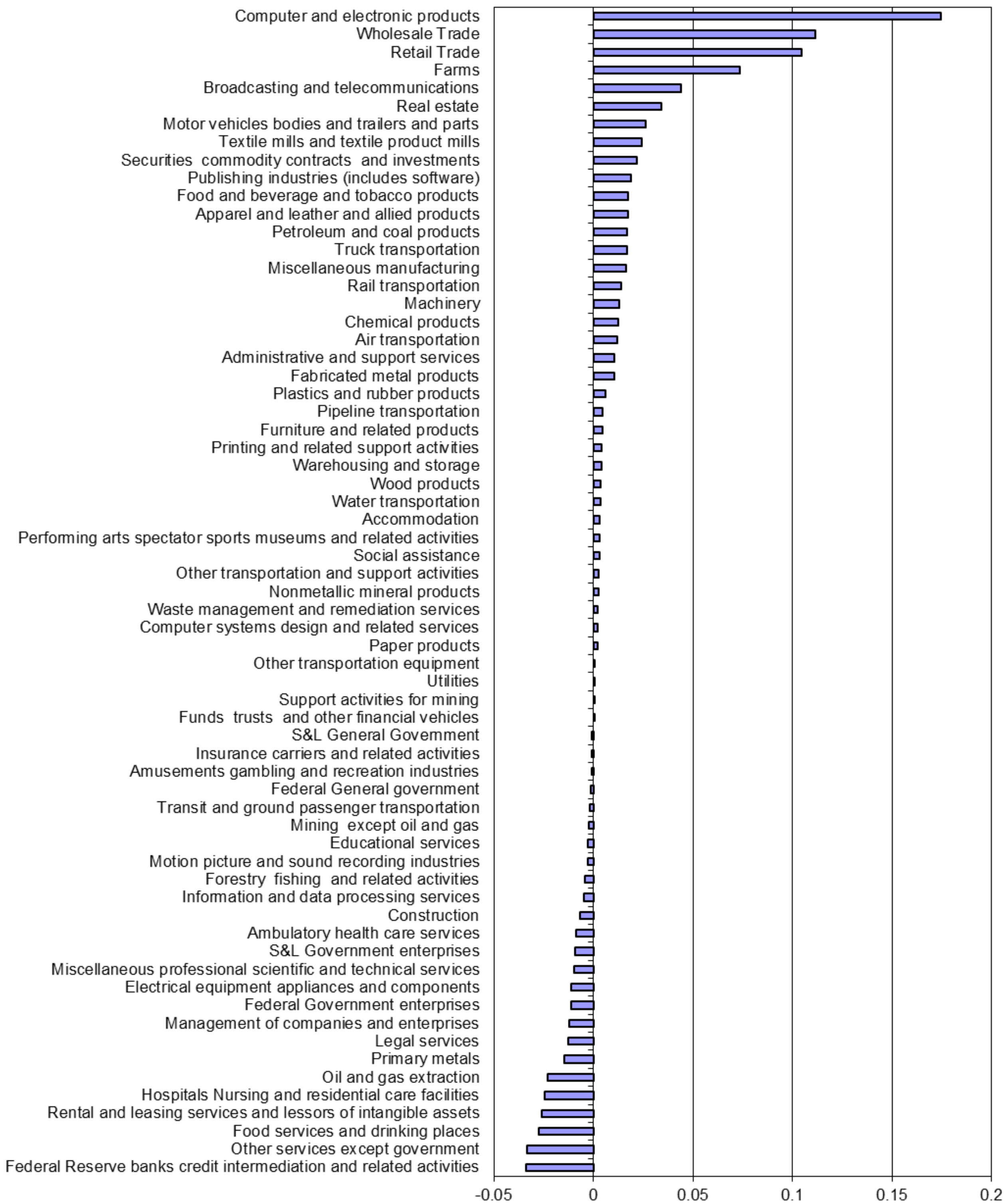


Figure 17. Sources of U.S. Economic Growth, 1947-2012

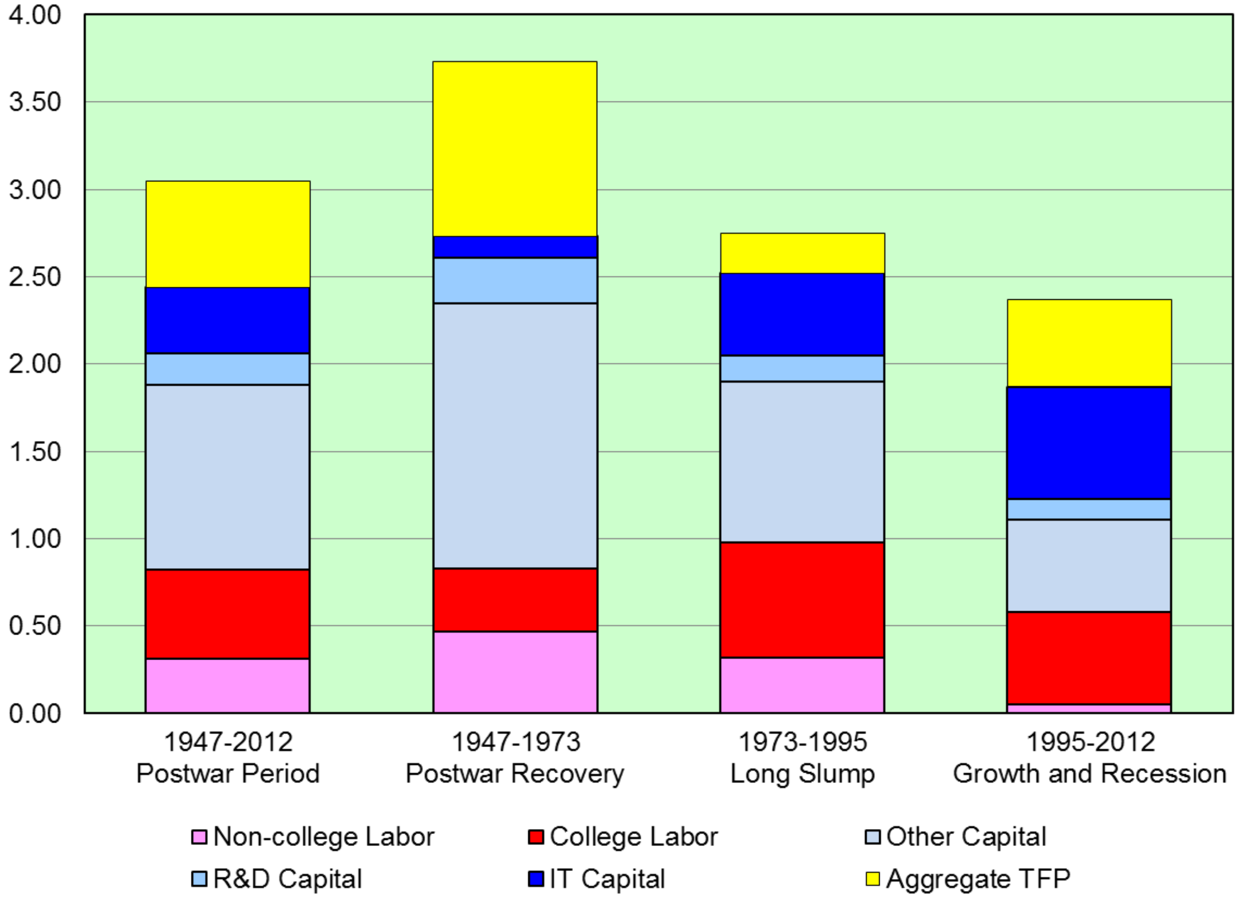


Figure 18. Sources of U.S. Economic Growth, 1995-2012

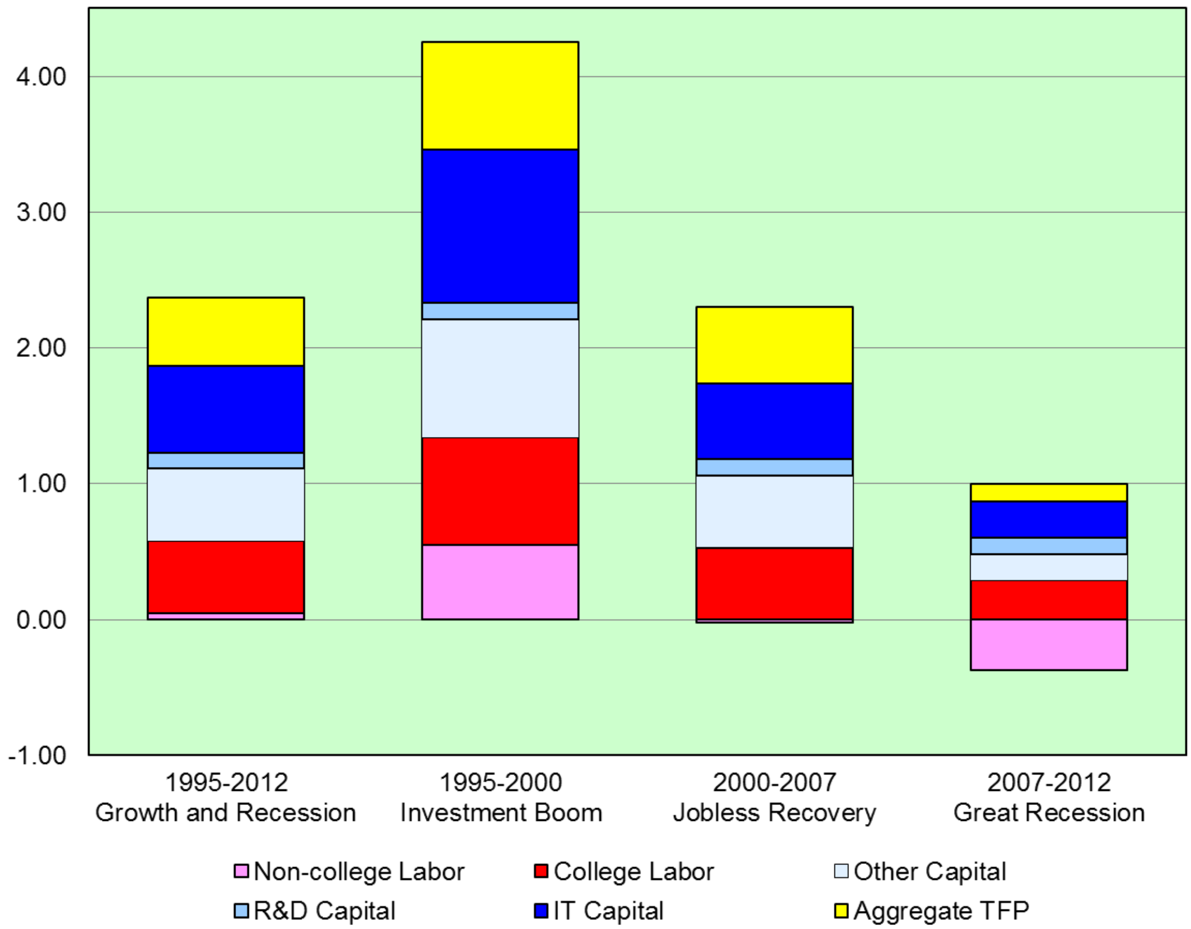


Figure 19. Contribution of Industry Groups to Productivity Growth, 2012-2022

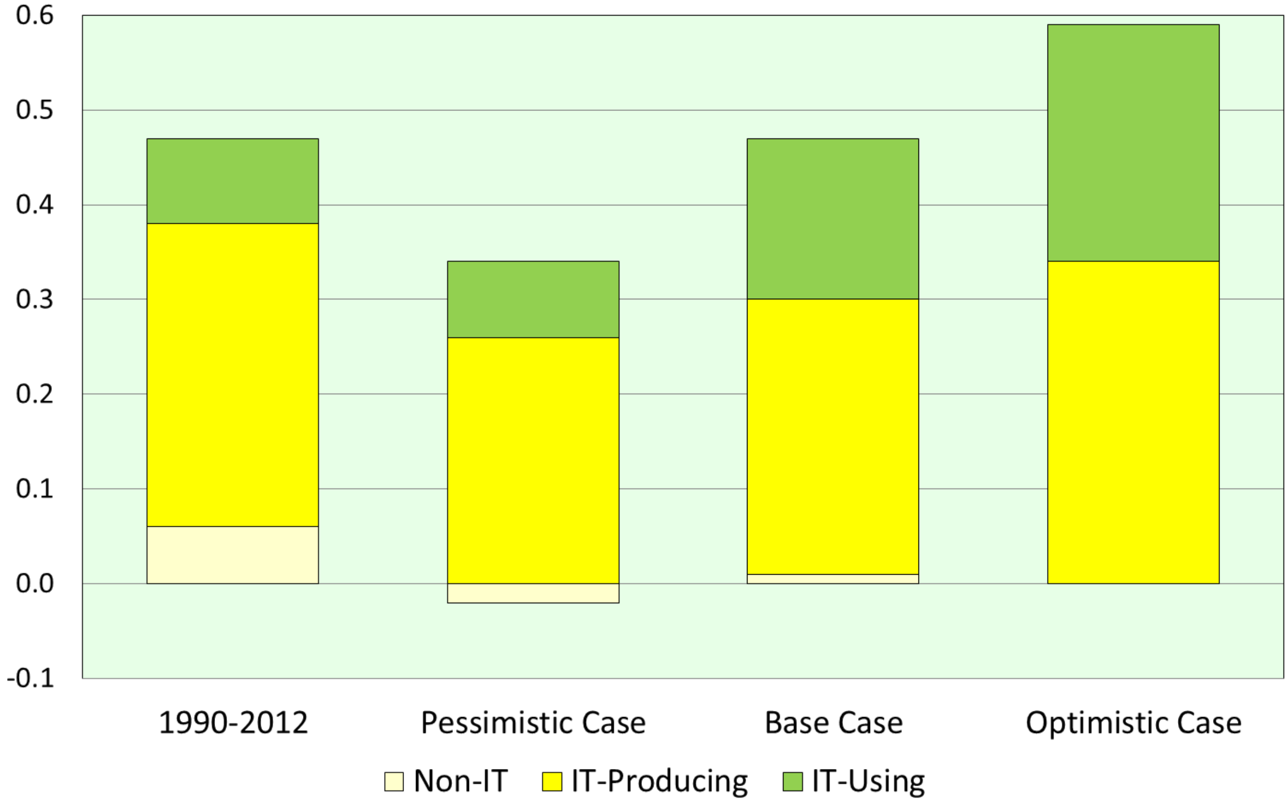


Figure 20. Range of Labor Productivity Projections, 2012-2022
Annual percentage growth rates

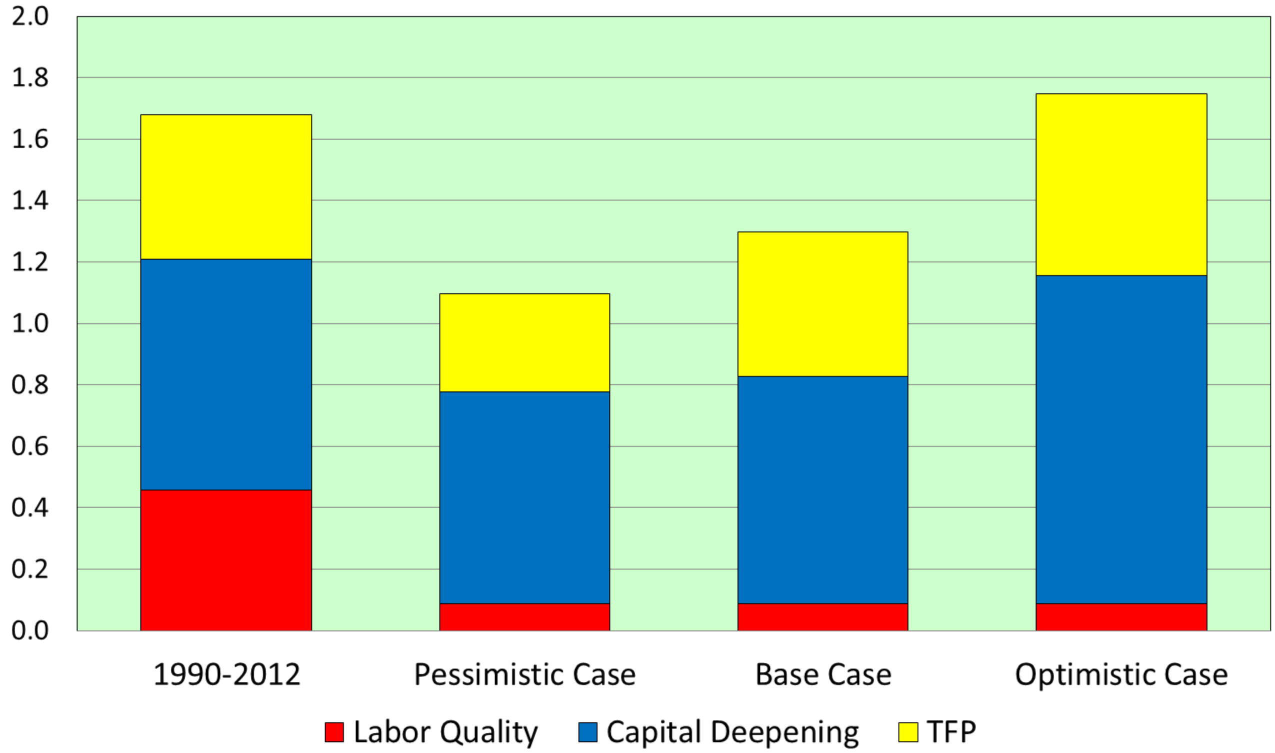


Figure 21. Range of U.S. Potential Output Projections, 2012-2022
Annual percentage growth rates