ECONOMIC GROWTH IN THE INFORMATION AGE:

A Prototype Industry-Level Production Account

for the United States, 1947-2010

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Introduction

The Information Age is one of many terms that direct attention to the rapidly growing economic importance of information technology (IT). Economists were notoriously late in recognizing the widespread economic impact of IT, despite the currency that this trend achieved among futurologists and journalists. Jorgenson (2009) summarizes these developments, beginning with the publication of Jorgenson and Kevin Stiroh (2000) and Steven Oliner and Dan Sichel (2000), and presents a collection of the key papers.[2]

The year 1929 is the initial year of the US National Income and Product Accounts (NIPAs), and the first benchmark input-output table was constructed for 1947. The year 2011 is the latest year for which the Annual Industry Economic Accounts are available. These are consistent with the NIPAs, generated by the Bureau of Economic Analysis (BEA), and described by Nicole Mayerhauser and Erich Strassner (2010). In *Information Technology and the American Growth Resurgence.* Jorgenson, Ho, and Stiroh (2005) provided a concise history of the main technological

[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.
[2] See: http://scholar.harvard.edu/jorgenson/publications/economics-productivity

innovations of the Information Age, beginning with the invention of the transistor, also in 1947. They have analyzed the economic impact of IT at the aggregate level for 1948-2002 and the industry level for 1977-2000.[3]

The objective of this paper is to provide a historical perspective on US economic growth in the Information Age, exploiting data now available from the NIPAs, including the Industry Economic Accounts. For this purpose we present a new data set on US productivity growth by industry. This covers 65 industries for the period 1947-2010 and uses the North American Industry Classification System (NAICS). The US statistical system has shifted gradually to NAICS, beginning with the Business Census of 1997. The NIPAs converted to NAICS in the 2003 Comprehensive Revision.

The paper begins with a brief summary of the methodology for productivity measurement. The focus of productivity measurement has shifted from the economy as a whole to individual industries, especially those involved in the production and use of IT. Paul Schreyer's OECD (2001) manual, *Measuring Productivity* has established international standards for economy-wide and industry-level productivity measurement. Our methodology is consistent with the OECD's international standards

The OECD standards are based on the production accounts constructed by Jorgenson, Frank Gollop, and Barbara Fraumeni (1987). These accounts were updated and revised to incorporate investments in IT hardware and software by Jorgenson, Ho, and Stiroh (2005). 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.

An important feature of our new data set is that we include output and intermediate input from the Industry Economic Accounts for the period 1998-2010, using BEA's 65-sector industry

[3] See: http://mitpress.mit.edu/books/productivity-0

classification. This will greatly ease the task of incorporating official industry data as they become available in the future. We have extrapolated the industry data backward from 1998, using information from our earlier studies as well as benchmark input-output tables, beginning in 1947.

We aggregate industries by means of the production possibility frontier introduced by Jorgenson (1966) and employed by Jorgenson, Ho, and Stiroh (2005) and Jorgenson and Schreyer (2013). This provides a link between industry-level data and macro-economic projections of growth, like those of David Byrne, Oliner, and Sichel (2013). Our data for individual industries could also be linked to firm-level data to incorporate differences in productivity levels among businesses that are the subject of the micro-economic research reviewed by Syverson (2011).

We illustrate the application of the prototype industry-level production account by analyzing data for the postwar US for three broad periods. These are the Postwar Recovery, 1947-1973, the Big Slump after the 1973 energy crisis, 1973-1995, and the period of Growth and Recession, 1995-2010. To provide more detail on the period of Growth and Recession, we consider the sub-periods 1995-2000, 2000-2005, and 2005-2010 – the Investment Boom, the Jobless Recovery, and the Great Recession.

The IT mantra – faster, better, cheaper – characterizes the speed of technological change in semiconductors, the key enabling technology. The economics of IT begins with the precipitous and continuing fall in semiconductor prices. The rapid price decline has been transmitted to the prices of a range of products that rely on this technology, like computers and telecommunications equipment. Semiconductor technology has also reduced the costs of aircraft, automobiles, scientific instruments, and a host of other products.

The hallmark of the new framework for productivity measurement, summarized by Jorgenson (2009), is the concept of capital services, including the services provided by IT

equipment and software. The economics of IT begins with the staggering rates of decline in the prices of IT equipment used for storage of information and computing. The “killer application” of the new framework is the impact of IT investment.

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. Our framework for productivity measurement provides the basis for distinguishing the economic impacts of innovation and investment.

Productivity growth is the key economic indicator of innovation. Economic growth can take place without innovation through replication of established technologies. Investment increases the availability of these technologies, while the labor force expands as population grows. With only replication and without innovation, output will increase in proportion to capital and labor inputs. By contrast the successful introduction of new products and new or altered processes, organization structures, systems, and business models generates growth of output that exceeds the growth of capital and labor inputs. This results in growth in productivity or output per unit of input.

We show that the great preponderance of economic growth in the US 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 Solow (1957) and Simon Kuznets (1971), innovation accounts for only about twenty percent of US economic growth. This is the most important empirical finding from the research on productivity measurement summarized by Jorgenson (2009).

The predominant role of replication of existing technologies in US economic growth is crucial to the formulation of economic policy. During the continuing recovery from the Great Recession of 2007-2009 in the US, economic policy must focus on maintaining the growth of employment and reviving investment. Policies that concentrate on enhancing the rate of innovation will have a very modest impact over the intermediate run. However, the growth of the US economy in the longer run depends critically on the performance of a relatively small number of sectors where innovation takes place.

By using our detailed industry data and adapting the methodology for projecting economic growth originated by Jorgenson, Ho, and Stiroh (2008), we consider the outlook for future US economic growth. We utilize historical data on the sources of US economic growth at the industry level and aggregate over industries to compare the results with projections by Byrne, Oliner and Sichel (2013) and others summarized by them. Our approach to constructing projections is similar in nature to the recent projections of economic growth for the US and the World Economy by Jorgenson and Vu (2013), but adds the industry dimension.

We project that potential US GDP growth will be 1.91 percent per year, considerably less than actual GDP growth during the period 1990-2010 of 2.31 percent per year. Almost all of the slowdown is due to much slower growth in the quality of the employed labor force due to rising levels of educational attainment and experience. During the period 1990-2010 labor quality grew at 0.465 percent per year, due to rising educational attainment and increasing experience. We project that educational attainment will stabilize. Most of the baby boomers have now retired, so that experience is declining. Labor quality growth will fall to only 0.06 percent 2010-2020.

Our projections also incorporate the future contributions of total factor productivity for IT-producing, IT-using, and Non-IT sectors. These will be similar to the average contributions for

1990-2010. We also project that the growth of capital quality due to the substitution of capital services from IT equipment and software for Non-IT capital services will be comparable to 1990-2010. Projected growth of average labor productivity (ALP) is 1.33 percent per year for 2010-2020, compared to 1.80 percent for 1990-2010. The final section of the paper presents our major conclusions.

New Architecture

Jorgenson and Steven Landefeld (2006) have developed a new architecture for the NIPAs that includes prices and quantities of capital services for all productive assets in the US economy. The incorporation of the price and quantity of capital services into the United Nations' *System of National Accounts 2008* (SNA,*2009*) was approved by the United Nations (UN) Statistical Commission at its February-March 2007 meeting. The Statistical Commission reversed the position of the UN *System of National Accounts 1993* (1993), which stated unequivocally that it was impossible to decompose income from capital (called net operating surplus) into price and quantity components.[5]

Schreyer, then head of national accounts at the OECD, prepared an OECD Manual, *Measuring Capital*, published in 2009. This provides detailed recommendations on methods for the construction of prices and quantities of capital services. In Chapter 20 of *SNA 2008* (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."

[5] United Nations, *System of National Accounts 1993*, p. 403.

The measures of capital and labor inputs in the prototype system of US national accounts presented by Jorgenson and Landefeld (2006) are consistent with the *OECD Productivity Manual*, *SNA 2008*, and the OECD Manual, *Measuring Capital*. The volume measure of input is a quantity index of capital and labor services, while the volume measure of output is a quantity index of investment and consumption goods. Productivity is the ratio of output to input.

The new architecture for the US national accounts was endorsed by the Advisory Committee on Measuring Innovation in the 21st Century Economy to the US Secretary of Commerce[6]:

> The proposed new 'architecture' for the NIPAs would consist of a set of income statements, balance sheets, flow of funds statements, and productivity estimates for the entire economy and by sector that are more accurate and internally consistent. The new architecture will make the NIPAs much more relevant to today's technology-driven and globalizing economy and will facilitate the publication of much more detailed and reliable estimates of innovation's contribution to productivity growth.

In response to the Advisory Committee's recommendations, BEA and BLS have produced an initial set of multifactor productivity estimates integrated with the NIPAs. Data on capital and labor inputs are provided by BLS. The results are reported by Michael Harper, Brent Moulton, Steven Rosenthal, and David Wasshausen (2009).[7] This is a critical step in implementing the new architecture. Estimates of productivity are essential for projecting the potential growth of the US economy, as demonstrated by Jorgenson, Ho, and Stiroh (2008). The omission of productivity

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[6] The Advisory Committee was established on December 6, 2007, with ten members from the business community, including Carl Schramm, President and CEO of the Kauffman Foundation and chair of the Committee. The Committee also had five academic members, including Jorgenson. The Advisory Committee met on February 22 and September 12, 2007, to discuss its recommendations. The final report was released on January 18, 2008.

[7] The most recent data set is available at: http://www.bea.gov/national/integrated_prod.htm

statistics from the NIPAs and the 1993 SNA has been a serious barrier to assessing potential growth.

Measuring Productivity at the Industry Level.

Reflecting the international consensus on productivity measurement at the industry level, the Advisory Committee on Measuring Innovation in the 21st Century Economy to the US Secretary of Commerce (2008, page 7) recommended that the Bureau of Economic Analysis (BEA) should:

> Develop annual, industry-level measures of total factor productivity by restructuring the NIPAs to create a more complete and consistent set of accounts integrated with data from other statistical agencies to allow for the consistent estimation of the contribution of innovation to economic growth.

The principles for constructing industry-level production accounts are discussed by Fraumeni, Harper, Susan Powers, and Robert Yuskavage (2006). Disaggregating the production account by industrial sector requires the fully integrated system of input-output accounts and accounts for gross product originating by industry. This is described by Ann Lawson, Brian Moyer, Sumiye Okubo and Mark Planting (2006), and Moyer, Marshall Reinsdorf, and Yuskavage (2006).

Moyer (2012) has described plans to integrate BEA's industry data with the NIPAs, beginning with the benchmark revision that will be published in July 2013. The NIPAs and the 2007 benchmark input-output table will be prepared within the same framework. The annual input-output data will be revised periodically along with the NIPAs and, for the first time, will form a continuous time series.

BEA's annual input-output data are employed in the industry-level production accounts presented by Susan Fleck, Rosenthal, Matthew Russell, Strassner, and Lisa Usher (2013) in their paper, "A Prototype BEA/BLS Industry-Level Production Account for the United States." This covers the period 1998-2010 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.[8] Labor quality estimates are based on a slightly earlier version of our data set.

The EU (European Union)-KLEMS (capital, labor, energy, materials, and services) study, described by Marcel Timmer, Robert Inklaar, Mary O'Mahony and Bart van Ark (2010), was completed on June 30, 2008. This landmark study presents productivity measurements for 25 of the 27 EU members. The study also included data for Australia, Canada, Japan, and Korea, and the US, based on the methodology of Jorgenson, Ho, and Stiroh (2005).[9]

Industry-level production accounts are now prepared on a regular basis by national statistical agencies in Australia, Canada, Denmark, Finland, Italy, The Netherlands, and Sweden, as well as the United States. Augmented by production accounts from the EU-KLEMS project, these accounts can be used in international comparisons of patterns of structural change like those presented by Jorgenson and Timmer (2011). The World-KLEMS Initiative will make it possible to extend these comparisons to forty countries around the world, including important developing and transition economies.[10]

Regional organizations in Asia and Latin America have joined the European Union in supporting research on KLEMS data sets. Due to the growing recognition of the importance of KLEMS data, an effort is underway to extend the KLEMS framework to emerging and transition

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[8] For current data, see: http://www.bea.gov/. BEA's data on output and intermediated inputs for 1998-2010 are included in our prototype industry-level production account for 1947-2010.

[9] Current data for the participating countries are available at the EU KLEMS website: http://www.euklems.net.

[10] See Jorgenson (2012), "The World KLEMS Initiative," *International Productivity Monitor,* Fall, pp. 5-19.

economies. These include Argentina, Brazil, Chile, China, India, Indonesia, Mexico, Russia, Turkey, and Taiwan. Brazil, Russia, India, and China have been widely recognized as future leaders in the growth of the world economy.

The Latin American Chapter of the World-KLEMS Initiative, LA KLEMS, was established in December 2009 at a conference at ECLAC, the Economic Commission for Latin America and the Caribbean, in Santiago, Chile. This Chapter is coordinated by ECLAC and includes seven research organizations in four leading Latin American countries – Argentina, Brazil, Chile, and Mexico.[11] Mario Cimoli, Andre Hofman, and Nanno Mulder (2010) summarize the results of the initial phase of the LA-KLEMS project.

The Asian Chapter of the World-KLEMS Initiative, Asia KLEMS, was founded in December 2010 and the first Asia-KLEMS Conference was held at the Asian Development Bank Institute in Tokyo in July 2011. The Asia-KLEMS Committee includes representatives of major Asian countries, including China, India, Japan, South Korea, and Singapore.[12] The second Asia-KLEMS Conference will be held at the Bank of Korea in Seoul in August 2013.

International comparisons of patterns of output, inputs, and productivity are very challenging, but have become crucial to growth strategies in an increasingly globalized world economy. Research on international supply chains has established the need for integration of KLEMS data sets with information on trade. The World Input-Output Database (WIOD) augments industry-level data sets for the forty countries of the World-KLEMS Initiative with data on international trade among these countries. This project has produced a database that includes

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[11] Additional information about LA KLEMS is available on the project website: http://www.cepal.org/cgi-bin/getprod.asp?xml=/la-klems/noticias/paginas/4/40294/P40294.xml&xsl=/la-klems/tpl-i/p18f-st.xsl&base=/la-klems/tpl-i/top-bottom.xsl An overview of LA-KLEMS is presented by Hofman (2012).

[12] Additional information about Asia KLEMS is available on the project website: http://asiaklems.net/1_1.html An overview of Asia KLEMS is presented by Hak K. Pyo (2012). Updated data for Australia, Canada, Japan, Korea, and the U.S. – the original participants in the EU-KLEMS study from outside the European Union –are posted on the World KLEMS website: http://www.worldklems.net/ As data become available from the Asia-KLEMS and LA-KLEMS projects, these data will also be posted on the World-KLEMS website. More details are given by Timmer (2012).

industry-level patterns of production and trade for all of the participating countries. The World Input-Output Database is a key resource for empirical research on international trade and the process of globalization.[13]

A Prototype Industry-Level Production Account for the United States, 1947-2010.

Incorporation of data on labor and capital inputs in constant prices into the national accounts is described in Chapters 19 and 20 of the *2008 System of National Accounts,* published in 2009. Jorgenson and Schreyer (2013) have shown how to integrate a complete system of production accounts at the industry level, like that provided by KLEMS data sets, into the *2008 System of National Accounts.* To illustrate the application of these data sets they present a summary of the prototype production account for the United States for 1947-2010, described in more detail below.

In December 2011 the Bureau of Economic Analysis (BEA) released a new industry-level data set. This integrates 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 annual input-output tables and gross domestic product data by industry form consistent time series. The input-output tables provide data on the output side of the national accounts along with intermediate inputs in current and constant prices.

Planting, formerly head of the input-output accounts at BEA, has developed a time series of input-output tables in current prices covering the period 1947-1997 on a NAICS basis. This incorporates all earlier benchmark input-output tables for the US, including the first benchmark table for 1947. BEA has linked these input-output tables to the official tables for 1998-2010.

[13] Information about WIOD is available on the project website: http://www.wiod.org/participants/index.htm The relationship of WIOD and World KLEMS is discussed by Timmer (2012).

We have constructed input-output tables in constant prices for 1947-2010, based on Jorgenson, Gollop, and Fraumeni for 1948-1979, Jorgenson, Ho, and Stiroh for 1977-2000, and Jorgenson, Ho, and Samuels (2012) for 1960-2007.[14] We have revised, extended, and updated data on capital and labor inputs in constant prices from the same sources to obtain an industry-level production account for the United States, covering the period 1947-2010 in current and constant prices. This KLEMS data set is consistent with BEA's annual input-output tables for 1998-2010.

The NAICS industry classification includes the industries identified by Jorgenson, Ho, and Samuels (2012) as IT-producing industries, namely, computers and electronic products and 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 US industries that do not produce IT equipment, software and services.

Value added in the IT-producing industries is only about three percent of the US economy, in the IT-using industries about 62 percent, and the Non-IT industries the remainder. 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.

The contribution of each industry to value added is the growth rate of value added for the industry, weighted by its share in value added for the economy as a whole. Prices of computers and electronic products have declined rapidly, relative to the GDP deflator, since the commercialization of the electronic computer in 1959. This trend accelerated with the switch from vacuum tubes to

[14] Our data are posted on the World KLEMS website: http://www.worldklems.net/data/index.htm

semiconductors around 1970. The two IT-services sectors have had declining prices, relative to the GDP deflator, since around 2000.

Figure 1 reveals a steady increase in the share of IT-producing industries in 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 2 decomposes the growth of value added for the period 1995-2010. 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 has also declined sharply and became negative during the Great Recession.

Figure 3 gives the contributions to value added for the 65 individual industries over the period 1947-2010. Real estate, wholesale and retail trade, and computer and electronic products are the leading contributors, followed by state and local governments, broadcasting and telecommunications, miscellaneous professional, scientific, and technical services, and Federal Reserve banks, credit intermediation, and related activities. The contributions of oil and gas extraction, other mining, transit and ground passenger transportation, primary metals, rail transportation, and federal general government are negative but small in magnitude.

In order to assess the relative importance of productivity growth at the industry level as a source of US economic growth, we utilize the production possibility frontier of Jorgenson (1966). This gives the relationship between aggregate productivity growth and productivity growth at the industry level. The growth rate of aggregate productivity includes a weighted average of industry productivity growth rates, using the ingenious weighting scheme originated by Domar (1961).

In the Domar weighting scheme the productivity growth rate of each industry is weighted by the ratio of the industry's gross output to aggregate value added. A distinctive feature of Domar

weights is that they sum to more than one, reflecting the fact that an increase in the rate of growth of the industry's productivity has two effects. The first is a direct effect on the industry's output and the second 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 Domar-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 growth rates of the inputs. Under this assumption aggregate capital and labor inputs grow more rapidly than the Domar-weighted averages of industry capital and labor input growth rates, so that the reallocations are positive. When industries with lower prices for inputs grow more rapidly, the reallocations are negative.

Figure 4 shows that the contributions of IT-producing, IT-using, and Non-IT industries to aggregate productivity growth are similar in magnitude for the period 1947-2010. 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 this Postwar Recovery, but became the predominant source of growth during the Big Slump, 1973-1995, and increased considerably during the period of Growth and Recession of 1995-2010. The IT-using industries contributed substantially to US economic growth during the postwar recovery, but disappeared during the Big Slump, 1973-1995, before reviving after 1995.

The reallocation of capital input made a small but positive contribution to growth of the US economy for the period 1947-2010, while the contribution of reallocation of labor input was negligible. Both reallocations were positive during the Postwar Recovery. Reallocation of capital

input contributed positively to US productivity growth during the Big Slump, while reallocation of labor contributed negatively during this period. Both were negative but very small in magnitude during the period of Growth and Recession.

Considering the period 1995-2010 in more detail in Figure 5, 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, 2000-2005, and 2005-2010 – despite the strong 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 first two sub-periods, but become negative and small in magnitude 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. The contributions of reallocations of capital and labor inputs were very small and negative during the period as a whole and fluctuated from negative in 1995-2000 to positive in 2000-2005. Figure 6 gives the contributions of each of the 65 industries to productivity growth for the period as a whole. The computer and electronic products industry was the leading contributor to US economic growth during this period, but important contributions were also made by real estate, wholesale and retail trade, and farms

Negative contributions to aggregate productivity for the period 1947-2010 as a whole were made by 29 of the 65 industries. The 29 industries include non-market services, such as health, education, and general government, as well as resource industries, such as oil and gas extraction and mining, except for oil and gas, 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 increased regulation, as in the cases of utilities and primary metals, which have been strongly affected by more stringent environmental regulation.

Sources of US Economic Growth

The prices of capital inputs are essential for assessing the contribution of investment in IT equipment and software to economic growth. This contribution is the share of IT equipment and software in the value of output, multiplied by the rate of growth of IT capital input. A substantial part of the growing contribution of capital input in the US can be traced to the change in composition of investment associated with the growing importance of IT equipment and software. The most distinctive features of IT assets are the rapid declines in prices of these assets, as well as relatively high rates of depreciation.

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 capital for the price of IT capital input is very large relative to the cost of capital for the price of Non-IT capital input.

The contributions of college-educated and non-college-educated workers to US economic growth is given by the relative shares of these workers in the value of output, multiplied by the growth rates of their hours worked. Personnel 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.

Productivity growth is the key economic indicator of *innovation*. Although Solow (1957) and Kuznets (1971) have attributed most of US economic growth to growth in productivity, Figure 7 shows that the productivity growth was far less important than the contributions of capital and labor inputs. For the period 1947-2010 productivity accounts for about twenty percent of US economic growth. The contribution of capital input accounts for the largest share of growth for the period as a whole, while the contribution of labor input accounts for the rest.

The great preponderance of US economic growth is due to replication of established technologies rather than innovation. Innovation is obviously far more challenging and subject to much greater risk. The diffusion of successful innovation requires mammoth financial commitments. These fund the investments that replace outdated products and processes and establish new organization structures, systems, and business models. Although innovation accounts for a relatively modest portion of economic growth, we re-emphasize that this portion is vital for maintaining gains in the US standard of living in the long run.

The contribution of capital input exceeded that of innovation, while the contribution of labor input was similar to that of innovation during the Postwar Recovery, 1947-1973. The standard explanation for the relative importance of innovation during this period is the backlog of new civilian technologies available at the end of the World War II. During the Big Slump of 1973-1995, growth of inputs remained about the same. The “slump” was due to the sharp slowdown in productivity growth.

The contribution of labor input increased in importance during the Big Slump, relative to the contribution of capital input. The contributions of college-educated workers and investment in information technology grew substantially, while the contributions of non-college workers and non-information technology declined considerably. After 1995 the rate of US growth continued to

decline and the contribution of non-college workers almost disappeared. Productivity growth revived, but failed to attain the high growth rate of the Postwar Recovery. Investment in IT became the predominant source of the contribution of capital input.

Figure 8 reveals that all of the sources of economic growth contributed to the US growth resurgence after 1995, relative to the Big Slump. Jorgenson, Ho, and Stiroh (2005) have analyzed the sources of the US growth resurgence in greater detail. After the dot-com crash in 2000 the overall growth rate of the US economy dropped to well below the long-term average of 1947-2010. The contribution of investment also declined below the long-term average, but the shift from Non-IT to IT capital input continued. Jorgenson, Ho, and Stiroh (2008) have shown that the rapid pace of US economic growth after 1995 was not sustainable.

The contribution of labor input dropped precipitously during the period of Growth and Recession, accounting for most of the decline in the rate of US economic growth during the Jobless Recovery. The contribution to growth by college-educated workers continued at a reduced rate, but that of non-college workers was negative. The most remarkable feature of the Jobless Recovery was the continued growth in productivity, indicating a continuing surge of innovation.

Both IT and Non-IT investment continued to contribute substantially to US economic growth during the Great Recession period after 2005. Productivity growth became negative, 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.

Combining the results presented in Figures 2, 5, and 8, we arrive at an interpretation of the sources of the substantial growth deceleration during the Great Recession. A substantial part of the

explanation is in the collapse of aggregate productivity growth. However, this was distributed very differently than during the Big Slump, when the Non-IT industries accounted for almost all of the slowdown in aggregate productivity growth.

During the Great Recession period 2005-2010, aggregate productivity growth became modestly negative. Only a minor portion of the drop in the growth rate was due to the IT-producing industries. Sharp declines took place in the contributions of IT-using industries and Non-IT industries. On balance, the negative contribution of productivity to US economic growth reflected the rising gap between actual and potential output during the Great Recession, especially during the recession period 2007-2009.

Continuing with our interpretation of the sources of the Great Recession, Figure 8 reveals a modest slowdown in investment in IT equipment and software and Non-IT capital. However, the contribution of college-educated workers actually increased, while the decline in the contribution of non-college workers accelerated substantially. The important contributors to the sharp slowdown in US economic growth during the Great Recession also included the decline in the contribution of productivity growth in the IT-using industries from large and positive to slightly negative and a total collapse in the contribution of productivity growth in the Non-IT industries.

Our overall conclusion is that the decline in the relative contribution of the Non-IT industries to aggregate growth continued a trend that has been evident throughout the Information Age of 1947-2010. The contribution of these industries became negative during the Great Recession, resulting in a sharp acceleration in Creative Destruction, a term employed by Joseph Schumpeter (1942) to capture the offsetting trends in rising and declining industries, especially during deep recessions.[15]

[15] Schumpeter's approach has been revived and greatly extended by Philippe Aghion and Peter Howitt (1998).

The interpretation of the Great Recession as Accelerated Creative Destruction is rounded out by the collapse of productivity growth in the Non-IT industries and the negative and declining contributions of growth in labor input from non-college workers after the dot-com crash of 2000. The contribution of the IT-producing industries to aggregate productivity growth diminished only modestly. The revival of US economic growth will require falling unemployment, especially of college-educated workers, and the recovery of investment, especially in IT equipment and software, but also in Non-IT capital. We turn next to a more detailed look at prospects for future US economic growth.

Future US Economic Growth

Byrne, Oliner and Sichel (2013) have provided a recent survey of contributions to the debate over prospects for future US economic growth. Tyler Cowen (2011) presented a pessimistic outlook in his book, *The Great Stagnation*: *How America Ate All the Low-Hanging Fruit, Got Sick, and Will (Eventually) Feel Better*: His views were supported by Robert Gordon (2012, 2013), who analyzed six headwinds facing the US economy, including the end of productivity growth in IT-producing industries. Cowen (2013) has expressed a more optimistic view in his forthcoming book, *Average is Over: Powering America Beyond the Age of the Great Stagnation.*

Gordon's pessimism about the future of IT has been strongly countered by Erik Brynjolfsson and Andrew McAfee (2011) in *Race Against the Machine: How the Digital Revolution is Accelerating Innovation, Driving Productivity, and Irreversibility Transforming Employment and the Economy.*[16] Martin Baily, James Manyika, and Shalabh Gupta (2013) have

[16] 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/

summarized an extensive series of studies of technological prospects for American industries, including IT, conducted by the McKinsey Global Institute and summarized by Manyika, *et al.* (2011). This also counters Gordon's pessimism about future US productivity growth.

Byrne, Oliner and Sichel present detailed evidence on the recent behavior of IT prices from research done at the Federal Reserve Board to provide deflators for IT components of the Index of Industrial Production. This also fails to support Gordon's pessimism about the future of IT. Chad Syverson (2013) points out that a more detailed view of developments in semiconductor technology supports the view of Byrne, Oliner and Sichel that the size of transistors has continued to shrink. However, performance of semiconductors devices has improved much less rapidly, severing a close link that had characterized Moore's Law as a description of the development of semiconductor technology.[17] This view is supported by Unni Pillai (2011) and by the computer scientists John Hennessey and David Patterson (2012). [18]

John Fernald 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 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, except for the Congressional Budget Office.

Our prototype industry production account generates the data necessary to construct economic projections based on the growth accounting decomposition of Jorgenson, Ho, Stiroh

[17] Moore's Law is discussed by Jorgenson, Ho, and Stiroh (2005), ch. 1.
[18] 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

(2008); our projections for the period 2010-2020 are summarized in Figures 9, 10 and 11. The methodology is adapted to incorporate projections of total factor productivity growth for IT-producing, IT-using, and Non-IT industries. Like Jorgenson, Ho, and Stiroh, we present base case, pessimistic, and optimistic projections of future growth in potential GDP. Our base case projections are based on the average contributions of total factor productivity growth for the three sectors for the period 1995-2010. Our optimistic projections omit the Great Recession period of 2005-2010, while our pessimistic project includes the final five years of the Big Slump, 1990-1995. We compare our projections with actual growth for 1990-2010.

Our base case projection of growth in potential GDP is 1.91 percent per year, compared with actual growth for 1990-2010 of 2.33 percent. The difference is due mainly to the projected slowdown in the growth of labor quality. Actual labor quality growth is driven mainly by increases in average educational attainment. Rising educational attainment has been a major driver of US economic growth throughout the Information Age. However, educational attainment will reach a plateau early in our projection period 2010-2020. Reduced labor quality growth will fall from 0.465 percent per year during 1990-2010 to only 0.06 percent per year in 2010-2020.

Our optimistic projection for potential US GDP growth is 2.61 percent per year during 2010-2020 by comparison with actual growth of 2.33 percent per year in 1990-2010. The contributions of IT-using and Non-IT industries along with more rapid growth in capital quality are mainly responsible for the increase in potential growth relative to actual growth. Our pessimistic projection for potential growth is only 1.59 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.[19]

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

Conclusion

The new framework for productivity measurement employed in constructing KLEMS data sets reveals that replication of established technologies through 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 US economic growth. International productivity comparisons reveal similar patterns for the world economy, its major regions, and leading industrialized, developing, and emerging economies.[20] Studies are now underway to extend these comparisons to individual industries for the forty countries included in the World-KLEMS Initiative.

Conflicting interpretations of the Great Recession can be evaluated from the perspective of our new data set. We reject the technological pessimism of Cowen (2011) and Gordon (2012), especially for the IT-producing industries. Our findings directly contradict Gordon's hypothesis that the Information Age, which he calls the "third industrial revolution," ended during the early years of the 21st century. However, careful studies of developments of semiconductor and computer technology show that the accelerated pace of innovation that began in 1995 reverted to the substantial, but lower, rates of innovation in IT, already evident in the Big Slump that ended in 1995.

Our findings also contribute to an understanding of the future potential for US economic growth, now the subject of a vigorous debate. 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

[20] See Jorgenson and Vu (2013),

quality. The disappearance of productivity growth during the Great Recession is transitory, but productivity growth is very 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 stimulation 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 for college-educated workers. These measures will contribute to closing the substantial gap between potential and actual output that still remains four years after the end of the recession.

References

Advisory Committee on Measuring Innovation in the 21st Century Economy. 2008. *Innovation Measurement: Tracking the State of Innovation in the American Economy*. Washington DC: U.S. Department of Commerce, January.

Aghion, Philippe, and Peter W. Howitt. 1998. *Endogenous Growth Theory*. Cambridge, MA: The MIT Press.

Baily, Martin, James Manyika, and Shalabh Gupta. 2013. U.S. Productivity Growth: An Optimistic Perspective. *International Productivity Monitor* 25: 3-12.

Brynjolfsson, Erik, and Andrew McAfee. 2011. *Race Against the Machine: How the Digital Revolution is Accelerating Innovation, Driving Productivity, and Irreversibility Transforming Employment and the Economy*. Lexington, MA: Digital Frontier Press.

Byrne, David, Steven Oliner, and Dan Sichel. 2013. Is the Information Technology Revolution

Over? *International Productivity Monitor* 25: 20-36.

Cimoli, Mario, Andre Hofman, and Nanno Mulder, eds. 2010. *Innovation and Economic Development.* Northampton, MA: Edward Elgar.

Cowen, Tyler. 2011. *The Great Stagnation: How America Ate All the Low-Hanging Fruit, Got Sick, and Will (Eventually) Feel Better*. New York: Penguin eSpecial.

Cowen, Tyler. 2013. *Average is Over: Powering America Beyond the Age of the Great Stagnation,* forthcoming.

Domar, Evsey. 1961. On the Measurement of Technological Change. *Economic Journal* 71(284): 709-729.

Fernald, John. 2012. Productivity and Potential Output before, during, and after the Great Recession. San Francisco: Federal Reserve Bank of San Francisco, September.

Fleck, Susan, Steven Rosenthal, Matthew Russell, Erich Strassner, and Lisa Usher. 2013. A Prototype BEA/BLS Industry-Level Production Account for the United States. In Dale W. Jorgenson, J. Steven Landefeld, and Paul Schreyer, eds., *Measuring Economic Stability and Progress.* Chicago: University of Chicago Press: forthcoming.

Fraumeni, Barbara M., Michael J. Harper, Susan G. Powers, and Robert E. Yuskavage. 2006. An Integrated BEA/BLS Production Account: A First Step and Theoretical Considerations. In Dale W. Jorgenson, J. Steven Landefeld, and William D. Nordhaus, eds., *A New Architecture for the U.S. National Accounts*. Chicago: University of Chicago Press: 355-438.

Gordon, Robert. 2012. Is U.S. Economic Growth Over? Faltering Innovation and the Six Headwinds. Cambridge, MA, National Bureau of Economic Research, Working Paper No 18315, August.

Gordon, Robert. 2013. U.S. Productivity Growth: the U.S. Slowdown Has Returned after a Temporary Revival. *International Productivity Monitor*, Spring: 13-19.

Harper, Michael, Brent Moulton, Steven Rosenthal, and David Wasshausen. 2009. Integrated GDP-Productivity Accounts. *American Economic Review* 99(2): 74-79.

Hennessey, John L., and David A. Patterson. 2012. *Computer Organization and Design*, 4th ed. Waltham, MA: Morgan Kaufmann.

Hofman, Andre. 2012. Overview of LA-KLEMS. Presentation to the Second World KLEMS Conference, Harvard University, Cambridge, MA. See: http://www.economics.harvard.edu/faculty/jorgenson/WorldKLEMS

Jorgenson, Dale W. 1963. Capital Theory and Investment Behavior. *American Economic Review* 53(2): 247-259.

Jorgenson, Dale W. 1966. The Embodiment Hypothesis. *Journal of Political Economy* 74(1): 1-17

Jorgenson, Dale W., ed., 2009. *The Economics of Productivity*. Northampton, MA: Edward Elgar.

Jorgenson, Dale W. 2012. The World KLEMS Initiative. *International Productivity Monitor*, Fall: 5-19.

Jorgenson, Dale W., Frank M. Gollop, and Barbara M. Fraumeni. 1987. *Productivity and U.S. Economic Growth*. Cambridge MA: Harvard University Press.

Jorgenson, Dale W., Mun S. Ho, and Jon Samuels. 2012. Information Technology and U.S. Productivity Growth. In Matilde Mas and Robert Stehrer, eds., *Industrial Productivity in Europe*, Northampton, MA, Edward Elgar: 34-65.

Jorgenson, Dale W., Mun S. Ho, and Kevin J. Stiroh. 2005. *Information Technology and the American Growth Resurgence*. Cambridge, MA: The MIT Press.

Jorgenson, Dale W., Mun S. Ho, and Kevin J. Stiroh. 2008. A Retrospective Look at the U.S. Productivity Growth Resurgence. *Journal of Economic Perspectives* 22(1): 3-24.

Jorgenson, Dale W., and J. Steven Landefeld. 2006. Blueprint for an Expanded and Integrated U.S. National Accounts: Review, Assessment, and Next Steps. In Dale W. Jorgenson, J. Steven Landefeld, and William D. Nordhaus, eds., *A New Architecture for the U.S. National Accounts*. Chicago: University of Chicago Press: 13-112.

Jorgenson, Dale W., and Paul Schreyer. 2013. Industry-Level Productivity Measurement and the 2008 System of National Accounts. *Review of Income and Wealth* 58(4): 185-211.

Jorgenson, Dale W., and Marcel P. Timmer. 2011. Structural Change in Advanced Nations: A New Set of Stylized Facts. *Scandinavian Economic Journal* 113(1): 1-29.

Jorgenson, Dale W., and Khuong M. Vu. 2013. The Emergence of the New Economic Order: Economic Growth in the G7 and the G20. *Journal of Policy Modeling,* 35(2): 389-399.

Kuznets, Simon. 1971. *Economic Growth of Nations: Total Output and Production Structure*. Cambridge, MA: Harvard University Press.

Lawson, Ann, Brian Moyer, Sumiye Okubo and Mark A. Planting. 2006. Integrating Industry and National Economic Accounts: First Steps and Future Improvements. In Dale W. Jorgenson, J. Steven Landefeld, and William D. Nordhaus, eds., *A New Architecture for the U.S. National Accounts.* Chicago: University of Chicago Press: 215-262.

Manyika, James, David Hunt, Scott Nyquest, Jaana Remes, Vikrram Malhotra, Lenny Mendonca, Byron August, and Samantha Test. 2011. *Growth and Renewal in the United States,* Washington, DC, McKinsey Global Institute, February.

Markoff, John. 2004. Intel's Big Shift after Hitting Technical Wall. *New York Times* 153(52,888). See: http://www.nytimes.com/2004/05/17/business/technology-intel-s-big-shift-after-

hitting-technical-wall.html?pagewanted=print&src=pm

Mas, Matilde, and Robert Stehrer, eds. 2012. *Industrial Productivity in Europe.* Northampton, MA, Edward Elgar.

Mayerhauser, Nicole, and Erich Strassner. 2010. Preview of the Comprehensive Revision of the Annual Industry Accounts. *Survey of Current Business*, 90(3): 21-34.

Moyer, Brian. 2012. Integration of the U.S. Industry Accounts and the NIPAs. Presentation to the Second World KLEMS Conference, Harvard University, Cambridge, MA. See:http://www.economics.harvard.edu/faculty/jorgenson/WorldKLEMS

Moyer, Brian, Marshall B. Reinsdorf, and Robert E. Yuskavage. 2006. Aggregation Issues in Integrating and Accelerating the BEA's Accounts: Improved Methods for Calculating GDP by Industry. In Dale W. Jorgenson, J. Steven Landefeld, and William D. Nordhaus, eds., *A New Architecture for the U.S. National Accounts.* Chicago: University of Chicago Press: 263-308.

Pillai, Unni. 2011. Technological Progress in the Microprocessor Industry. *Survey of Current Business* 91(2): 13-16.

Pyo, Hak Kil. 2012. Overview of Asia KLEMS. Presentation to the Second World KLEMS Conference, Harvard University, Cambridge, MA. See: http://www.economics.harvard.edu/faculty/jorgenson/WorldKLEMS

Schreyer, Paul. 2001. *OECD Manual: Measuring Productivity: Measurement of Aggregate and Industry-Level Productivity Growth*. Paris: Organisation for Economic Development and Cooperation.

Schreyer, Paul. 2009. *OECD Manual: Measuring Capital*. Paris: Organisation for Economic Development and Cooperation.

Schreyer, Paul, 2012. From the OECD Productivity Handbook to World KLEMS. Presentation to the Second World KLEMS Conference, Harvard University, Cambridge, MA. See: http://www.economics.harvard.edu/faculty/jorgenson/WorldKLEMS

Schumpeter, Joseph A. 1942. *Capitalism, Socialism, and Democracy.* New York: Harper.

Solow, Robert M. 1957. Technical Change and the Aggregate Production Function. *Review of Economics and Statistics* 39(3):312-320.

Syverson, Chad. 2011. What Determines Productivity? *Journal of Economic Literature* 49(2): 325-365.

Syverson, Chad. 2013. Will History Repeat Itself? Comments on 'Is the Information Technology Revolution Over? *International Productivity Monitor* 25: 37-40.

Timmer, Marcel. 2012. World KLEMS Initiative: The Future. Presentation to the Second World KLEMS Conference, Harvard University, Cambridge, MA. See: http://www.economics.harvard.edu/faculty/jorgenson/WorldKLEMS

Timmer, Marcel, Robert Inklaar, Mary O'Mahony, and Bart van Ark. 2010. *Economic Growth in Europe: A Comparative Industry Perspective*, Cambridge, Cambridge University Press.

United Nations, Commission of the European Communities, International Monetary Fund, Organisation for Economic Co-operation and Development, and World Bank. 2009. *System of National Accounts 2008.* New York, United Nations. See: http://unstats.un.org/unsd/nationalaccount/sna2008.asp.

United Nations, Commission of the European Communities, International Monetary Fund, Organisation for Economic Co-operation and Development, and World Bank. 1993. *System of National Accounts 1993.* New York, United Nations.

Figure 1: Contributions of Industry Groups to Value Added Growth, 1947-2010

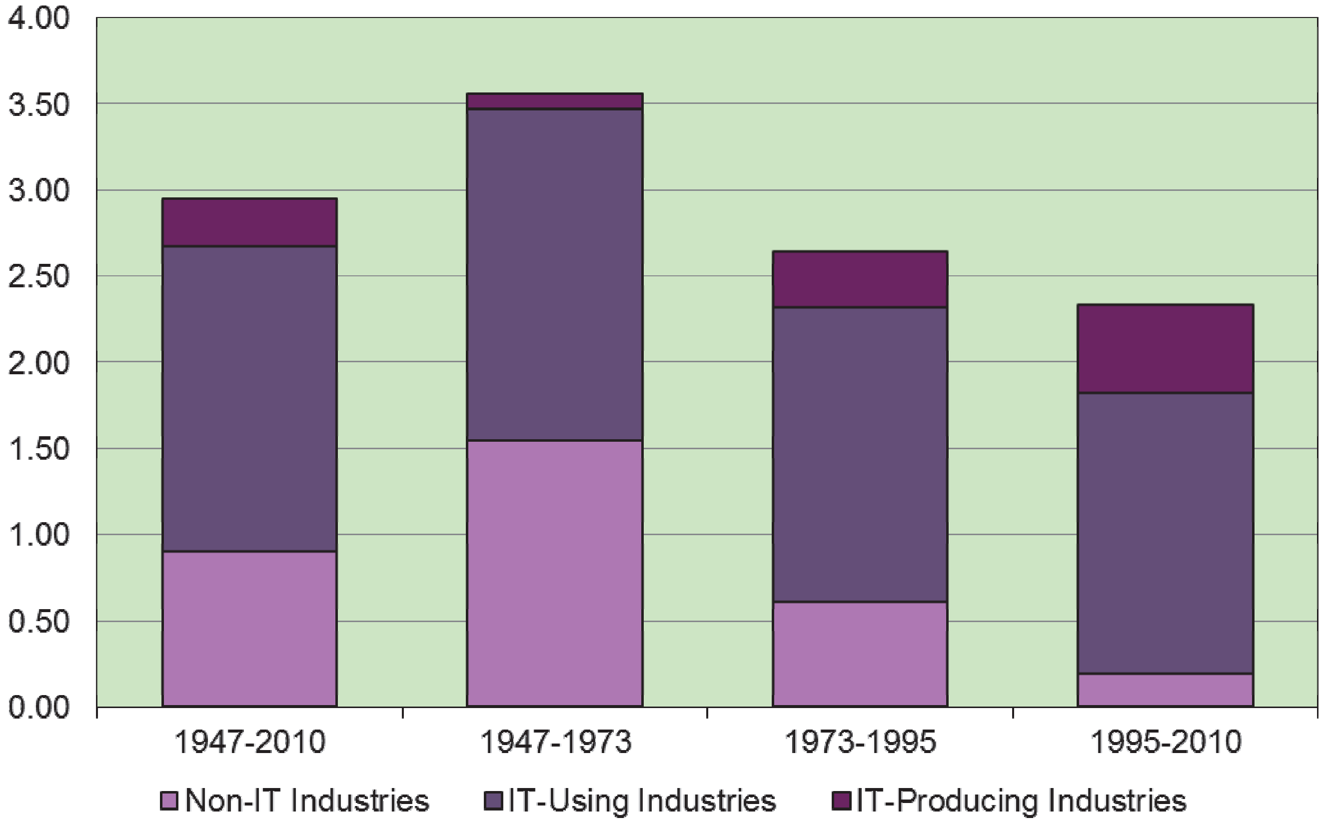


Figure 2: Contributions of Industry Groups to Value Added Growth, 1995-2010

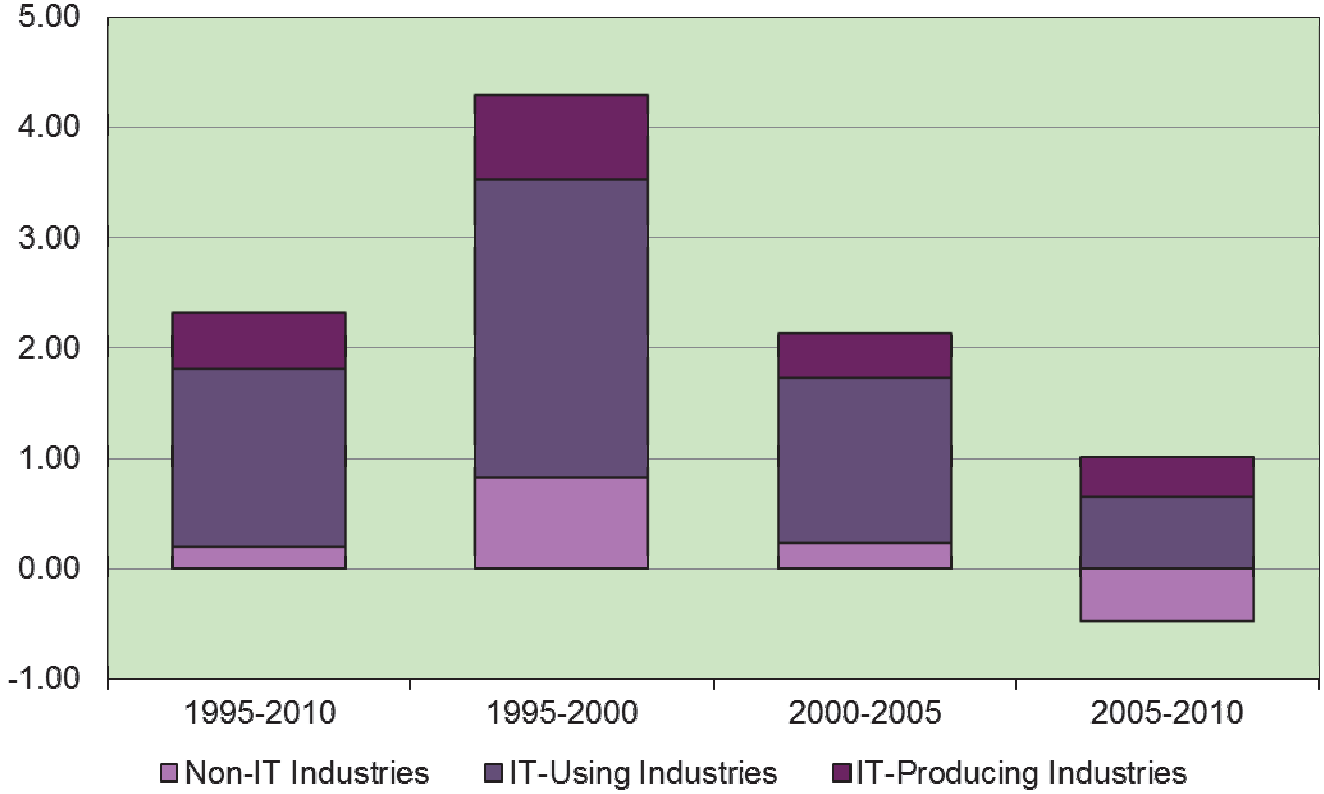


Figure 3: Contributions of Individual Industries to Value Added 1947-2010

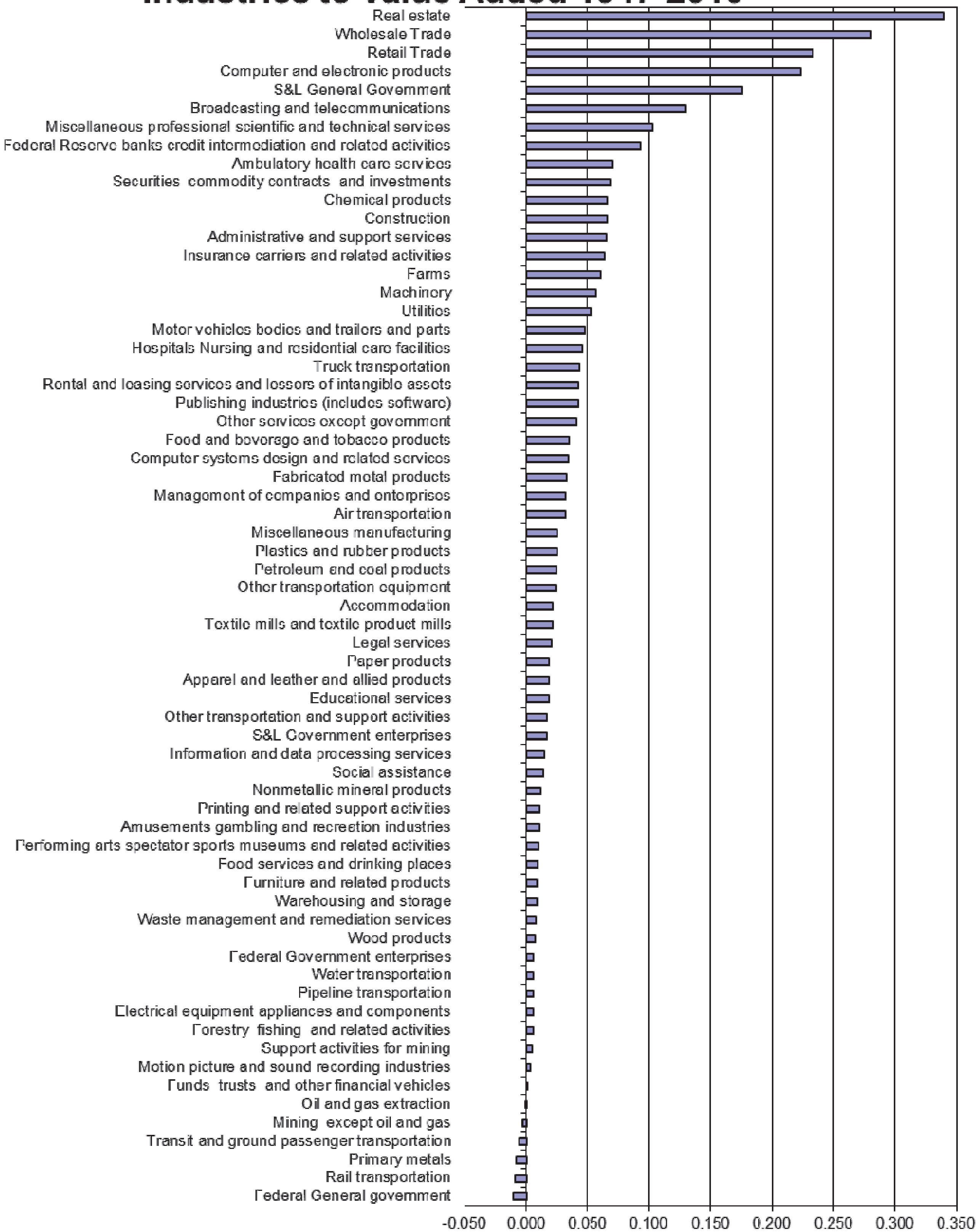


Figure 4: Contribution of Industry Groups to Productivity Growth, 1947-2010

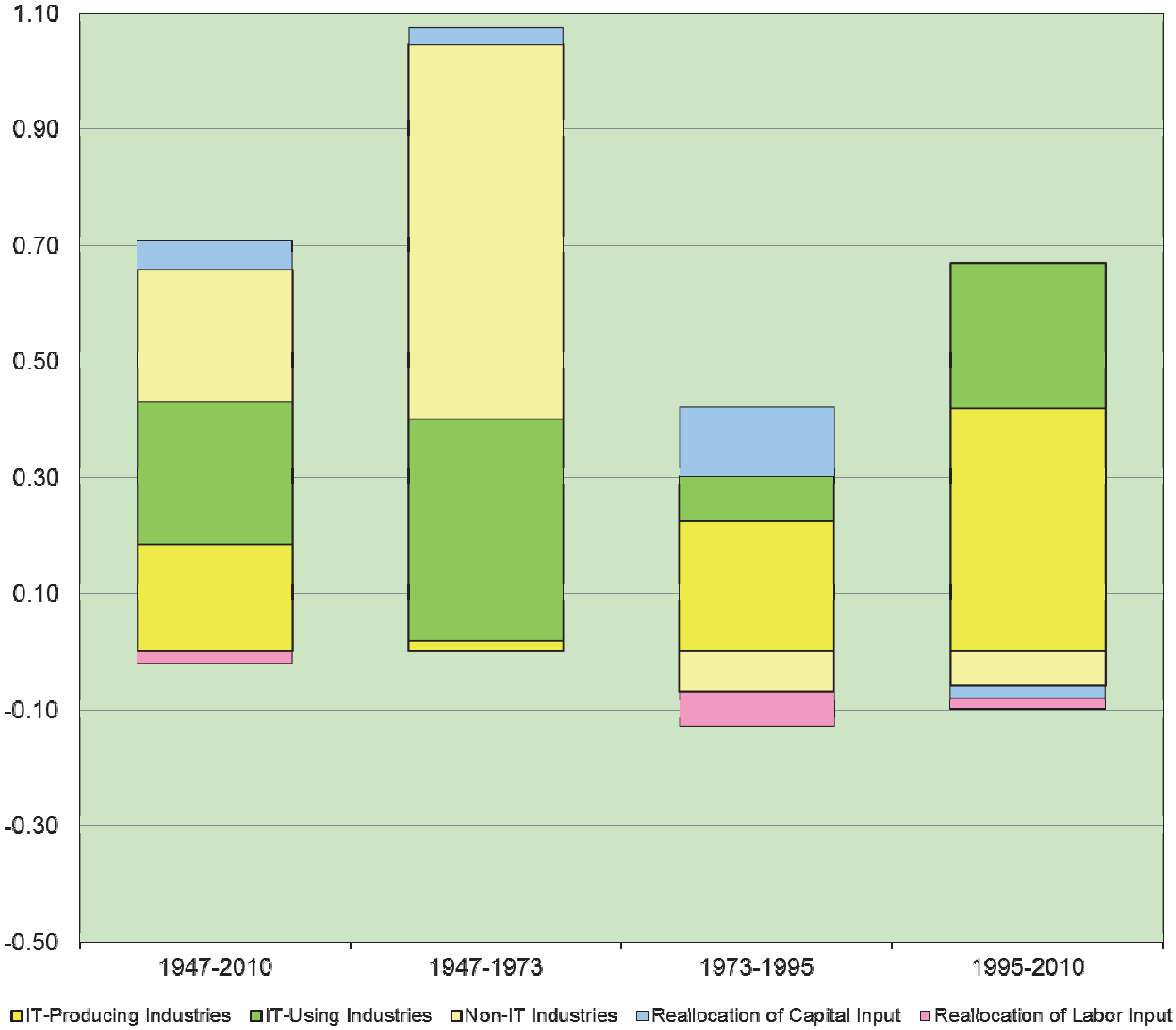


Figure 5: Contribution of Industry Groups to Productivity Growth, 1995-2010

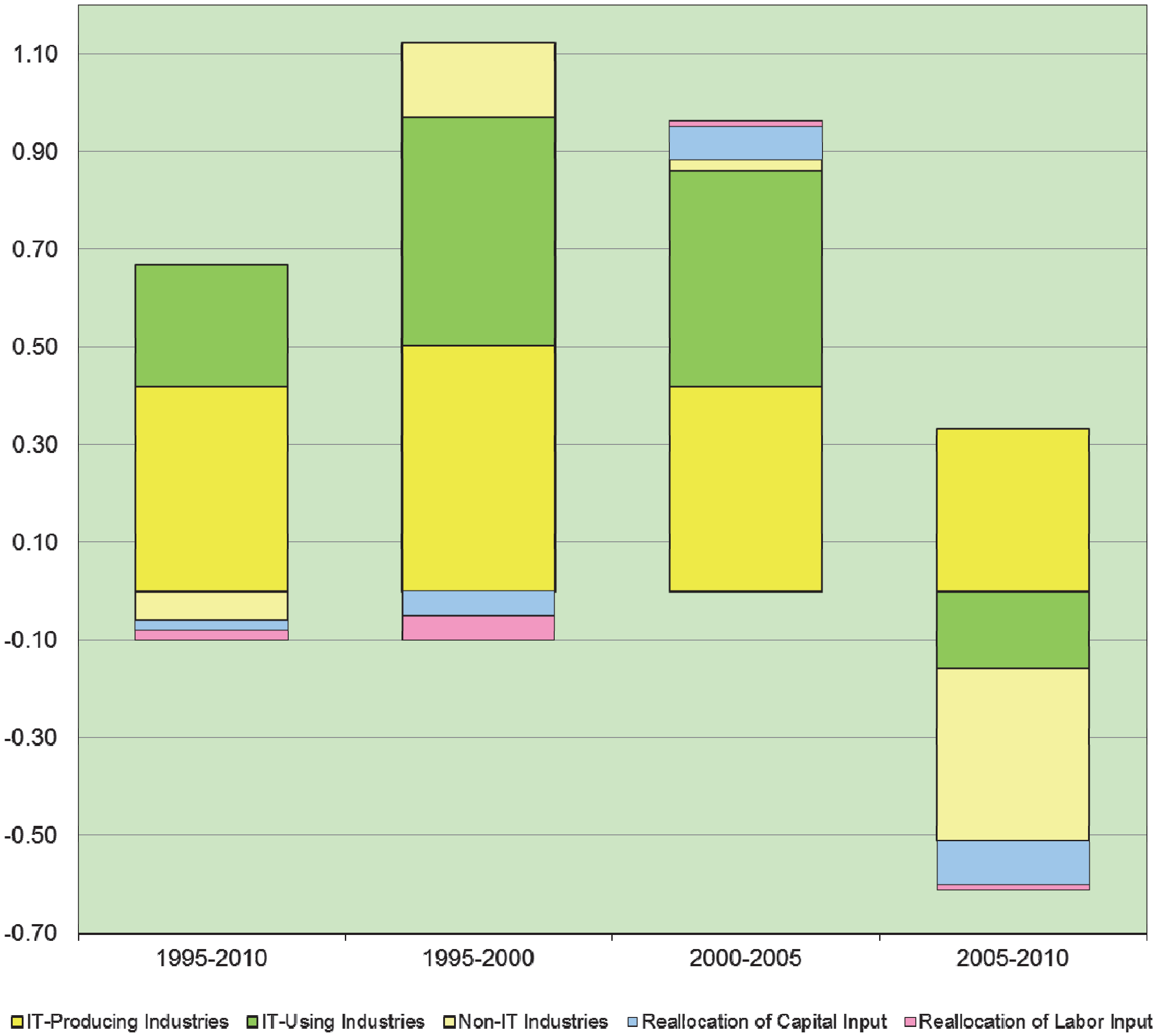


Figure 6: Contributions of Individual Industries to Productivity Growth, 1947-2010

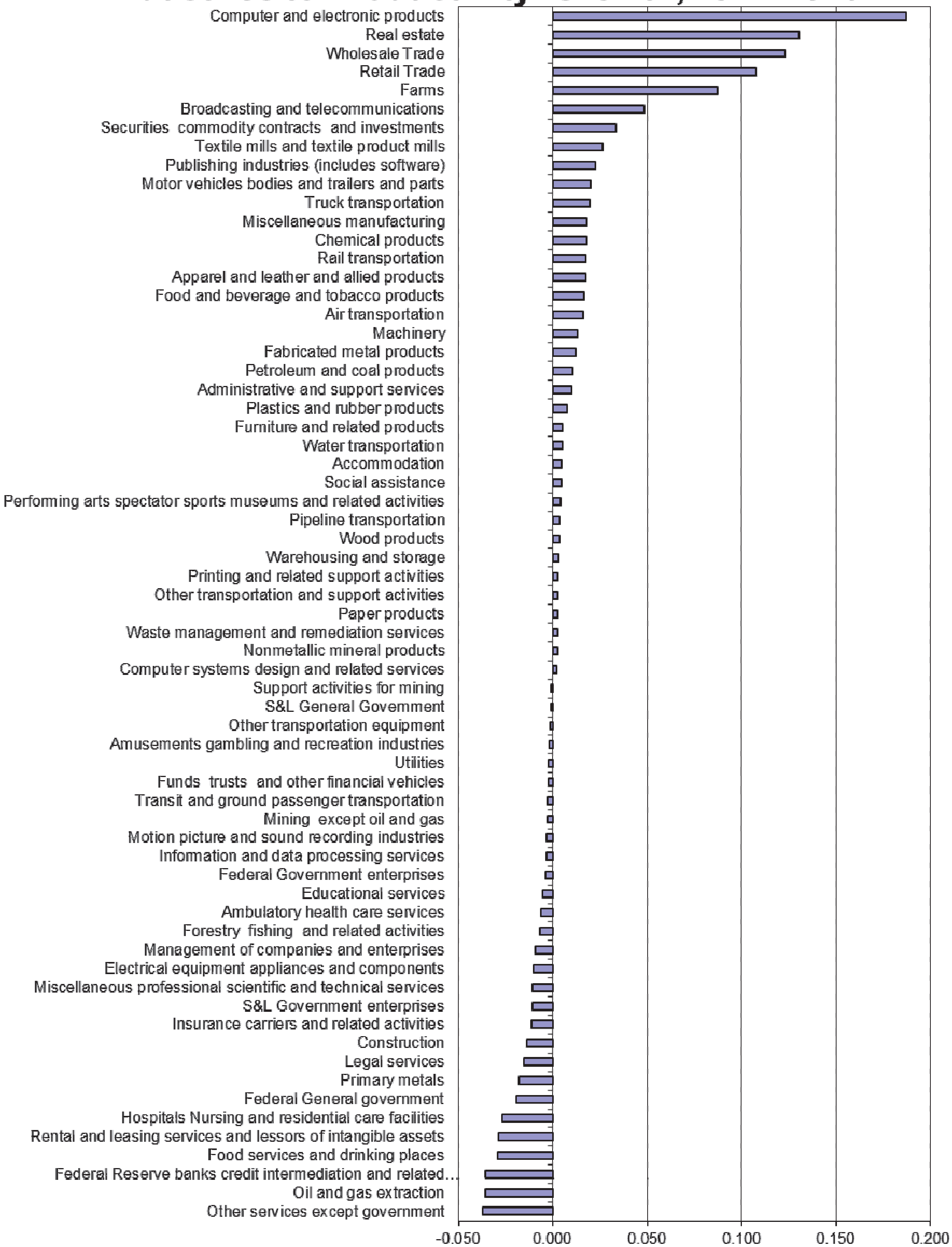
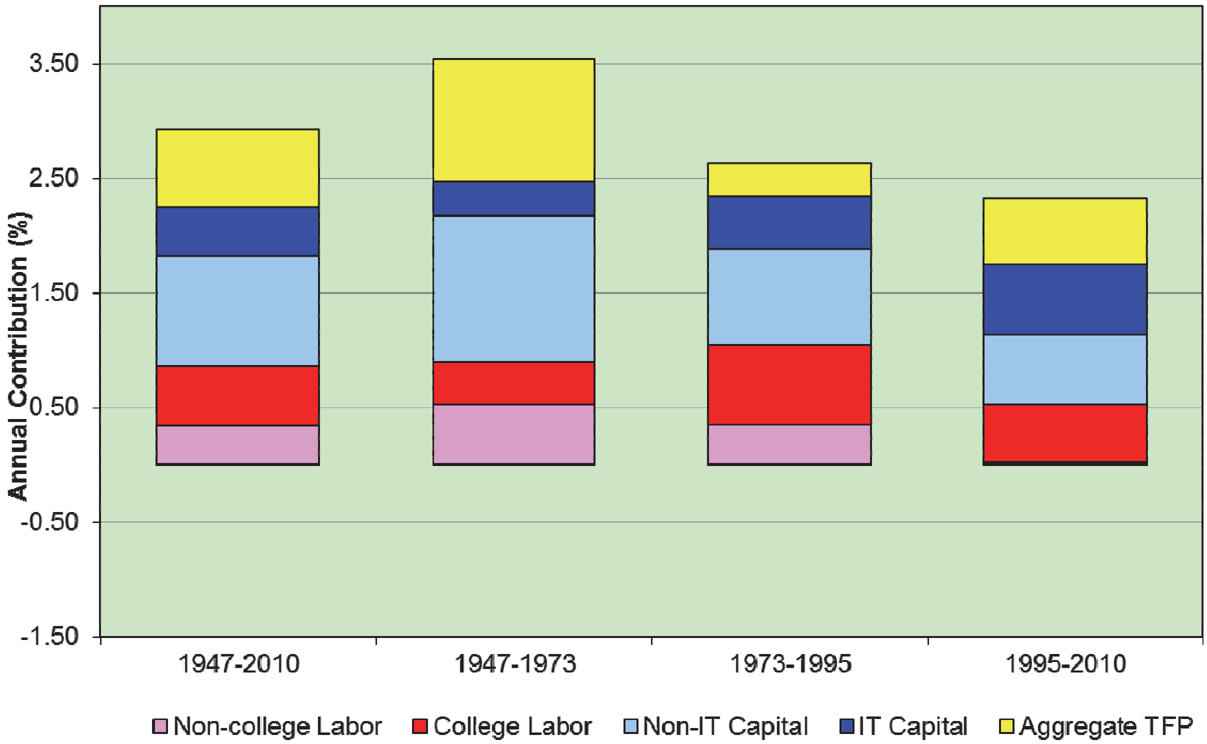


Figure 7: Sources of U.S. Economic Growth, 1947-2010



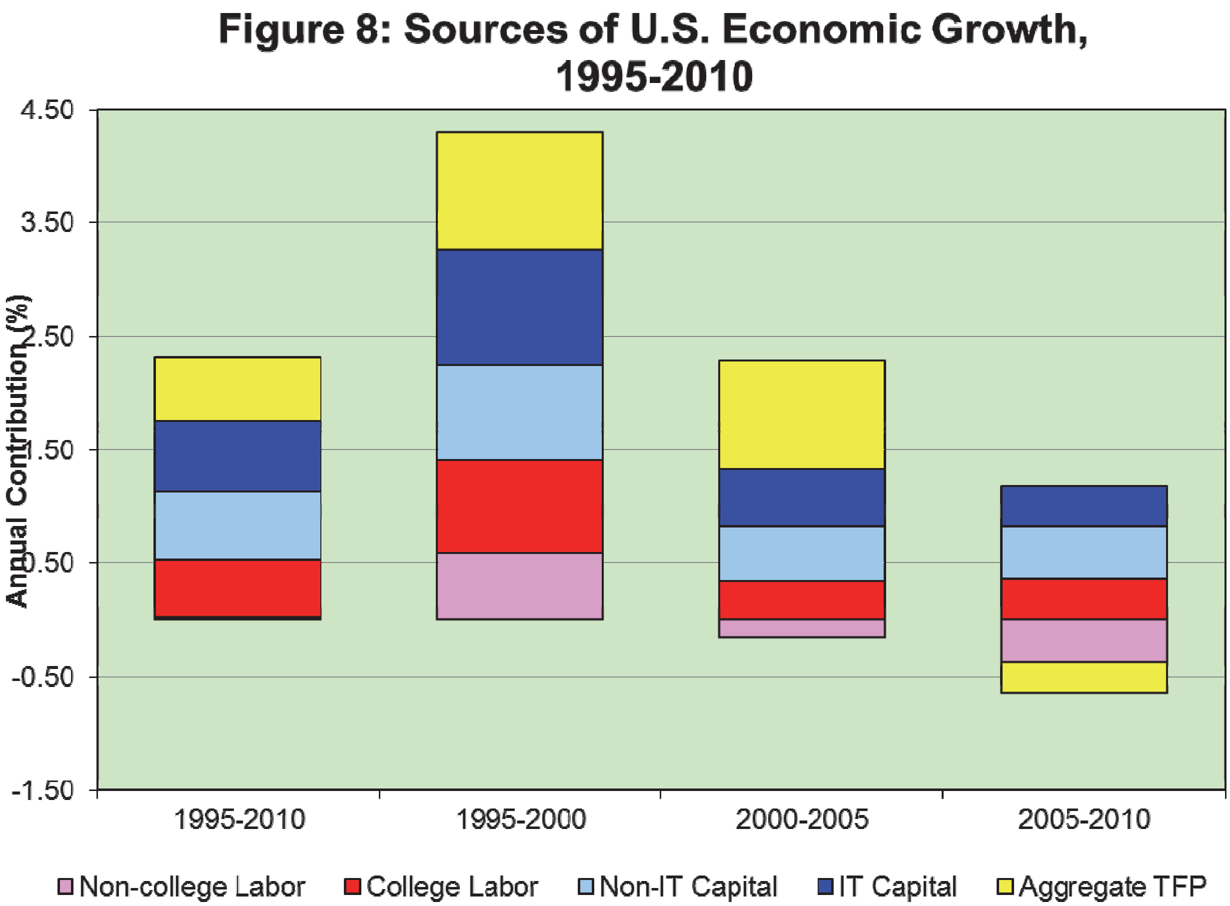


Figure 8: Sources of U.S. Economic Growth, 1995-2010
Annual Contribution (%)
4.50
3.50
2.50
1.50
0.50
-0.50
-1.50
1995-2010
1995-2000
2000-2005
2005-2010
Non-college Labor
College Labor
Non-IT Capital
IT Capital
Aggregate TFP

Figure 9. Contribution of Industry Groups to Productivity Growth, 2010-2020

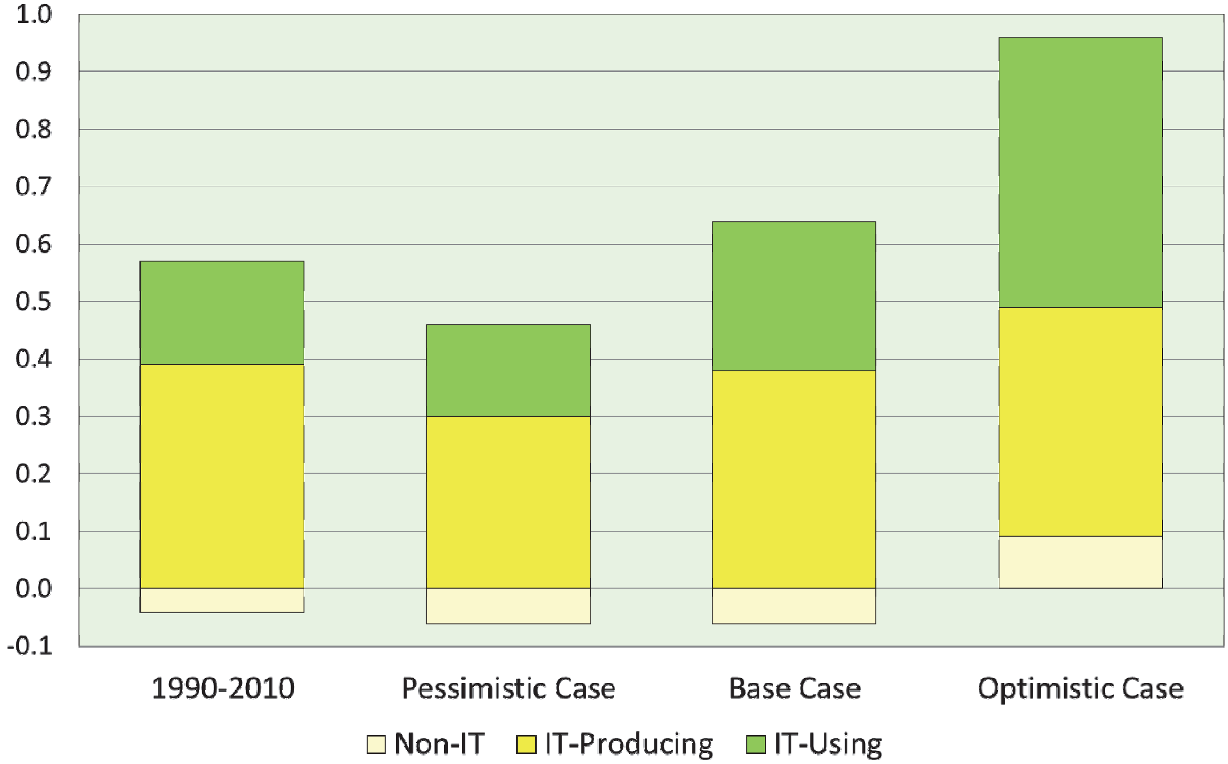


Figure 10. Range of Labor Productivity Projections, 2010-2020
Annual percentage growth rates

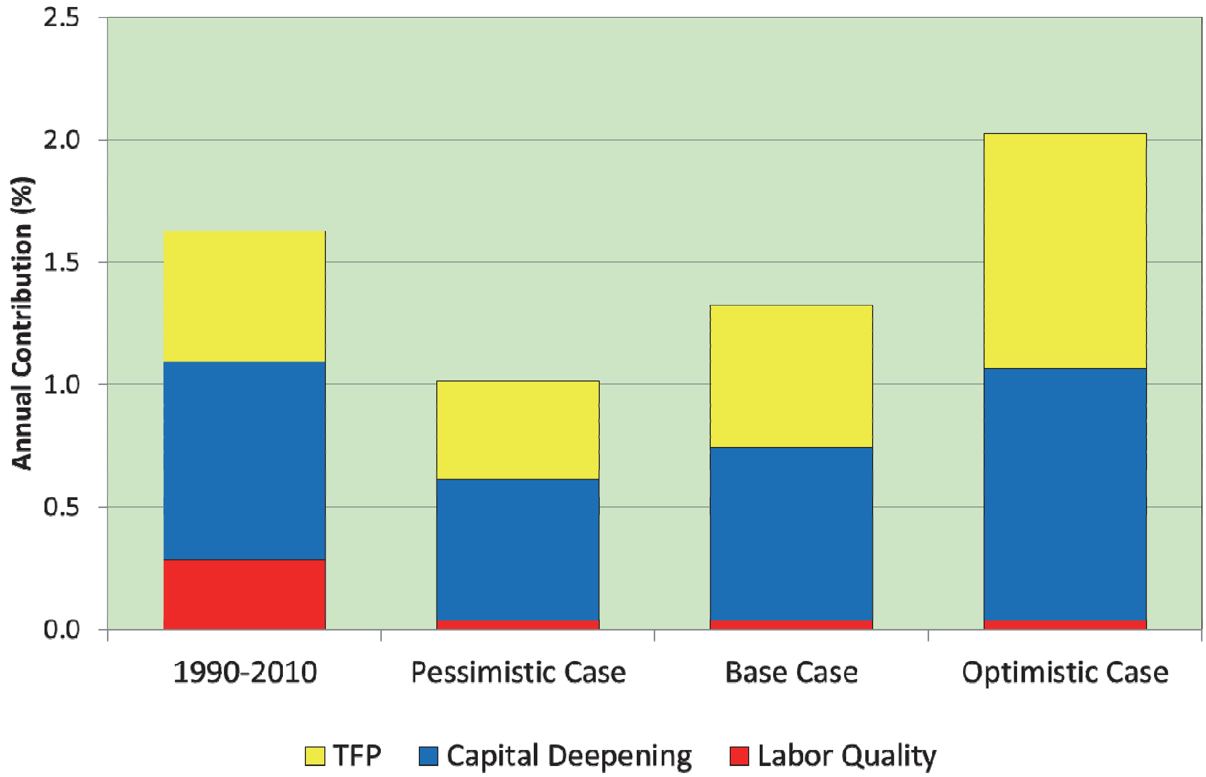


Figure 11. Range of U.S. Potential Output Projections, 2010-2020
Annual percentage growth rates

Appendix Table 1: Growth in Aggregate Value-Added and the Sources of Growth

Aggregate Production Possibility Frontier

	1947-2010	1947-1973	1973-1995	1995-2010	1995-2000	2000-2005	2005-2010
Contributions							
Value-Added	2.95	3.56	2.64	2.32	4.30	2.14	0.54
IT-Producing Industries	0.27	0.09	0.33	0.51	0.76	0.40	0.36
IT-Using Industries	1.77	1.92	1.71	1.62	2.71	1.50	0.65
Non-IT Industries	0.90	1.55	0.61	0.20	0.83	0.24	-0.47
Capital Input	1.39	1.57	1.30	1.22	1.86	0.98	0.82
IT Capital	0.43	0.29	0.46	0.62	1.03	0.49	0.35
Non-IT Capital	0.96	1.28	0.84	0.60	0.84	0.49	0.47
Labor Input	0.87	0.91	1.06	0.53	1.40	0.19	0.00
College Labor	0.52	0.37	0.70	0.51	0.82	0.35	0.37
Non-college Labor	0.34	0.52	0.35	0.02	0.58	-0.15	-0.37
Aggregate TFP	0.68	1.08	0.29	0.57	1.03	0.96	-0.27
Quality and Stock Contributions							
Contribution of Capital Quality	0.38	0.46	0.30	0.36	0.75	0.19	0.14
Contribution of Capital Stock	1.01	1.11	1.00	0.86	1.11	0.79	0.67
Contribution of Labor Quality	0.26	0.26	0.24	0.28	0.22	0.25	0.36
Contribution of Labor Hours	0.61	0.66	0.81	0.25	1.18	-0.06	-0.36

Notes: All figures are average annual percentages. The contribution of an output or input is the growth rate multiplied by the average value share. The IT-producing, IT-using, and non-IT industries are defined in Table 2.10. IT capital input includes computer hardware, computer software, and telecommunications equipment.

Appendix Table 2: Growth and Shares of Aggregate Variables
Aggregate Production Possibility Frontier

	1947-2010	1947-1973	1973-1995	1995-2010	1995-2000	2000-2005	2005-2010
Growth Rates							
Value-Added	2.95	3.56	2.64	2.32	4.30	2.14	0.54
IT-Producing Industries	10.76	5.05	13.83	16.14	24.28	13.34	10.80
IT-Using Industries	3.24	3.80	2.98	2.64	4.45	2.43	1.04
Non-IT Industries	2.00	3.21	1.57	0.54	2.31	0.68	-1.36
Capital Input	3.58	3.94	3.42	3.17	4.88	2.58	2.04
IT Capital	15.07	17.56	14.80	11.17	18.95	8.45	6.11
Non-IT Capital	2.64	3.33	2.40	1.81	2.56	1.52	1.35
Labor Input	1.44	1.55	1.71	0.87	2.27	0.32	0.02
College Labor	3.37	3.94	3.73	1.87	3.15	1.21	1.26
Non-college Labor	0.74	1.07	0.86	-0.01	1.62	-0.44	-1.21
Shares							
Value-Added	100.0	100.0	100.0	100	100.0	100.0	100.0
IT-Producing Industries	2.3	1.7	2.4	3.14	3.1	3.0	3.3
IT-Using Industries	55.4	50.1	57.4	61.66	60.9	61.8	62.3
Non-IT Industries	42.3	48.2	40.2	35.20	36.0	35.2	34.4
Capital Input	39.0	40.2	37.9	38.66	38.1	38.2	39.7
IT Capital	3.0	1.4	3.1	5.66	5.4	5.9	5.7
Non-IT Capital	36.0	38.7	34.8	33.00	32.8	32.3	34.0
Labor Input	61.0	59.8	62.1	61.34	61.9	61.8	60.3
College Labor	17.6	9.8	19.6	28.16	26.0	28.5	29.9
Non-college Labor	43.4	50.0	42.5	33.18	35.8	33.3	30.4

Notes: Growth rates are average annual percentages. Shares are the mean two-period average for each period in percentages.

Appendix Table 3: Decomposition of Aggregate Labor Productivity Aggregate Production Possibility Frontier							
	1947-2010	1947-1973	1973-1995	1995-2010	1995-2000	2000-2005	2005-2010
Contributions							
Average Labor Productivity	1.93	2.45	1.33	1.91	2.39	2.22	1.12
Capital Deepening	0.99	1.12	0.80	1.06	1.13	1.01	1.03
IT Capital	0.40	0.27	0.41	0.60	0.92	0.50	0.38
Non-IT Capital	0.59	0.84	0.38	0.46	0.21	0.51	0.65
Labor Quality	0.26	0.26	0.24	0.28	0.22	0.25	0.36
College Labor Quality	-0.01	0.00	0.00	-0.02	0.00	-0.01	-0.04
Non-college Labor Quality	0.12	0.16	0.09	0.09	0.08	0.08	0.11
Reallocation of Hours	0.15	0.10	0.16	0.21	0.15	0.18	0.30
Aggregate TFP	0.68	1.08	0.29	0.57	1.03	0.96	-0.27
Growth Rates							
Aggregate Value-Added	2.95	3.56	2.64	2.32	4.30	2.14	0.54
Average Labor Productivity	1.93	2.45	1.33	1.91	2.39	2.22	1.12
Hours	1.01	1.11	1.31	0.41	1.91	-0.08	-0.58

Notes: Notes: All figures are average annual percentages. The contribution of an output or input is the growth rate multiplied by the average value share. IT capital includes computer hardware, computer software, and telecommunications equipment.

Appendix Table 4: Aggregate Reallocation Effects							
	1947-2010	1947-1973	1973-1995	1995-2010	1995-2000	2000-2005	2005-2010
Aggregate Production Possibility Frontier vs. Aggregate Production Function							
Aggregate Production Function Value-Added	2.41	3.06	1.95	1.95	3.11	2.00	0.73
Aggregate Production Possibility Frontier Value-Added	2.95	3.56	2.64	2.32	4.30	2.14	0.54
Reallocation of Value-Added	-0.54	-0.50	-0.69	-0.37	-1.19	-0.14	0.19
Aggregate Production Possibility Frontier vs. Direct Aggregation Across Industries							
Aggregate TFP	0.68	1.08	0.29	0.57	1.03	0.96	-0.27
Domar-Weighted Productivity	0.66	1.05	0.23	0.61	1.12	0.88	-0.18
IT-Producing Industries	0.19	0.02	0.22	0.42	0.50	0.42	0.33
IT-Using Industries	0.24	0.38	0.08	0.25	0.47	0.44	-0.16
Non-IT Industries	0.23	0.64	-0.07	-0.06	0.15	0.02	-0.35
Reallocation of Capital Input	0.05	0.03	0.12	-0.02	-0.05	0.07	-0.09
Reallocation of Labor Input	-0.02	0.00	-0.06	-0.02	-0.05	0.01	-0.01

Notes: Notes: All figures are average annual percentages. The contribution of an output or input is the growth rate multiplied by the average value share.

Appendix Table 5: Industry Decomposition of Labor Productivity Growth							
	1947-2010	1947-1973	1973-1995	1995-2010	1995-2000	2000-2005	2005-2010
Average Labor Productivity	1.93	2.45	1.33	1.910	2.39	2.22	1.12
Decomposition using Industry Gross Output Productivity							
Weighted dlny	1.98	2.23	1.64	2.040	3.23	2.32	0.58
IT-Producing Industries	0.15	0.06	0.16	0.270	0.40	0.18	0.23
IT-Using Industries	1.10	0.98	1.09	1.310	1.89	1.45	0.59
Other Industries	0.73	1.19	0.38	0.460	0.93	0.68	-0.24
Material Reallocation, $-R^M$	-0.17	-0.20	-0.26	0.01	-0.44	-0.02	0.48
Hours Reallocation, R^H	0.12	0.42	-0.05	-0.140	-0.40	-0.08	0.06
Decomposition using Industry Value-Added Productivity							
Weighted dlnv	1.81	2.04	1.38	2.050	2.79	2.30	1.06
IT-Producing Industries	0.23	0.04	0.27	0.510	0.61	0.53	0.40
IT-Using Industries	0.92	0.83	0.83	1.230	1.60	1.37	0.71
Other Industries	0.66	1.17	0.29	0.310	0.58	0.40	-0.05
Hours Reallocation, R^H	0.12	0.42	-0.05	-0.140	-0.40	-0.08	0.06

Note: Decomposition framework is defined in Equations (6.26) and (6.27).

Table 6: Industry Contributions to Aggregate Value-Added and TFP Growth, 1947-2010						
	Value-Added			Productivity		
	V-A Weight	V-A Growth	Contribution to Aggregate V-A	Domar Weight	TFP Growth	Contribution to Aggregate TFP
Farms	0.027	2.55	0.061	0.054	1.54	0.087
Forestry fishing and related activities	0.003	1.46	0.005	0.007	-0.96	-0.007
Oil and gas extraction	0.011	-0.52	-0.001	0.018	-1.76	-0.036
Mining except oil and gas	0.006	0.50	-0.003	0.012	0.23	-0.003
Support activities for mining	0.002	2.58	0.005	0.006	0.22	-0.001
Utilities	0.021	2.71	0.053	0.036	0.14	-0.002
Construction	0.046	1.49	0.066	0.106	-0.16	-0.014
Wood products	0.004	1.46	0.007	0.014	0.35	0.004
Nonmetallic mineral products	0.007	1.04	0.012	0.014	0.16	0.002
Primary metals	0.014	-1.36	-0.008	0.040	-0.34	-0.018
Fabricated metal products	0.017	1.58	0.033	0.040	0.29	0.012
Machinery	0.019	2.58	0.057	0.038	0.40	0.013
Computer and electronic products	0.015	13.71	0.223	0.037	4.37	0.187
Electrical equipment appliances and compo	0.008	0.30	0.005	0.017	-0.52	-0.010
Motor vehicles bodies and trailers and parts	0.016	1.80	0.048	0.059	0.30	0.020
Other transportation equipment	0.012	1.44	0.024	0.028	-0.03	-0.001
Furniture and related products	0.004	1.81	0.009	0.009	0.61	0.005
Miscellaneous manufacturing	0.006	4.27	0.026	0.015	1.21	0.018
Food and beverage and tobacco products	0.022	1.10	0.035	0.096	0.07	0.017
Textile mills and textile product mills	0.007	2.14	0.022	0.022	1.10	0.027
Apparel and leather and allied products	0.008	0.45	0.019	0.024	0.66	0.018
Paper products	0.009	1.57	0.019	0.024	0.12	0.003
Printing and related support activities	0.005	1.83	0.011	0.013	0.24	0.003
Petroleum and coal products	0.006	6.83	0.024	0.034	0.47	0.011
Chemical products	0.019	3.36	0.066	0.049	0.44	0.018
Plastics and rubber products	0.007	3.39	0.025	0.016	0.48	0.008
Wholesale Trade	0.051	5.46	0.280	0.073	1.68	0.123
Retail Trade	0.068	3.39	0.233	0.109	0.98	0.108
Air transportation	0.004	9.32	0.032	0.010	2.10	0.016
Rail transportation	0.010	-0.55	-0.009	0.015	1.11	0.018
Water transportation	0.001	4.73	0.006	0.005	1.32	0.005
Truck transportation	0.010	4.47	0.044	0.019	1.04	0.020
Transit and ground passenger transportatior	0.003	-0.49	-0.006	0.005	-0.24	-0.003
Pipeline transportation	0.001	4.50	0.005	0.003	1.40	0.004
Other transportation and support activities	0.007	2.23	0.017	0.011	0.22	0.003
Warehousing and storage	0.002	3.57	0.009	0.003	1.07	0.003
Publishing industries (includes software)	0.009	4.73	0.042	0.019	1.17	0.022
Motion picture and sound recording industr	0.004	1.51	0.003	0.006	-0.21	-0.003
Broadcasting and telecommunications	0.022	6.00	0.130	0.035	1.37	0.048
Information and data processing services	0.003	4.67	0.015	0.005	-1.59	-0.003
Federal Reserve banks credit intermediatior	0.026	3.83	0.093	0.042	-0.80	-0.036
Securities commodity contracts and invest	0.006	8.56	0.068	0.013	1.14	0.034
Insurance carriers and related activities	0.019	3.66	0.064	0.036	-0.34	-0.011
Funds trusts and other financial vehicles	0.001	1.16	0.001	0.005	-0.52	-0.003
Real estate	0.105	3.32	0.340	0.137	0.99	0.131
Rental and leasing services and lessors of in	0.010	4.45	0.042	0.014	-2.03	-0.029
Legal services	0.010	2.72	0.021	0.014	-0.94	-0.015
Computer systems design and related servic	0.005	6.57	0.035	0.007	-0.55	0.002
Miscellaneous professional scientific and tec	0.025	4.66	0.103	0.038	-0.26	-0.011
Management of companies and enterprises	0.014	2.35	0.032	0.022	-0.32	-0.009
Administrative and support services	0.014	5.17	0.065	0.021	0.58	0.010
Waste management and remediation service	0.002	3.91	0.008	0.005	0.59	0.003
Educational services	0.007	3.04	0.019	0.012	-0.25	-0.005
Ambulatory health care services	0.021	3.58	0.071	0.032	-0.05	-0.006
Hospitals Nursing and residential care facilit	0.019	2.92	0.046	0.031	-0.73	-0.027
Social assistance	0.003	5.84	0.014	0.005	1.67	0.004
Performing arts spectator sports museums a	0.003	3.39	0.011	0.006	0.75	0.004
Amusements gambling and recreation indust	0.004	2.90	0.011	0.006	-0.20	-0.002
Accommodation	0.007	3.32	0.022	0.011	0.44	0.005
Food services and drinking places	0.017	0.59	0.009	0.037	-0.73	-0.029
Other services except government	0.027	1.48	0.041	0.043	-0.87	-0.037
Federal General government	0.053	-0.05	-0.010	0.086	-0.21	-0.019
Federal Government enterprises	0.007	0.73	0.006	0.009	-0.46	-0.004
S&L Government enterprises	0.008	1.99	0.017	0.014	-0.72	-0.011
S&L General Government	0.073	2.67	0.176	0.102	0.08	-0.001
Sum	1.000		2.947	1.887		0.658

Notes: All figures are annual averages. Value-added weights are industry value-added as a share of aggregate value-added. Domar weights are industry output as a share of aggregate value-added. A contribution is a share-weighted growth rate.

Table 7: Industry Contributions to Aggregate Capital and Labor Input Growth, 1947-2010

	Capital			Labor		
	Total	IT	Non-IT	Total	College	Non-College
Farms	0.015	0.000	0.014	-0.041	0.001	-0.042
Forestry fishing and related activities	0.008	0.001	0.007	0.004	0.001	0.003
Oil and gas extraction	0.032	0.002	0.030	0.003	0.002	0.001
Mining except oil and gas	0.005	0.000	0.004	-0.005	0.000	-0.005
Support activities for mining	0.004	0.001	0.004	0.001	0.001	0.000
Utilities	0.049	0.006	0.044	0.006	0.003	0.002
Construction	0.018	0.004	0.014	0.062	0.016	0.045
Wood products	0.003	0.001	0.003	0.000	0.001	-0.001
Nonmetallic mineral products	0.008	0.002	0.005	0.002	0.001	0.000
Primary metals	0.016	0.004	0.013	-0.006	0.002	-0.008
Fabricated metal products	0.011	0.004	0.007	0.010	0.004	0.006
Machinery	0.039	0.013	0.026	0.005	0.004	0.001
Computer and electronic products	0.020	0.011	0.009	0.017	0.013	0.004
Electrical equipment appliances and compo	0.014	0.002	0.012	0.002	0.002	0.000
Motor vehicles bodies and trailers and parts	0.022	0.007	0.016	0.006	0.005	0.001
Other transportation equipment	0.015	0.003	0.011	0.011	0.007	0.004
Furniture and related products	0.002	0.000	0.001	0.002	0.001	0.001
Miscellaneous manufacturing	0.005	0.002	0.003	0.002	0.003	-0.001
Food and beverage and tobacco products	0.018	0.004	0.013	0.001	0.004	-0.003
Textile mills and textile product mills	0.002	0.001	0.002	-0.007	0.001	-0.008
Apparel and leather and allied products	0.005	0.001	0.004	-0.004	0.001	-0.005
Paper products	0.011	0.002	0.010	0.005	0.002	0.003
Printing and related support activities	0.003	0.001	0.002	0.005	0.003	0.003
Petroleum and coal products	0.014	0.003	0.011	0.000	0.001	-0.001
Chemical products	0.038	0.009	0.030	0.010	0.009	0.001
Plastics and rubber products	0.010	0.001	0.009	0.008	0.002	0.006
Wholesale Trade	0.100	0.026	0.075	0.057	0.031	0.027
Retail Trade	0.064	0.017	0.047	0.062	0.027	0.035
Air transportation	0.009	0.005	0.004	0.007	0.003	0.004
Rail transportation	-0.002	0.001	-0.003	-0.024	0.000	-0.024
Water transportation	0.000	0.001	0.000	0.000	0.001	0.000
Truck transportation	0.009	0.001	0.008	0.015	0.002	0.012
Transit and ground passenger transportatior	-0.002	0.001	-0.003	-0.001	0.001	-0.001
Pipeline transportation	0.002	0.001	0.001	-0.001	0.000	-0.001
Other transportation and support activities	0.003	0.002	0.001	0.011	0.004	0.007
Warehousing and storage	0.001	0.000	0.001	0.005	0.001	0.004
Publishing industries (includes software)	0.012	0.009	0.003	0.008	0.009	-0.001
Motion picture and sound recording industr	0.006	0.002	0.004	0.001	0.002	-0.001
Broadcasting and telecommunications	0.071	0.048	0.023	0.011	0.007	0.004
Information and data processing services	0.013	0.009	0.004	0.005	0.003	0.002
Federal Reserve banks credit intermediatior	0.099	0.040	0.059	0.030	0.018	0.012
Securities commodity contracts and investi	0.013	0.012	0.002	0.021	0.018	0.003
Insurance carriers and related activities	0.051	0.026	0.025	0.025	0.017	0.008
Funds trusts and other financial vehicles	0.004	0.001	0.002	0.000	0.001	0.000
Real estate	0.193	0.005	0.233	0.016	0.009	0.007
Rental and leasing services and lessors of in	0.066	0.025	0.041	0.005	0.002	0.003
Legal services	0.025	0.010	0.015	0.011	0.010	0.001
Computer systems design and related servic	0.013	0.009	0.004	0.020	0.015	0.005
Miscellaneous professional scientific and tec	0.058	0.032	0.026	0.056	0.040	0.016
Management of companies and enterprises	0.028	0.019	0.009	0.013	0.018	-0.005
Administrative and support services	0.017	0.010	0.007	0.038	0.012	0.026
Waste management and remediation service	0.003	0.000	0.002	0.003	0.001	0.002
Educational services	0.007	0.003	0.004	0.017	0.014	0.003
Ambulatory health care services	0.018	0.004	0.015	0.059	0.035	0.024
Hospitals Nursing and residential care facilit	0.027	0.005	0.022	0.046	0.022	0.023
Social assistance	0.002	0.000	0.001	0.008	0.003	0.005
Performing arts spectator sports museums a	0.002	0.001	0.001	0.005	0.004	0.001
Amusements gambling and recreation indust	0.005	0.001	0.005	0.007	0.002	0.005
Accommodation	0.008	0.001	0.007	0.010	0.003	0.007
Food services and drinking places	0.008	0.001	0.006	0.031	0.007	0.024
Other services except government	0.020	0.004	0.016	0.059	0.017	0.042
Federal General government	0.002	0.005	-0.003	0.007	0.013	-0.006
Federal Government enterprises	0.009	0.001	0.008	0.001	0.001	0.000
S&L Government enterprises	0.017	0.002	0.015	0.010	0.003	0.008
S&L General Government	0.079	0.010	0.070	0.098	0.074	0.024
Sum	1.441	0.429	1.057	0.848	0.536	0.311

Notes: All figures are annual averages. Value-added weights are industry value-added as a share of aggregate value-added. Domar weights are industry output as a share of aggregate value-added. A contribution is a share-weighted growth rate.