The World KLEMS Initiative

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ABSTRACT

The objective of this article is to provide an overview of the World KLEMS Initiative, which brings together EU KLEMS, Latin America KLEMS, and Asia-KLEMS. This project generates KLEMS data sets, consisting of inputs of capital (K) and labour (L) at the industry level, together with inputs of energy (E), materials (M) and services (S), for countries around the world. Growth of output, inputs, and productivity at the industry level is critical to understanding changes in the structure of an economy, especially the relative importance of different industries and different inputs. The article illustrates the insight into the growth process provided by the KLEMS framework by analyzing the sources of economic growth in the United States over the 1947-2010 period, including contributions to growth from IT-producing and IT-using and non-IT-using industries as well as college and non-college labour.

RÉSUMÉ

Un aperçu de l'initiative World KLEMS, qui regroupe EU-KLEMS, LA-KLEMS, et Asia-KLEMS, est présenté dans cet article. Cette initiative génère des ensembles de données, formés d'intrants de capital (K) et de travail (L pour Labour) au niveau des industries, et d'intrants d'énergie (E), de matières (M) et de services (S) pour des pays partout dans le monde. La croissance de la production, des intrants et de la productivité au niveau des industries est essentielle pour comprendre les changements structurels d'une économie, en particulier l'importance relative de différentes industries et de différents intrants. Cet article illustre ce que le cadre KLEMS peut nous apprendre sur le processus de croissance en analysant les sources de la croissance économique aux États-Unis pendant la période 1947 à 2010, y inclus la contribution à la croissance des industries qui produisent des TI, qui utilisent des TI et qui n'en utilisent pas, ainsi que celle de la main-d'œuvre ayant effectué des études collégiales et de la main-d'œuvre n'en ayant pas fait.

THE WORLD KLEMS INITIATIVE was established at the First World KLEMS Conference, held at Harvard University on August 19-20, 2010. The purpose of this Initiative is to generate KLEMS data sets, consisting of inputs of capital (K) and labour (L) at the industry level, together with inputs of energy (E), materials (M) and services (S), for countries around the world. These data sets will provide the framework for analyzing the sources of economic growth at the industry level and will fill a void in systems of national accounts. Growth of output, inputs, and productivity at the industry level is also critical to understanding changes in

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the structure of an economy especially the relative importance of different industries and different inputs. Furthermore, international comparisons of level differences based on purchasing power parities of outputs and inputs at the industry level provide a second focus for KLEMS research. These comparisons are essential in assessing changes in comparative advantage and formulating growth policy.

The EU (European Union) KLEMS study provides industry-level data on the sources of growth for 25 of the 27 EU member countries.[2] Two volumes have been published on the results of the study. Marcel Timmer, Robert Inklaar, Mary O'Mahony, and Bart van Ark (2010 and 2011) describe the data sets and analyze the sources of economic growth in Europe at the industry level. These data sets are essential for tracing the slowdown in European economic growth that preceded the current financial and fiscal crisis to slower productivity growth and lower levels of investment in information technology. The EU KLEMS project also includes data sets for Australia, Canada, Japan, Korea, and the United States. Matilde Mas and Robert Stehrer (2012) present international comparisons within Europe and between Europe and advanced economies in Asia and North America. As European policy-makers focus on removing barriers to the revival of economic growth, international differences in the sources of growth have become central to the development of new directions for policy.

The Second World KLEMS Conference was held at Harvard University on August 9-10, 2012. The conference included reports on recent progress in the development of KLEMS data sets, as well as extensions and applications.[3] Regional organizations in Asia and Latin America have now 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 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. This chapter is coordinated by ECLAC and includes seven research organizations in four leading Latin American countries – Argentina, Brazil, Chile, and Mexico.[4] 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.[5] The Asia-KLEMS Commit-

2 Updated data are available for the EU countries are posted on the EU KLEMS website: http://www.euklems.net/

3 The conference program and presentations are available at: http://www.economics.harvard.edu/faculty/jorgenson/WorldKLEMS.

4 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).

5 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 Pyo (2012). Updated data for Australia, Canada, Japan, Korea, and the United States– 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, they will also be posted on the World KLEMS website. More details are given by Timmer (2012).

tee includes representatives of major Asian countries, including China, India, Japan, South Korea, and Singapore.

International comparisons of patterns of output, inputs, and productivity are very challenging, but have become crucial to growth strategy 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 countries of the World KLEMS Initiative with data on international trade among these countries. This project has produced a database that includes 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.[6]

The New Framework for Productivity Measurement

The traditional approach to productivity measurement has been greatly enhanced by the KLEMS accounting framework and the focus of productivity measurement has shifted from the economy as a whole to individual industries.[7] Paul Schreyer's (2001) OECD *Productivity Manual* has established international standards for economy-wide and industry-level productivity measurement.[8] The hallmarks of the new framework for productivity measurement are constant quality indexes of capital and labour services at the industry level and indexes of energy, materials, and services inputs constructed from a time series of input-output tables.

The first data set containing time series data on output, capital, labour, and intermediate inputs, and productivity for all industries in the United States was constructed by Dale Jorgenson, Frank Gollop, and Barbara Fraumeni (1987). This study provided annual data for the period 1948-1979 and was recognized as the international standard in Paul Schreyer's (2001) *OECD Productivity Manual*. Dale Jorgenson, Mun Ho, and Kevin Stiroh (2005) updated the data set and revised it to include data on investment in information technology. This demonstrated the importance of KLEMS data in understanding the IT investment boom and provided the framework for the KLEMS data sets and international comparisons for Europe, Japan, and the United States presented in Jorgenson (2009).

The key idea underlying a *constant quality index of labour input* is to capture the heterogeneity of different types of labour inputs. Hours worked for each type of labour input are combined into a constant quality index of labour input, using labour compensation per hour as weights.[9]

Similarly, a *constant quality index of capital input* deals with the heterogeneity among different types of capital inputs. These capital inputs are combined into a constant quality index, using prices of the inputs with rental prices as weights, rather than the asset prices used in measuring capital stocks. The KLEMS accounting framework employs the concept of the cost of capital introduced by Jorgenson (1963). This makes it possible to incorporate differences among depreciation rates on different assets, as well as variations in returns due to the tax treatment of

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

7 A detailed survey of recent research on sources of economic growth is given in Jorgenson (2005). A survey of earlier research is given in Jorgenson (1990).

8 A brief history of World KLEMS is presented by Schreyer (2012).

9 Constant quality indexes of labour input for the United States at the industry level are discussed in detail by Jorgenson, Gollop, and Fraumeni (1987:69-108 and 261-300) and Jorgenson, Ho, and Stiroh (2005:201-290).

different types of capital income, into the rental prices. These prices also include asset-specific inflation rates that are particularly important in analyzing the impact of investments in information technology.[10]

The new framework for productivity measurement has posed the challenge of developing a system of production accounts for individual sectors of the U.S. economy. This is a set of accounts for outputs of individual industries as well as inputs of capital and labour services and intermediate goods for these industries in current and constant prices. The basic accounting identity for each industry is that the value of output is equal to the sum of values of the inputs. A complete system of production accounts for the U.S. economy was constructed by Jorgenson, Gollop, and Fraumeni (1987). The system incorporates a time series of input-output tables in current and constant prices.[11]

Finally, industry-level data on output, inputs and productivity are linked to aggregate data on the sources of economic growth by means of the *production possibility frontier* introduced by Jorgenson (1966). This allows for joint production of consumption and investment goods from capital and labour services. Nicholas Oulton (2007) demonstrates that Robert Solow's (1960) model of embodied technical change is a special case of the model proposed by Jorgenson (1966). Jeremy Greenwood and Per Krussell (2007) employ Solow's one-sector model, replacing constant quality price indexes for investment goods with "investment-specific" or embodied technical change. The deflator for the single output is used to deflate both consumption and investment, while separate deflators are provided for consumption and investment in the systems of national accounts discussed below.

The new framework for productivity growth measurement was adopted by the Panel to Review Productivity Statistics of the National Research Council, chaired by Albert Rees. The Rees Report of 1979, *Measurement and Interpretation of Productivity*, became the cornerstone of this new measurement framework for the official productivity statistics. This was implemented by the Bureau of Labor Statistics (BLS), the U.S. government agency responsible for these statistics. Under the leadership of Jerome Mark and Edwin Dean, the BLS Office of Productivity and Technology undertook the construction of a production account for the U.S. economy with measures of capital and labour inputs and total factor productivity, renamed *multifactor productivity*.[12]

New Architecture

Dale Jorgenson and Steven Landefeld (2006) have developed a new architecture for the U.S. national income and product accounts (NIPAs) that includes prices and quantities of capital services for all productive assets in the U.S. economy. The incorporation of the price and quantity of capital services into the *System of National Accounts 2008* was approved by the United Nations Statistical Commission at its February-March 2007 meeting (United Nations *et.al.*, 2009). Schreyer, then head of national accounts at the OECD, prepared an OECD

10 Constant quality indexes of capital input for the United States at the industry level are presented by Jorgenson, Fraumeni, and Gollop (1987:109-140 and 267-300), and by Jorgenson, Ho, and Stiroh (2005:147-200).

11 Details on the construction of the time series of input-output tables are presented by Jorgenson, Gollop and Fraumeni (1987:149-182), and Jorgenson, Ho, and Stiroh (2005:87-146).

12 A detailed history of the BLS productivity measurement program is found in Dean and Harper (2001). The BLS (1983) framework was based on GNP rather than NNP and included a constant quality index of capital input. A constant quality index for labour input was incorporated in 1993 (BLS, 1993). The expert advisory group for the *OECD Productivity Manual* was chaired by Edwin Dean, then Associate Commissioner for Productivity at the BLS and leader of the successful effort to implement the Rees report (Rees, 1979).

Manual, *Measuring Capital*, published in 2009. This provides detailed recommendations on methods for the construction of prices and quantities of capital services. In effect, the UN Statistical Commission reversed the position of the *System of National Accounts 1993*, which had stated that it was impossible to decompose income from capital (called net operating surplus) into price and quantity components (United Nations *et.al.*, 1993:403).

The *SNA 2008* (United Nations *et.al.*, 2009:415) estimates of capital services are described as follows:

> By associating these estimates with the standard breakdown of value added, the contribution of labour 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.

The measures of capital and labour inputs in the prototype system of U.S. 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 labour 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 U.S. national accounts was endorsed by the Advisory Committee on Measuring Innovation in the 21st Century Economy to the U.S. Secretary of Commerce: [13]

> 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, the Bureau of Economic Analysis (BEA) and the BLS have produced an initial set of multifactor productivity estimates integrated with the NIPAs. Data on capital and labour inputs are provided by the BLS. The results are reported by Michael Harper, Brent Moulton, Steven Rosenthal, and David Wasshausen (2009) and will be updated annually.[14] This is a critical step in implementing the new architecture. Estimates of productivity are essential for projecting the potential growth of the U.S. economy, as demonstrated by Jorgenson, Ho, and Stiroh (2008). The omission of productivity 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 U.S. Secretary of Commerce (2008:7) recommended that the 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 consis-

13 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 the author . The Advisory Committee met on February 22 and September 12, 2007, to discuss its recommendations. The final report was released on January 18, 2008.

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

tent estimation of the contribution of innovation to economic growth.

The principles for constructing industry-level production accounts are found in Fraumeni, Harper, Powers, and 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 as described by Lawson, Moyer, Okubo, and Planting (2006), and Moyer, Reinsdorf, and Yuskavage (2006). Moyer (2012) described plans to integrate the BEA's industry data with the NIPAs, beginning with the benchmark revision of 2013, at the Second World KLEMS Conference. 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 will form a continuous time series. The annual input-output data are employed in the industry-level production accounts presented by Susan Fleck, Steven Rosenthal, Matthew Russell, Erich Strassner, and Lisa Usher (2012) in their paper for the Second World KLEMS Conference, "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.[15] The capital and labour input are provided by the BLS, while the data on output and intermediate inputs are generated by the BEA.

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 described by Timmer, Inklaar, O'Mahony, and van Ark (2010), 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 numerous countries around the world, including important developing and transition economies.

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

To illustrate the application of KLEMS data sets, I will summarize the prototype production account for the United States for 1947-2010 constructed by Jorgenson, Ho and Samuels (2012b). The incorporation of data on labour and capital inputs in constant prices into the national accounts is described in Chapters 19 and 20 of the *System of National Accounts 2008*, published in 2009. Jorgenson and Schreyer (2012) have shown how to integrate a complete system of production accounts at the industry level, such as provided by KLEMS data sets, into the *System of National Accounts 2008*. The lengthy time series is especially valuable for comparing recent changes in the sources of economic growth with longer term trends.

In December 2011, the BEA released a new industry-level data set. This has a number of features that are useful in constructing KLEMS data sets. The data set employs the North American Industry Classification System (NAICS). The NIPAs have been based on NAICS since the benchmark revision of 2003. The new industry data set 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 by industry form consistent time series. The input-output tables provide data on the output side of the national

15 The most recent date set is availbale at: http://bea.gov/industry/index.htm#integrated.

accounts along with intermediate inputs in current and constant prices.

Mark Planting, formerly head of the input-output accounts at the BEA, has developed a time series of input-output tables in current prices covering the 1947-1997 period on a NAICS basis. This incorporates all earlier benchmark input-output tables for the United States, including the first benchmark table for 1947. The BEA has linked these input-output tables to the official tables for 1998-2010. Jorgenson, Ho, and Samuels (2012b) have constructed input-output tables in constant prices for 1947-2010 on a NAICS basis. This data set incorporates input-output tables in constant prices from Jorgenson, Gollop, and Fraumeni (1987) for 1948-1979, from Jorgenson, Ho, and Stiroh (2008) for 1977-2000, and from Jorgenson, Ho, and Samuels (2012a) for 1960-2007.[16] We incorporate data on capital and labour inputs in constant prices from the same sources to obtain an industry-level production account for the United States covering the period 1947-2010. This KLEMS data set is consistent with the BEA's annual input-output tables for 1998-2010.

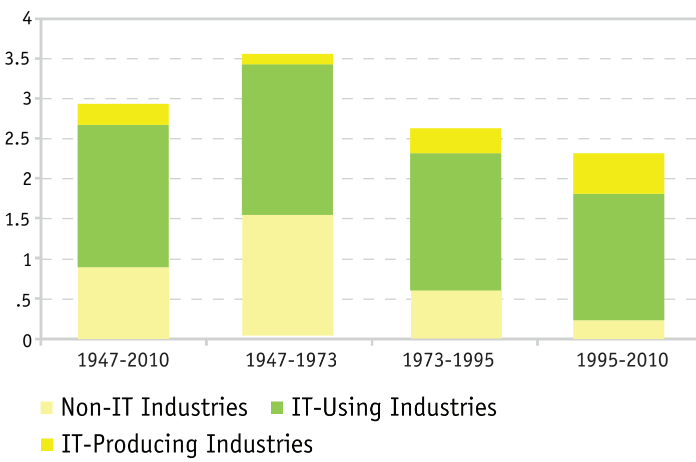
I will illustrate the application of the prototype industry-level production account by analyzing postwar U.S. economic history for three broad periods. These are the postwar recovery, 1947-1973; the big slump following the energy crisis of 1973, 1973-1995; and the period of growth and recession, 1995-2010. To provide more detail on the period of growth and recession, I will consider the sub-periods 1995-2000, 2000-2005, and 2005-2010 – the investment boom, the jobless recovery, and the great recession.

The NAICS industry classification includes the industries identified by Jorgenson, Ho, and Samuels (2012b) 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 have classified industries as IT-using if at least 15 per cent of capital input in the industry was associated with IT equipment and software in 2005. This sector now comprises about 45 per cent of the U.S. economy. The IT-producing industries include about 3 per cent, while non-IT industries make up the remainder.[17] The IT-using industries are mainly in trade and services, while 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. I will begin by discussing the results for the IT-producing sectors, now defined to include the two IT-service sectors.

Chart 1

Contributions of Industry Groups to Value Added Growth in the United States, 1947-2010

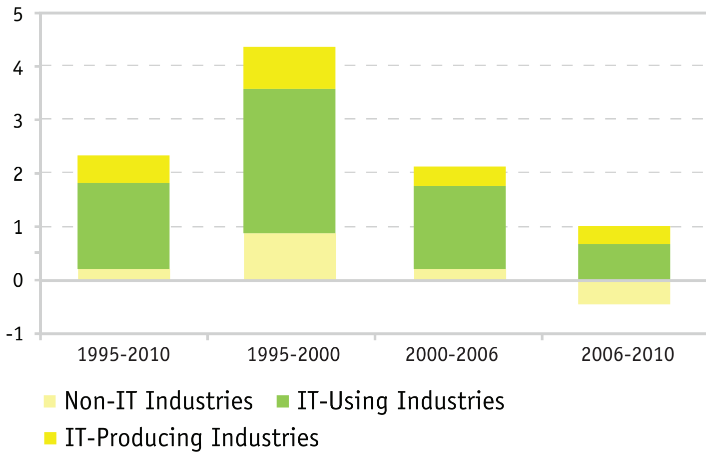
(percentage points per year)



16 Data for 1960-2007 are posted on the World KLEMS website: http://www.worldklems.net/data/index.htm.

17 The three industry categories are mutually exclusive. There are 3 IT-producing industries, 34 IT-using industries and 30 non-IT industries. More details are found at: http://www.economics.harvard.edu/faculty/jorgenson/files/12_0425_WIOD.pdf.

Chart 2
Contributions of Industry Groups to Value Added Growth in the United States, 1995-2010
(percentage points per year)



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 semiconductors around 1970. The two IT-services sectors have had declining prices, relative to the GDP deflator, since around 2000. Chart 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. Chart 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. Chart 3 gives the contributions to value added for the 65 individual industries over the period 1947-2010.

In order to assess the relative importance of productivity growth at the industry level as a source of U.S. economic growth, we utilize the production possibility frontier of Jorgenson, Gollop, and Fraumeni (1987:301-342) and Jorgenson, Ho, and Stiroh (2005:361-416). 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 an 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 labour 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 labour 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 labour inputs grow more rapidly than the Domar-weighted averages of industry capital and labour input growth rates, so that the reallocations are positive. When industries with lower prices for inputs grow more rapidly, the reallocations are negative.

Chart 4 shows that the contributions of IT-producing, IT-using, and non-IT industries to aggregate MFP productivity growth are similar in magnitude for the period 1947-2010.

Chart 3

Contributions of Individual Industries to Real Value Added Growth in the United States, 1947-2010

(percentage points per year)

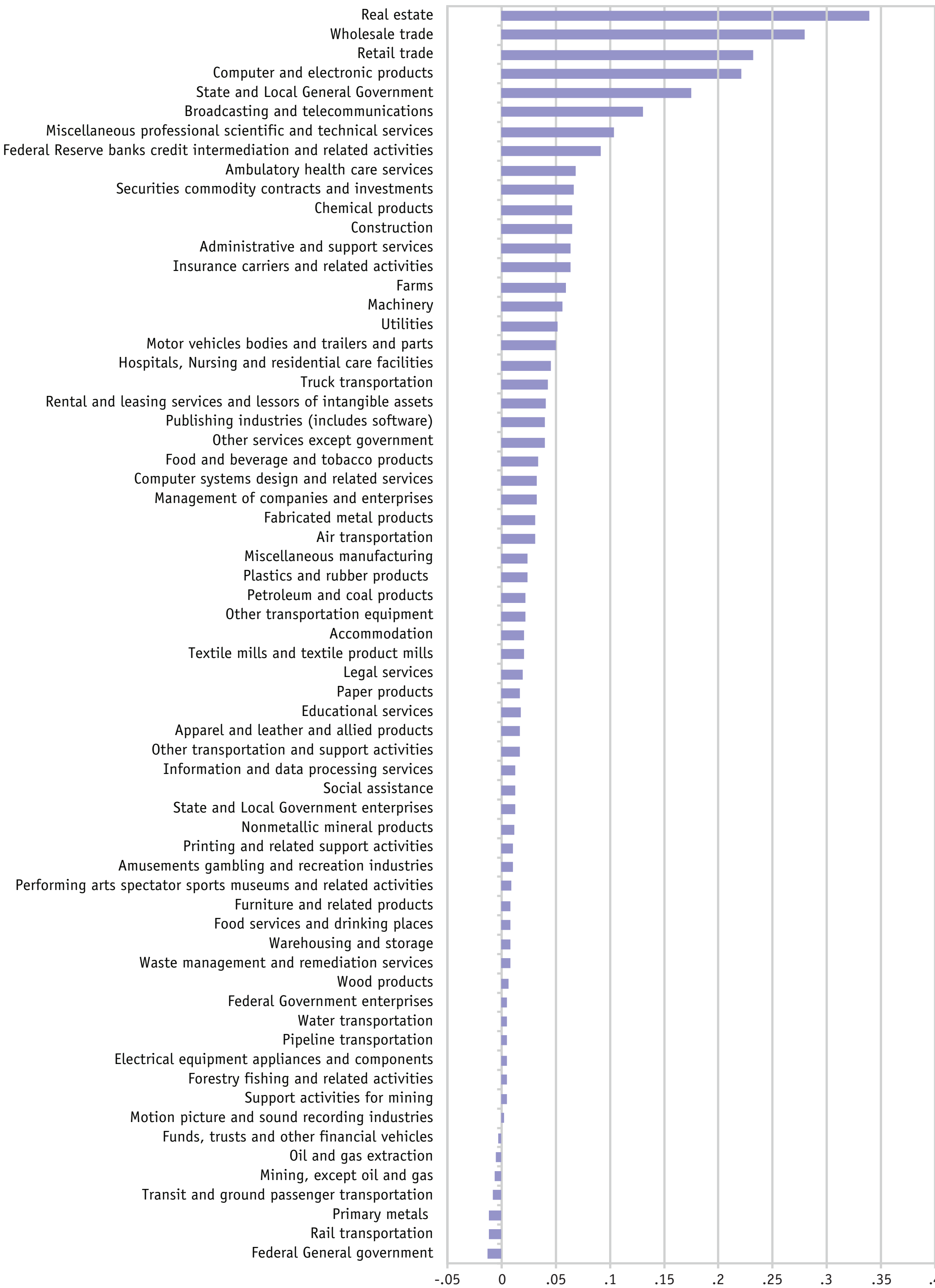


Chart 4

Contributions of Industry Groups to Multifactor Productivity Growth in the United States, 1947-2010

(percentage points per year)

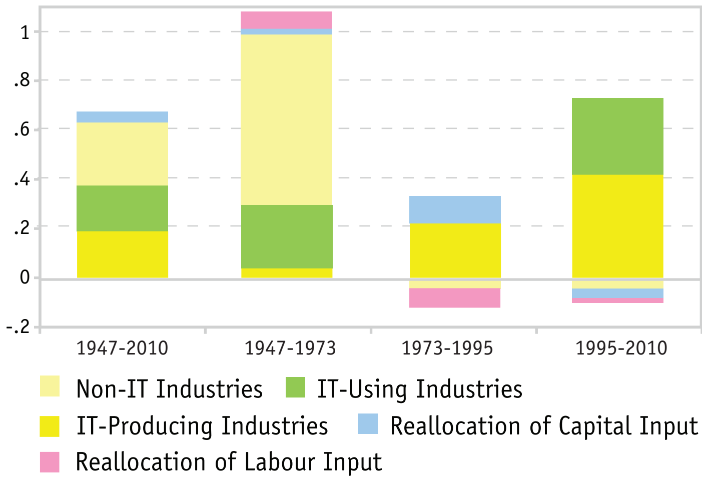
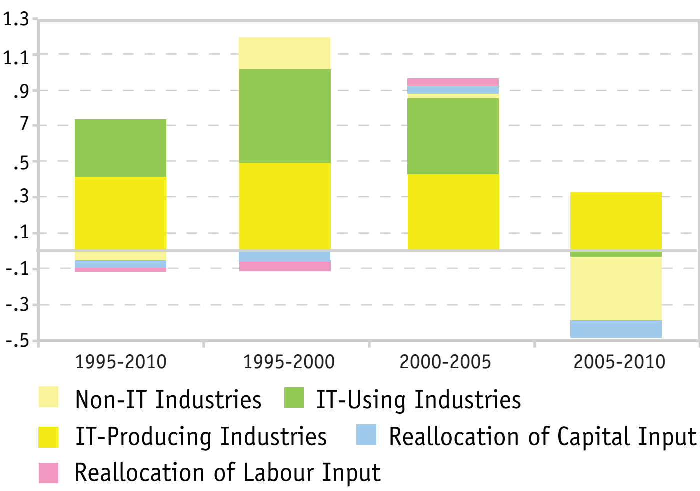


Chart 5

Contributions of Industry Groups to Multifactor Productivity Growth in the United States, 1995-2010

(percentage points per year)



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 period, but became the predominant source of growth during the big slump, 1973-1995, and increased considerably during the resurgence and recession of 1995-2010. The IT-using industries contributed substantially to U.S. 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 U.S. economy for the period 1947-2010, while the contribution of reallocation of labour input was negligible. Both reallocations were positive during the postwar recovery and both were negative during the resurgence and recession, but very small in magnitude.

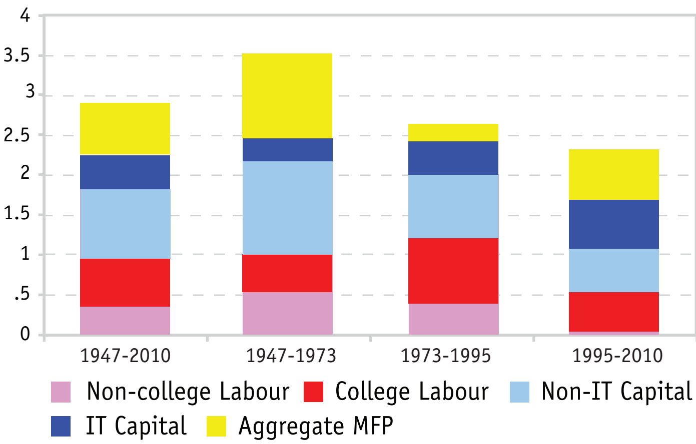
Considering the period 1995-2010 in more detail in Chart 5, the IT-producing industries were the most important source of productivity growth during the period as a whole. The contribution of these industries remained substantial during each sub-period – 1995-2000, 2000-2005, and 2005-2010 – despite 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 period of the great recession. The non-IT industries contributed positively to productivity growth during the investment boom of 1995-2000, but were almost negligible during the jobless recovery and became substantially negative during the great recession. The contributions of reallocations of capital and labour inputs were very small and negative during the period as a whole and fluctuated from negative in 1995-2000 to positive in 2000-2005. Chart 6 gives the contributions of each of the 65 industries to multifactor productivity growth for the period as a whole. The computer and electronic products industry was the leading contributor to U.S. economic growth during this period.

Chart 6

Contributions of Individual Industries to Multifactor Productivity Growth in the United States, 1947-2010

(percentage points, per year)

Chart 7
Sources of Economic Growth in the United States, 1947-2010
(percentage points per year)



Research on the impact of investment in IT equipment and software on economic growth is summarized by Jorgenson (2009). 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 relative 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 United States 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 U.S. 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. Multifactor 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 labour force expands as population grows. With only replication and without innovation, output will increase in proportion to capital and labour 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 labour inputs. This results in growth in multifactor productivity or output per unit of input.

Multifactor productivity growth was identified as the predominant source of economic growth by Solow (1957). However, Chart 7 shows that the productivity growth was far less important than the contributions of capital and labour inputs. For the period 1947-2010 multifactor productivity accounts for about 20 per cent of U.S. economic growth. The contribution of capital input accounts for the largest share of growth for the period as a whole, while the contribution of labour input accounts for the rest. The great bulk of U.S. 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, this portion is vital for maintaining gains in the U.S. standard of living in the long run.

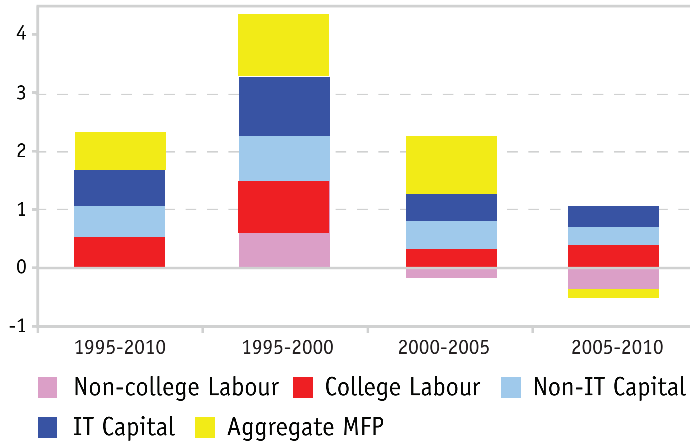
The contribution of capital input exceeded that of innovation, while the contribution of labour input was similar to that of innovation during the postwar recovery, 1947-1973. The standard explanation for the substantial importance of innovation during the period is the backlog of new technologies available at the end of 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 multifactor productivity growth. The contribution of labour input increased in importance, 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 U.S. economic growth continued to decline and the contribution of non-college workers almost disappeared. Multifactor productivity growth revived and investment in information technology became the predominant source of the contribution of capital input.

Chart 8 shows that all of the sources of economic growth we have identified contributed to the U.S. growth acceleration after 1995, relative to the big slump. Jorgenson, Ho, and Stiroh (2008) have shown that the rapid pace of U.S. economic growth after 1995 was not sustainable. After the dot-com crash in 2000 the overall growth rate 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 remained. The contribution of labour

Chart 8

Sources of Economic Growth in the United States, 1995-2010

(percentage points per year)



input dropped precipitously, accounting for most of the decline in 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 multifactor productivity, indicating a continuing surge of innovation. Both IT and non-IT investment continued to contribute to U.S. economic growth during the recession period after 2005, while multifactor 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.

Conclusion

The new framework for productivity measurement employed in constructing KLEMS data sets reveals that replication of established technologies through growth of capital and labour inputs, recently through the growth of college-educated workers and investments in both IT and Non-IT capital, explains by far the largest proportion of U.S. economic growth. International productivity comparisons reveal similar patterns for the world economy, its major regions, and leading industrialized, developing, and emerging economies (Jorgenson and Vu, 2009). Studies are now underway to extend these comparisons to individual industries for the countries included in the World KLEMS Initiative.

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