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INTERNATIONAL PRODUCTIVITY MONITOR

NUMBER THIRTY-THREE, FALL 2017

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World KLEMS: Productivity and Economic Growth in the World Economy: An Introduction

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This issue of the *International Productivity Monitor* contains papers presented at the Fourth World KLEMS Conference, held at the BBVA Foundation, Madrid, Spain, on May 23-24, 2016.² This is the latest in a series of international conferences devoted to research on productivity and growth in the world economy. World KLEMS is based on outputs and inputs of capital (K), labour (L), energy (E), materials (M), and services (S) for individual industries. Productivity of each industry is the ratio of output to all inputs.

The point of departure for research on economic growth and productivity is the volume edited by Dale W. Jorgenson, Kyoji Fukao, and Marcel P. Timmer (2016), *The World Economy: Growth or Stagnation?* This volume presents studies for more than forty countries by teams involving thirty-eight authors. The methodology follows Chapters 19 and 20 of the System of National Accounts 2008 (SNA 2008) produced by the United Nations Statistical Division (UN, 2009). Jorgenson and Schreyer (2013) show how to incorporate accounts for industry-level growth and productivity into the SNA 2008.

More than a dozen countries have added industry-level data on growth and productivity to their national accounts. This follows SNA

2008 and assures a higher degree of international comparability. The Madrid World KLEMS Conference included reports from three regional organizations. The first of these, European Union (EU) KLEMS, arose from a research project supported by the European Commission. This project was initiated in 2003 and completed in 2008. The Economic Commission for Latin America and the Caribbean (ECLAC) in Santiago, Chile, an agency of the United Nations, established the Latin American regional organization LA KLEMS in 2009. The third regional organization, Asia KLEMS, was organized by the Asian Development Bank Institute (ADBI) in Tokyo, Japan, in 2010.

The EU KLEMS project was led by the Groningen Growth and Development Center (GGDC) at the University of Groningen, in the Netherlands, and involved 18 participating organizations. The project applied international standards for data on growth and productivity to 25 of the (then) 27 members of the European Union. The project generated similar data for Australia, Canada, Japan, and the United States. Marcel Timmer, Robert Inklaar, Mary O'Mahony, and Bart van Ark (2010) reported the results in their monograph *Growth of the*

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2 The conference program is available on the World KLEMS website: <http://www.worldklems.net/conferences.htm>.

European Economy: A Comparative Industry Perspective.³

The main conclusion of the EU KLEMS project is that Europe's unsatisfactory economic performance preceded the downturn in the European economy following the Great Recession in the United States. This was due to underinvestment in human capital, information technology, and research and development. The volume *Industrial Productivity in Europe: Growth and Crisis*, edited by Matilde Mas and Robert Stehrer (2012), presented international comparisons of growth and productivity within Europe and between Europe and advanced economies in Asia and North America.

Updated estimates of the industry-level sources of European economic growth for the period 1999-2014 were presented by van Ark and O'Mahony (2016) in Chapter 4 of *The World Economy*. The Great Recession that began in the United States during 2007-2009 was transmitted to Europe in 2008 and 2009. This resulted in a "double dip" recession in Europe and widened the gap in growth rates between Europe and the United States. Slower growth in Europe can be attributed to demand-side factors, such as "secular stagnation", and supply-side slowdowns in the growth of employment and productivity.

In 2016, the European Commission launched a project to update the EU KLEMS database. The original EU KLEMS study included data on outputs, inputs, and productivity for 72 industrial sectors. The update is based on value added for 34 industrial sectors with inputs of capital and labour services. This employs Eurostat's (2013) European System of Accounts 2010 (ESA 2010), which is closely related to SNA 2008. The estimates are based on the International System of Industrial Classification (ISIC), Revision 4, and are consistent with the national

accounts that individual countries report to Eurostat, the European statistical agency.

The initial update of the EU KLEMS database for ten European countries by van Ark and Kirsten Jäger, "Recent Trends in Europe's Output and Productivity Growth Performance at the Sector Level, 2002-2015" is found in this volume. Results are available for manufacturing and market services, as well as the total economy. The emerging picture of the European economy reveals little evidence of a recovery from the Great Recession. The database will be updated and extended to cover the EU 28, the United States, and Japan.

Substantial differences in economic performance characterize the major European economies. In "The Role of Capital Accumulation in the Evolution of Total Factor Productivity in Spain," Francisco Pérez and Eva Benages show that relatively satisfactory economic growth in Spain is due to substantial investments in human and non-human capital with negative contributions of growth in total factor productivity. Italy has had little economic growth in per capita terms since the adoption of the Euro in 2000. Germany's more satisfactory performance can be traced to a successful program of economic reforms.

The Latin American regional organization, LA KLEMS, was originally coordinated by ECLAC and included research organizations and statistical agencies in the leading Latin American countries. Mario Cimoli, André Hofman, and Nanno Mulder (2010) summarized the results of the initial phase of the project. André Hofman, Matilde Mas, Claudio Aravena, and Juan Fernández de Guevara (2016) presented industry-level production accounts for Argentina, Brazil, Chile, Columbia, and Mexico for 1990-2010 in Chapter 5 of *The World Economy*. A striking finding is that there has been no total

3 See Timmer *et al.* (2011) for an accessible overview of the monograph.

factor productivity growth in the leading economies of Latin America during the past two decades.

A detailed report on Mexico KLEMS was published by the Mexican statistical agency, INEGI (2013). Mexico KLEMS includes a complete industry-level database for 1990-2011, integrated with the Mexican national accounts and updated annually. Since 1990 periods of positive economic growth have been offset by the negative impacts of the Mexican sovereign debt crisis of 1995, the U.S. dot-com crash in 2000, and the U.S. financial and economic crisis of 2007-2009. Mexican total factor productivity at the economy-wide level has remained unchanged throughout two decades.

André Hofman, Claudio Aravena, and Jorge Friedman analyze industry-level data on growth and productivity for Argentina, Brazil, Chile, Columbia, and Mexico in "Sources of Productivity and Economic Growth in Latin America and the Caribbean, 1990-2013" in this volume. In addition, they report aggregate data on growth and productivity for 18 Latin American countries. In 2016, the LA KLEMS project was transferred from ECLAC to the Inter-American Development Bank (IDB) in Washington, D.C.

Ariel Coremberg summarizes a remarkable application of Argentina KLEMS in his contributions to this volume, "Argentina Was Not the Productivity and Economic Growth Champion of Latin America." In 2007, the Argentine government embarked on a program to manipulate the official statistics to exaggerate Argentina's economic performance. This policy was reversed by the current government. The Argentine statistical agency, INDEC, has reconstructed the Argentine national accounts according to internationally accepted principles. Earlier, the Argentina KLEMS research group at the University of Buenos Aires developed an unofficial system of national accounts for Argentina, largely anticipating the necessary

revisions. This was based on data sources less subject to political manipulation, including those for Argentina KLEMS.

Asia KLEMS is the third regional organization devoted to research on productivity and economic growth at the industry level. This includes the Japan Industrial Productivity database, used in analyzing the sources of Japan's lost decades since 1991 by Kyoji Fukao, Kenta Ikeuchi, Hyeogug Kwon, Younggae Kim, Tatsuji Makino, and Miho Takizawa (2016) in Chapter 3 of *The World Economy*. This database is supported by the Research Institute for Economy, Trade and Industry (RIETI), an agency of the Japanese government. RIETI also supports the China Industrial Productivity database reported by Harry X. Wu (2016) in Chapter 6 of *The World Economy*. The Korea Industrial Productivity database, supported by the Korea Productivity Center, was reported by Hak K. Pyo, Hyunbae Chun, and Kyunhee Rhee (2016).

The construction of the India KLEMS database is supported by the Reserve Bank of India. Deb Kusum Das, Abdul A. Erumban, Suresh Aggarwal, and Sreerupa Sengupta (2016) present the results in Chapter 7 of *The World Economy*. There is an extensive literature on China-India comparisons of economic growth. The first study to use industry-level data on growth and productivity for this purpose is found in this volume by Harry Wu, K. L. Krishna, Deb Kusum Das, and Pilu Chandra Das, "How Does the Productivity and Economic Growth Performance of China and India Compare in the Post-Reform Era, 1981-2011?."

Both China and India grew much more rapidly than the world economy, especially after India's economic reforms of the 1990s and China's accession to the World Trade Organization in 2001. China's aggregate output grew more than 50 per cent faster than India's. China's total factor productivity growth was adversely affected by the collapse of world trade

during the Great Recession and India's productivity growth was 25 per cent faster. Manufacturing accounted for 50.9 per cent of China's growth, but only 22.5 per cent of India's, while services contributed 56.2 per cent of India's growth, but only 29.0 per cent of China's. While India's total factor productivity performance for the two sectors reflected the positive contribution of the sectors to economic growth, China experienced negative productivity growth in services.

In the contribution, "Can Intangible Investments Ease Declining Rates of Return on Capital in Japan?," Tsutomu Miyagawa, Miho Takizawa, and Konomi Tonogi analyze the stagnation of the Japanese economy after the collapse of the "bubble economy" in 1991. Growth accounting based on the Japan Industrial Productivity database reveals a sharp decline in the rate of capital formation and an associated decline in the rate of return to capital. Detailed modeling shows that the rate of return is positively associated with intangible forms of investment, especially research and development, human capital, and information technology. The authors conclude that economic policy in Japan should stimulate investment in intangibles to revitalize capital formation and economic growth.

Investment in human capital is an important focus of research on economic growth and productivity. In Chapter 12 of *The World Economy* Gang Liu and Barbara Fraumeni provide an international survey of research on human capital investment. Michael S. Christian's article, "Net Investment and Stocks of Human Capital in the United States, 1975-2013," in this volume, provides an annual time series for the value of human capital and investment in human capital in the United States, eliminating an important gap in the literature.

Christian employs the lifetime income approach to human capital of Jorgenson and

Fraumeni (1989). This incorporates the costs of human capital investment, as well as the impact of this investment on labour incomes over the lifetime of each individual. Christian's primary conclusion is that human capital per capita in the United States has remained relatively constant with increased educational attainment offset by aging of the population. He compares the results with a cost-based approach to human capital measurement and confirms previous findings that the lifetime income approach yields estimates of investment in human capital that are several times larger. He concludes that the characterization of investment in human capital by the cost-based approach is incomplete and can be misleading.

Investment in information technology is a second important focus of research on growth and productivity. In Chapter 9 of *The World Economy*, Carol Corrado, Jonathan Haskel, and Cecilia Jona-Lasinio analyze the impact of investment in information technology and other intangible assets on productivity growth at the industry level in Europe. In article, "ICT Prices and ICT Services: What Do They Tell Us about Productivity and Technology" in this volume, David Byrne and Carol Corrado summarize a new line of research on the prices of information technology. These include prices for hardware and software, as well as prices for services like cloud computing and computer systems design.

Byrne and Corrado show that the composition of ICT outputs in the United States has shifted from hardware and software towards services. They also show that official prices indexes for ICT products have failed to track recent changes in technology. They present new estimates of ICT prices and new estimates of the contributions of ICT investments and ICT services to economic growth. They conclude that the contribution of information technology to economic growth is much larger than suggested by the official estimates.

International trade is a third important focus of research on growth and productivity. In Chapter 15 of *The World Economy*, Marcel Timmer, Bart Los, and Gaaitzen J. de Vries summarize research on global value chains (GVCs). They decompose international production processes for deliveries to final demand — consumption, investment, government, and exports — into the stages in which value is added by industry and country. The value chain is usefully identified by the final stage of production, for example, German automobiles. The value added at each stage of production is decomposed by the factors of production, capital and labour inputs. These factors can be further disaggregated, as in the KLEMS-type data sets described in the other chapters of *The World Economy*.

Timmer, Los, and de Vries present a new conceptual framework, the World Input-Output Database (WIOD), linking KLEMS-type data sets for more than forty countries by means of bilateral trade flows. Using Wassily Leontief's (1977) World Input-Output Model, the income generated by each of hundreds of global value chains can be broken down by industry, country, and capital and labour inputs. International trade is analyzed in terms of exchanges of value added among countries. Among the trends that emerge from this new perspective is greater fragmentation of international production with a diminishing role for domestic sources of value added. There is a greater role for emerging economies as sources of value added and a diminishing role for advanced economies. More value is added by capital and less by labour.

In Timmer's contribution in this volume, "Productivity Measurement in Global Value Chains," the WIOD database is applied to the measurement of productivity. Changes in the income generated in each global value chain are separated into price and quantity components.

Taking deliveries to final demand as outputs and the contributions of factors of production by all countries and industries as inputs, productivity of the value chain is output per unit of all inputs. Timmer illustrates the new approach to productivity measurement by the international production of German automobiles. The contribution of capital input accounts for about half of output growth, labour input for another 30 per cent and total factor productivity 20 per cent. He also shows that three-quarters of the productivity growth in the German automobile industry takes place in Germany.

I conclude that the World KLEMS Initiative established by Jorgenson, Timmer, and van Ark at the First World KLEMS Conference, held at Harvard University in 2010, is flourishing.⁴ The three regional organizations in the European Union, Latin America, and Asia are generating important new research on productivity and economic growth for the leading economies of the world. The contributions of capital and labour inputs have emerged as the predominant sources of economic growth in both advanced and emerging economies. Economic growth depends primarily on investments in human and non-human capital, including investments in both tangible and intangible assets. These investments take place through markets and the central role of government policy is to assure that the markets function properly and are relatively free of distortions. This has proved to be an enormous challenge during the Great Recession and the incomplete recovery.

Productivity continues to play an important role as a source of economic growth, but this role has diminished sharply in the aftermath of the Great Recession. Total factor productivity growth disappeared for long periods of time, for example, during the last two decades in the leading economies of Latin America and in the lost

4 For an overview of the initiative see Jorgenson (2012).

decades in Japan after the collapse of the bubble economy. Governments play a key role in providing incentives for productivity improvements. An example is the creation of property rights for the accumulation of intellectual capital through patent systems. A much more important role for governments is the maintenance of orderly markets for different types of investments. This must be adapted quickly to new circumstances like the emergence of new sources of financial instability.

The success of the World KLEMS Initiative has inspired governments to provide new information on growth and productivity. This has led to important innovations, like the creation of KLEMS-type databases as part of the national accounts. However, the framework for new data development is now expanding to encompass the world economy, as in the World Input-Output Database. This will open many opportunities for research like those already underway in human capital, information technology, and global value chains. It will also create an expanded role for international organizations like the United Nations and the OECD in providing the institutional framework for new research on growth and productivity in the world economy.

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Recent Trends in Europe's Output and Productivity Growth Performance at the Sector Level, 2002-2015

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ABSTRACT

Using the latest release of sector-level growth and productivity data up to 2015 from the EU KLEMS database, evidence is mounting that the global financial crisis (2008/09) and the Euro Area recession (2011/12) have significantly damaged the growth potential of European economies across the board. None of the countries in the 12 EU member states included in the analysis have recovered to growth rates anywhere near to what they were in the decade before the crisis. Slow productivity growth which was already visible in most market services sectors before the crisis has broadened to the goods-producing sector for most European economies since the crisis. The manufacturing sector was particularly hard hit, and has only partially recovered. The dynamics of the global and Euro Area crises and their impact seem still to be in full swing, making it too early to judge whether output and productivity growth rates can still recover to the pre-crises rate or whether growth in Europe will end up as a slower long-term trend.

Despite recent modest improvements in growth, the global economic and financial crisis in 2008-09 and the ensuing recession in 2011 and 2012 in Europe have raised concerns about the region's ability and potential to restore its long-term growth to pre-crisis rates. In the decade before the global financial crisis, between 1999 and 2006 real GDP growth grew at a 2.3 per cent average annual for the Euro

Area and 2.6 per cent for the EU-28. It slowed to 0.6 per cent and 0.9 per cent respectively between 2007 and 2016. For both periods, Europe's average growth performance was below that of the United States which recorded an average GDP growth of 3.4 per cent in the 1999-2006 period and 1.5 per cent in the 2007-2016 period (The Conference Board, 2017a).

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Earlier research has documented that productivity growth, which is an important metric of the long-term growth potential of an economy, has been an important cause of the growth slowdown in Europe since the mid-1990s (van Ark *et al.*, 2008, 2013a, Timmer *et al.*, 2010, Mas and Stehrer, 2012). For example, in the United States total economy GDP per hour increased 2.9 per cent per year, on average, from 1999 to 2006 compared to 1.5 per cent in the Euro Area and 1.9 per cent in the EU-28. In 2007-2016, the average annual growth rate of output per hour worked slowed to 0.6 per cent for the Euro Area and 0.7 per cent for the EU-28, even though a modest improvement in labour productivity growth has been recorded for 2015 and 2016. Strikingly, the slowdown in productivity growth for the United States has been even larger as it dropped to 1.2 per cent in 2007-2016 without any recovery in the most recent years (The Conference Board, 2017a).

Recent analysis has shown that the global financial crisis and the Euro Area recession have exacerbated the growth slowdown since 2008-09 because of slowing demand, weak investment and structural rigidities in product, labour and capital markets (van Ark, 2016a; van Ark and O'Mahony, 2016). In addition, while creating major business opportunities, the complex characteristics of the New Digital Economy, characterized by the combined shifts to mobile technology, cloud computing and storage and ubiquitous access to broadband, have created major business challenges in how to leverage these new technologies to drive productivity growth (van Ark, 2016b, van Ark *et al.*, 2016).

What has been less known so far is how the post-crises productivity dynamics in Europe

have played out at the sector level. In this article we employ the latest update of the EU KLEMS Growth and Productivity Accounts with updated estimates to 2015 which has been published recently on www.euklems.net.² The new data provide a unique opportunity to analyze eight years of productivity growth for the aggregate (total) economy and two major sectors in the economy (manufacturing and market services) since the beginning of the Global Financial Crisis for 12 European economies. Taken together those 12 economies (Austria, Belgium, Czech Republic, Denmark, Germany, Finland, France, Italy, the Netherlands, Spain, Sweden and the United Kingdom) will be called the EU-12. They accounted for 90 per cent of the European Union's nominal GDP in 2015.

Since the new estimates, which are based on the new European System of Accounts (ESA 2010), do not go back to the mid-1990s for some countries, we can only currently provide an integrated look at labour productivity growth for the period 2002-2015. In our analysis we divide this period into three sub-periods: the pre-crisis period (2002-2007), the global financial crisis itself and the immediate recovery (2008-2010), and the post-crisis period (2011-2015).³ It should be emphasized that most EU countries and the Eurozone as a whole experienced another recession (the Eurocrisis) in 2011/2012, which is included in the most recent period.

In addition to estimates of output and labour productivity growth (Table 1), we decompose output growth into the contributions of growth in hours worked, labour composition, ICT-capital, non-ICT capital, and total factor productivity for the aggregate (or total) economy, manufacturing, and market services (which

2 For an earlier review of EU KLEMS with data up to 2011/12, see Bart van Ark, Vivian Chen, and Kirsten Jäger (2013a).

3 Average annual compound growth rates use as a base for the calculation the year before the start of the period. Hence 2001 serves as the base for the 2002-2015 period, 2007 as the base for the 2008-2010 period, and 2010 as the base for the 2011-2015 period.

excludes the entire health care, education and government sectors of the economy) (Tables 2-4).⁴

Based on our analysis, it is fair to say that with sector data covering the first eight years since the beginning of the global financial crisis, the impact of the crisis on growth is still visible. It is therefore too early to make a final judgment on whether output and productivity growth in Europe can recover to the pre-crisis growth rates or whether Europe is ending up with a slower trend as predicted by many in recent years. However, so far the services sector and especially the manufacturing sector have not returned to pre-crisis or historical growth rates for output and productivity in most EU countries. Furthermore, projections for the aggregate economy for the next ten years from The Conference Board Global Economic Outlook suggest a partial return to that pre-crisis trend at best (The Conference Board, 2016).

The remainder of this article is organized as follows. In section 2 we briefly discuss the history of the EU KLEMS database and the characteristics of the latest update. In section 3 we highlight some of the important growth differences between two sectors (manufacturing and market services) in the EU-12 as well as between countries, looking separately at the larger economies (France, Germany, Italy, Spain and the United Kingdom) and the smaller ones (Austria, Belgium, Czech Republic, Denmark, Finland, the Netherlands and Sweden). Finally, in section 4 we conclude and discuss how growth and productivity in Europe might evolve over the next decade.

The EU KLEMS Project in the Post-Financial Crisis Period

The EU KLEMS project goes back to the late 1990s when the first initiatives were undertaken to develop productivity measures at the industry level for the European Union, following the seminal works by Jorgenson, Gollop and Fraumeni (1987) for the United States, Jorgenson, Kuroda and Nishimizu (1987) for Japan, and Conrad and Jorgenson (1985) for Germany. "KLEMS" refers to the decomposition of output growth into contributing factor inputs — capital (K) and labour (L) — and intermediate inputs — energy (E), materials (M), and service inputs (S).

The study of European growth accounts received a significant boost from the work by a Europe-wide consortium between 2004 and 2008 which culminated in several key publications on Europe's productivity performance (van Ark *et al.*, 2008; Timmer *et al.*, 2010; and Mas and Stehrer, 2012).⁵ The original EU KLEMS database, which was published in 2008 and which is still available from www.euklems.net, covers long-term series of output, input (including intermediates) and productivity measures at the industry level, based on official national accounts as well as secondary data going beyond official data. The original data series ran up to 2005 and included 72 industries.

Since 2008 several updates of the EU KLEMS accounts were published on www.euklems.net for a smaller number of European economies, for value added and capital and labour inputs only, and for a smaller number of industries: 34 down from the original 72 industries. The latest update was done in 2012/2013 by the University

4 Manufacturing and market services together make up an average of 58 per cent of aggregate (or total) economy nominal GDP for the 12 countries between 2010 and 2015 in the dataset, and exclude the primary sector (agriculture and mining), utilities, construction, and the public sector. The health care and the education sectors are entirely excluded from market services, as most organizations in those sectors are government-owned or largely funded by the government. Market services is therefore not precisely equivalent to services which are part of business sector in the United States and Canadian accounts, which would include all privately owned businesses. For more detailed estimates for all 34 industries, see www.euklems.net.

5 See Timmer *et al.* (2011) for an easily accessible summary version of Timmer *et al.* (2010).

of Groningen, with updates mostly to 2009 (and in a few cases to 2010, 2011 or 2012) for 12 countries, including the United States (Van Ark *et al.*, 2013a).

The new estimates for 12 European countries, presented in this article and also available from www.euklems.net, have been developed with a research grant from the European Commission to bring the accounts up to 2014/2015, to transfer the estimates to the new European System of Accounts (ESA 2010), which is part of the broader 2008 revision of the System of National Accounts under the auspices of the United Nations, and to make the accounts as consistent as possible with the official national accounts estimates for European countries.⁶ European national statistical institutes (NSIs) now all produce industry-level data based on the NACE 2 industry classification, which is consistent with the international standardized ISIC Revision 4 industry classification. The NACE 2 data used in this release are based on Eurostat insofar available.⁷

An important change between ESA 2010 and the previous national accounts system dating back to 1995 concerns the boundaries of physical assets in the national accounts. The inclusion of more assets in the definition of Gross Fixed Capital Formation (GFCF) required a significant revision to the structure of the non-financial assets classification in EU KLEMS. In previous EU KLEMS versions, ICT capital was classified in three categories, namely computing equipment (IT), communication equipment (CT) and software. The asset composition in the 2016 EU KLEMS version of the accounts is as follows:

- Computer hardware which is defined as computing equipment (IT) and telecommunications equipment (CT) together com-

prise ICT equipment. The series are comparable to what has been available under ESA 95.

- Computer software now includes databases and is therefore not entirely comparable to what was measured as software in the previous EU KLEMS datasets.
- Computer software and databases are now a subcomponent of intellectual property products (IPP), which also includes research and development and other intellectual property products (OIPP) consisting of mineral exploration and artistic originals (formerly known as other assets). OIPP is not readily available from Eurostat and has therefore been calculated by deducting computer software and databases and research and development from intellectual property products.
- Investment in cultivated assets (including livestock for breeding, dairy and draught, and vineyards, orchards and other plantations of trees) accounts for only a minor share in total GFCF as they are almost exclusively found in agriculture, forestry and fishing. Cultivated assets were part of 'other assets' in previous EU KLEMS releases and are treated as a separate asset type in the 2016 release to retain as much detail as possible.

The main methodological difference between the current release and previous EU KLEMS releases concerns the measurement of capital stocks and capital services. Prior to the 2016 release, capital stocks were calculated by applying the standard Perpetual Inventory Method (PIM) with consistent assumptions over time and across countries about the pattern of depreciation, the length of asset lives and the deflators for each of the assets. This so-called analytical

6 For a more detailed methodological analysis of the latest release, see Jäger (2016).

7 In addition to those 12 EU countries, additional partial productivity and input data up to 2015 for other EU member states, and the United States are also available from www.euklems.net.

module of the EU KLEMS database represented a deviation from the official estimates of capital stocks.

The new EU KLEMS release deviates from this previous practice as it uses capital stocks by industry and asset type which are directly obtained from Eurostat to ensure that official data are being used to the maximum extent. In addition, the computation of capital services, which are critical for the estimation of the capital contribution to growth, is not part of ESA (2010). For the calculation of capital services we therefore continue to rely on previous EU KLEMS practices of using geometric depreciation rates and internal rates of return. This approach creates an internal inconsistency as the depreciation rates used for the capital stock calculations by the national statistical offices may be different from the depreciation rates we use in the capital services calculations.⁸ We therefore recommend using the growth accounting data from the current release primarily for period averages, rather than year to year changes, and at more aggregate sector levels – as we do in this article – rather than for individual industries. The output and labour productivity estimates are not affected by this measurement issue.

The national accounts data from ESA 2010 which are used for the current EU KLEMS release span a shorter time period than the previous estimates which were available under ESA 1995. Earlier releases of the EU KLEMS databases provide time series back to 1970 and growth accounting decomposition with estimations of total factor productivity (TFP) growth generally starting in 1980. Back-casts of the time

series of output and labour data back to 1970 were made for the 2017 release through linkages to former EU KLEMS files to the extent possible.

Finally, unfortunately most EU countries are no longer providing detailed estimates of intermediate inputs broken down into value and prices for energy, material and services inputs by industry. To obtain such data one would need to estimate the inputs on the basis of input-output techniques. In order to preserve consistency with the published national accounts, we have therefore refrained here from producing estimates for energy, manufacturing, and services intermediates by industry.

Growth Performance Across European Economies

Table 1 provides an aggregate analysis of growth rates of output (measured as real GDP and real value added by industry) and labour productivity (measured as real value added per hour worked) for the total economy, manufacturing and the market services sector. Using a growth accounting framework, Tables 2-4 decompose the growth of aggregate value added into the contributions of labour quantity and quality, capital quantity and quality, and TFP for the total economy, manufacturing, and market services for the pre-crisis period (2002-2007), the global financial crisis itself and the immediate recovery (2008-2010), and the post-crisis period (2011-2015). It should be emphasized that most EU countries and the Eurozone as a whole experienced another recession in 2011/2012, which is included in the last period.⁹

8 To check the importance of this problem, we tried using the implicit depreciation rates from official data. While the implicit depreciation rates are generally close to the standard EU KLEMS depreciation rates, they can fluctuate substantially from one year or industry to another and sometimes even turn negative. Hence we decided to continue to rely on the standard EU KLEMS depreciation rates for all countries to calculate capital services (Jäger, 2016).

9 For more detailed estimates for all 34 industries, the reader is referred to the EU KLEMS website (www.euklems.net).

Table 1: Value Added and Labour Productivity in 12 EU Member States, 2002-2007, 2008-2010, and 2011-2015 (Average annual per cent change)

		EU-12	Austria	Belgium	Czech Republic	Denmark	Finland	France	Germany	Italy	Netherlands	Spain	Sweden	United Kingdom
Total Economy														
Gross Value Added	2002-2007	2.0	2.5	2.2	4.6	1.4	3.0	1.8	1.5	1.0	1.9	3.4	3.2	2.7
	2008-2010	-0.6	-0.3	0.5	0.1	-0.9	-1.8	-0.2	-0.4	-1.7	0.0	-0.7	-0.1	-1.0
	2011-2015	1.0	1.1	1.0	1.6	1.1	-0.3	1.0	1.5	-0.6	0.9	-0.2	1.4	1.9
Labour Productivity (value added per hour)	2002-2007	1.1	1.7	1.5	3.8	1.0	2.2	1.2	1.5	-0.2	1.7	0.0	2.7	1.5
	2008-2010	0.2	0.1	0.4	-0.1	0.3	-0.9	0.4	0.1	-0.1	0.3	1.6	-0.3	-0.3
	2011-2015	0.7	0.8	0.4	1.6	1.1	0.2	0.8	0.9	0.5	0.8	1.2	0.7	0.1
Manufacturing														
Gross Value Added	2002-2007	2.2	3.6	2.2	8.9	0.2	5.8	1.8	2.7	1.3	2.2	1.7	5.5	0.3
	2008-2010	-2.9	-2.4	-2.3	1.9	-3.2	-7.2	-2.3	-2.2	-4.8	-2.8	-4.6	-1.4	-2.7
	2011-2015	1.3	2.5	2.1	2.8	3.4	-3.0	1.2	2.5	-0.5	0.8	0.6	-0.8	0.5
Labour Productivity (value added per hour)	2002-2007	3.7	3.9	4.1	8.6	3.1	6.8	3.8	3.9	1.3	4.3	2.5	7.2	4.5
	2008-2010	0.7	0.3	1.9	4.8	3.8	-1.7	1.4	-0.4	0.7	-0.7	0.9	2.0	1.6
	2011-2015	1.4	2.1	3.2	1.5	3.6	-1.2	2.0	1.2	1.4	1.5	3.4	0.8	0.1
Market Services														
Gross Value Added	2002-2007	2.6	3.0	3.0	5.0	3.2	3.0	2.4	1.6	1.3	2.5	3.9	4.1	4.0
	2008-2010	-0.8	0.6	0.7	-0.8	-1.1	-0.5	0.1	-1.4	-1.1	-0.4	-0.5	1.0	-1.6
	2011-2015	1.6	0.9	1.1	1.2	1.8	0.9	1.4	1.8	-0.6	1.4	0.6	2.9	3.0
Labour Productivity (value added per hour)	2002-2007	1.4	2.0	2.3	3.9	2.3	1.3	1.4	0.6	-0.2	1.8	-0.1	3.7	3.2
	2008-2010	-0.5	1.0	0.2	-2.0	0.0	-0.6	-0.3	-1.2	-0.5	0.4	-0.3	-0.3	-0.3
	2011-2015	0.9	0.4	0.5	1.0	1.3	0.7	0.7	1.3	0.0	1.0	1.1	2.2	0.8

Notes: EU-12 refers to the value added weighted average of the 12 countries. Data from the 2011-2015 period end in 2014 for Italy, Czech Republic, and Sweden. All rates of change are expressed in log terms so that the growth rates are fully additive. The base year for the 2002-2007 period is 2001, for the 2008-2010 period it is 2007, and for the 2011-2015 period it is 2010.

Data source: EU KLEMS 2017 release, available at www.euklems.net.

Average EU-12 performance

Focusing on the EU-12 as a whole first, it can be observed that there has been a large drop in economy-wide output growth from 2.0 per cent per year on average in 2002-2007 to -0.6 per cent in 2008-2010, followed by recovery to 1.0 per cent in 2011-2015 which is well below the pre-crisis average. Labour productivity growth has shown more moderate swings from 1.1 per cent per year from 2002 to 2007 to 0.2 per cent from 2008 to 2010 back to 0.7 per cent from 2011 to 2015. This implies that labour hoarding, while employed in some countries during the crisis (such as in Germany) has been limited. Total hours worked declined 0.8 per cent on average per year from 2008-2010, and recovered at only 0.3 per cent per year from 2011-2015. Hence the output recovery since 2011 has been largely driven by a recovery in hours worked.

Following two back-to-back recessions, one might have expected a pro-cyclical productivity recovery to mostly benefit the manufacturing sector as companies wait before increasing their inputs (such as labour and investment) until they see whether the output recovery is sustained. While manufacturing productivity growth for the EU-12 recovered to 1.4 per cent on average in 2011-2015, following the collapse to only 0.7 per cent during the crisis (2008-2010), it is still just over one-third of the pre-crisis growth of 3.7 per cent (2002-2007).

In contrast to manufacturing, one normally expects the services sector to first boost employment in response to rising demand, as service productivity growth is usually harder to achieve in the short-term. Although the contribution of employment, in this study measured as total hours worked, to output growth in market ser-

Table 2: Contributions to Value Added Growth in the Total Economy in 12 EU Member States, 2002-2007, 2008-2010, and 2011-2015 (percentage points per year)

TOTAL ECONOMY	EU-12	Austria	Belgium	Czech Republic	Denmark	Finland	France	Germany	Italy	Netherlands	Spain	Sweden	United Kingdom
2002-2007													
GROSS VALUE ADDED GROWTH	2.0	2.5	2.2	4.6	1.4	3.0	1.8	1.5	1.0	1.9	3.4	3.2	2.7
Contribution of													
Labour input growth	0.6	0.5	0.6	0.7	0.5	0.7	0.5	-0.1	0.8	0.6	1.9	1.5	0.7
Total hours worked	0.4	0.3	0.4	0.3	0.2	0.6	0.4	-0.1	0.6	0.3	1.9	0.2	0.4
Labour composition	0.2	0.2	0.1	0.4	0.2	0.1	0.1	0.0	0.3	0.3	0.1	1.3	0.3
Capital input growth	1.0	0.9	1.0	1.7	0.7	0.6	1.0	0.7	1.0	0.4	1.8	1.3	0.9
ICT capital	0.2	0.1	0.3	0.2	0.2	0.2	0.2	0.3	0.1	0.2	0.4	0.3	0.2
Non-ICT capital	0.7	0.8	0.7	1.5	0.5	0.4	0.8	0.4	0.9	0.2	1.4	1.0	0.6
Total factor productivity growth	0.5	1.0	0.7	2.2	0.2	1.8	0.3	0.8	-0.8	1.0	-0.4	0.4	1.1
2008-2010													
GROSS VALUE ADDED GROWTH	-0.6	-0.3	0.5	0.1	-0.9	-1.8	-0.2	-0.4	-1.7	0.0	-0.7	-0.1	-1.0
Contribution of													
Labour input growth	-0.2	-0.2	0.3	0.3	-0.3	-0.4	0.2	0.1	-0.8	0.1	-0.9	0.5	-0.2
Total hours worked	-0.5	-0.3	0.1	0.0	-1.1	-0.5	-0.2	-0.2	-0.9	-0.1	-1.4	0.1	-0.6
Labour composition	0.3	0.1	0.3	0.3	0.8	0.2	0.4	0.4	0.1	0.2	0.4	0.4	0.4
Capital input growth	0.5	0.5	0.6	2.0	1.1	0.4	0.5	0.6	0.4	0.3	1.1	1.3	-0.1
ICT capital	0.1	0.1	0.2	0.1	0.1	0.1	0.1	0.3	0.0	0.2	0.2	0.3	0.1
Non-ICT capital	0.4	0.4	0.4	1.9	1.0	0.3	0.4	0.4	0.4	0.2	0.9	1.1	-0.1
Total factor productivity growth	-1.0	-0.6	-0.5	-2.3	-1.8	-1.8	-0.9	-1.1	-1.2	-0.4	-0.9	-2.0	-0.7
2011-2015													
GROSS VALUE ADDED GROWTH	1.0	1.1	1.0	1.6	1.1	-0.3	1.0	1.5	-0.6	0.9	-0.2	1.4	1.9
Contribution of													
Labour input growth	0.4	0.2	0.6	0.2	0.4	0.1	0.6	0.5	-0.5	0.2	-0.3	0.5	1.4
Total hours worked	0.2	0.2	0.4	0.0	0.1	-0.1	0.1	0.4	-0.6	0.0	-0.8	0.5	1.0
Labour composition	0.3	0.0	0.2	0.2	0.3	0.2	0.5	0.1	0.1	0.2	0.4	0.0	0.4
Capital input growth	0.4	0.6	0.3	2.3	0.3	0.1	0.4	0.4	-0.1	0.2	0.3	0.7	0.5
ICT capital	0.1	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1
Non-ICT capital	0.3	0.5	0.2	2.1	0.2	0.0	0.2	0.3	-0.1	0.1	0.2	0.6	0.4
Total factor productivity growth	0.2	0.3	0.1	-1.0	0.4	-0.4	0.0	0.6	0.0	0.4	-0.2	0.2	-0.1

Notes: For EU-12 composition, see Table 1. Italy, Czech Republic and Sweden exclude 2015, and the EU aggregate for 2011-2015 therefore only includes the average growth rate for those three countries from 2011-2014 instead of 2011-2015. All rates of change are expressed in log terms so that the growth rates are fully additive. The base year for the 2002-2007 period is 2001, for the 2008-2010 period it is 2007, and for the 2011-2015 period it is 2010. Data source: EU KLEMS 2017 release, available at www.euklems.net.

vices has improved since 2011, and average labour productivity growth recovered to 0.9 per cent (2011-2015), the latter remained less than two thirds of the pre-crisis (2002-2007) productivity growth rate in the sector, as well as two thirds of the manufacturing productivity growth rate from 2011-2015.

When decomposing the sources of growth (capital, labour and total factor productivity

growth) for the aggregate EU 12 into the performance for the aggregate economy (Table 2), manufacturing (Table 3) and market services (Table 4), we find confirmation that the two recessions (2008/09 and 2011/12) seriously impacted the growth of total hours worked in Europe. In manufacturing, the collapse in hours worked contributed more than three quarters to the overall contraction of output in 2008-2010.

In market services, where labour hoarding has been more common, the hours worked contribution was only modestly negative during the crisis period. From 2011 to 2015 the growth in hours worked returned to a positive contribution of less than half of the aggregate output growth in market services, while it remained negative for manufacturing.

Capital input has been a positive driver of growth in all three sub-periods, but also a major source of slower growth in the post-crisis period. While the contribution of capital input to output growth shrank during the crisis, it remained modestly positive even then. However, capital input has not seen any significant improvement since 2011 reflecting the weak recovery in investment in Europe. Especially in manufacturing, the contribution of capital has been less than 10 per cent of aggregate output growth in 2011–2015, and in market services only about one third of output growth. At the aggregate level, the contribution of non-ICT capital was three times as high as the ICT contribution from 2002–2007, a ratio which has remained roughly the same since.

Finally, TFP growth remains the Achilles' heel of Europe's growth performance. Even during the pre-crisis period (2002–2007) TFP in the total economy increased by only 0.5 per cent per year on average, and during the crisis period (2008–2010) the decline in TFP growth (at -1.0 per cent) was larger than for the other sources of growth sources, labour (-0.2 per cent) and capital (0.5 per cent). While the TFP recovery during the most recent period (2011–2015) was stronger than the rebound in the contributions of labour and especially capital, the TFP growth rate for the EU-12 has only just recovered to positive territory (0.2 per cent). The weak pace in TFP growth characterizes the slow diffusion of technology and innovation largely related to the weak growth of ICT capital and other important investments in productivity-related

capital, such as the stagnancy in the updating of equipment, and slow growth in parts of intangible capital, including R&D, training and economic competencies such as brand equity and organizational improvements.

While the broad trends of productivity slowdown and recovery apply to most individual countries, there are important cross-country differences. In the remainder of this section we review those differences between two groups of countries: the five larger economies (France, Germany, Italy, Spain and the United Kingdom) and seven of the smaller more open economies (Austria, Belgium, Czech Republic, Denmark, Finland, the Netherlands and Sweden).

The large European economies

While consumption and investment account for a large part of GDP in Europe's largest economies, these economies are quite distinct in terms of their external exposure and their policy responses to the global crisis. For example, according to the World Bank, the trade-to-GDP ratios (defined as the sum of exports and imports of goods and services measured as a share of gross domestic product) among the five largest economies in the EU-12 range from 57 per cent in the United Kingdom to 86 per cent in Germany. Related to this, the specialization patterns and industrial policy frameworks have differed among European countries, ranging from deep labour market reforms to boost employment growth (Germany, Spain and the United Kingdom) to more protectionist policies to support industrial growth and retain high wage levels across the economy (France and Italy).

Manufacturing sector performance

Germany, which is Europe's largest economy, stands out among the EU-12 for its relatively strong manufacturing performance. While Germany was the growth laggard during the pre-crisis

Table 3: Contributions to Value Added Growth in Manufacturing in 12 EU Member States, 2002-2007, 2008-2010, and 2011-2015 (percentage points per year)

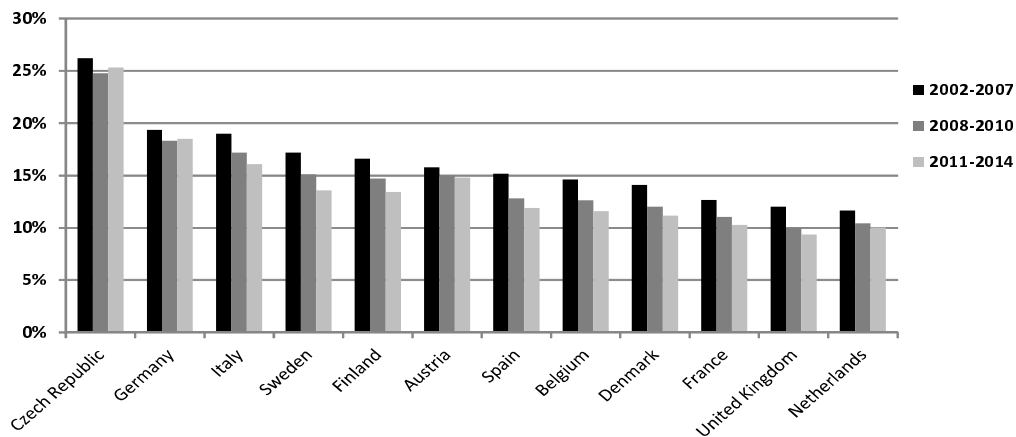
MANUFACTURING	EU-12	Austria	Belgium	Czech Republic	Denmark	Finland	France	Germany	Italy	Netherlands	Spain	Sweden	United Kingdom
2002-2007													
GROSS VALUE ADDED GROWTH	2.2	3.6	2.2	8.9	0.2	5.8	1.8	2.7	1.3	2.2	1.7	5.5	0.3
Contribution of													
Labour input growth	-0.7	0.2	-0.9	0.6	-1.5	-0.2	-0.8	-0.8	0.6	-0.7	-0.7	-0.6	-2.6
Total hours worked	-1.1	-0.2	-1.2	0.2	-1.9	-0.5	-1.2	-0.8	0.0	-1.2	-0.5	-0.8	-3.2
Labour composition	0.3	0.4	0.3	0.4	0.4	0.3	0.5	0.1	0.6	0.5	-0.1	0.2	0.6
Capital input growth	0.5	1.0	0.4	2.5	0.5	0.6	0.4	0.3	0.6	0.3	0.7	1.0	0.3
ICT capital	0.1	0.1	0.2	0.1	0.1	0.2	-0.1	0.1	0.0	0.1	0.2	0.2	0.0
Non-ICT capital	0.4	0.9	0.2	2.4	0.3	0.4	0.5	0.2	0.6	0.2	0.5	0.9	0.3
Total factor productivity growth	2.4	2.4	2.7	5.8	1.2	5.4	2.2	3.2	0.1	2.6	1.7	5.1	2.6
2008-2010													
GROSS VALUE ADDED GROWTH	-2.9	-2.4	-2.3	1.9	-3.2	-7.2	-2.3	-2.2	-4.8	-2.8	-4.6	-1.4	-2.7
Contribution of													
Labour input growth	-2.1	-1.5	-2.3	-1.1	-4.4	-2.6	-1.9	-0.9	-3.3	-0.6	-2.9	-1.8	-3.7
Total hours worked	-2.4	-1.5	-2.6	-1.6	-4.7	-2.9	-2.4	-1.2	-3.7	-1.2	-3.4	-1.7	-3.4
Labour composition	0.3	0.0	0.3	0.5	0.3	0.3	0.5	0.3	0.4	0.6	0.5	-0.1	-0.3
Capital input growth	0.2	0.8	-0.4	2.2	0.6	-0.2	0.1	0.4	0.2	0.1	0.2	0.7	-0.4
ICT capital	0.1	0.1	0.1	0.1	0.1	0.2	-0.1	0.1	0.0	0.1	0.2	0.2	0.0
Non-ICT capital	0.2	0.7	-0.5	2.1	0.6	-0.3	0.2	0.3	0.3	0.0	0.0	0.5	-0.5
Total factor productivity growth	-1.0	-1.7	0.5	0.8	0.6	-4.5	-0.4	-1.7	-1.7	-2.2	-1.9	-0.4	1.4
2011-2015													
GROSS VALUE ADDED GROWTH	1.3	2.5	2.1	2.8	3.4	-3.0	1.2	2.5	-0.5	0.8	0.6	-0.8	0.5
Contribution of													
Labour input growth	0.2	0.4	-0.3	1.0	0.2	-0.9	0.2	1.1	-0.9	-0.2	-1.3	-0.6	0.6
Total hours worked	-0.1	0.2	-0.7	0.7	-0.1	-1.1	-0.5	0.9	-1.2	-0.4	-1.7	-0.7	0.3
Labour composition	0.3	0.2	0.4	0.2	0.3	0.3	0.7	0.2	0.3	0.2	0.5	0.0	0.4
Capital input growth	0.1	1.0	-0.4	0.8	0.5	-1.2	0.2	0.3	-0.1	0.0	-0.5	0.2	-0.3
ICT capital	0.1	0.1	0.0	0.4	0.2	0.0	0.1	0.1	0.0	0.1	0.0	0.0	0.1
Non-ICT capital	0.0	0.9	-0.4	0.5	0.2	-1.2	0.1	0.3	-0.1	-0.1	-0.5	0.1	-0.3
Total factor productivity growth	0.9	1.0	2.8	1.0	2.8	-0.9	0.8	1.1	0.6	1.0	2.4	-0.3	0.1

Notes: For EU-12 composition, see Table 1. Italy, Czech Republic and Sweden exclude 2015, and the EU aggregate for 2011-2015 therefore only includes the average growth rate for those three countries from 2011-2014 instead of 2011-2015. All rates of change are expressed in log terms so that the growth rates are fully additive. The base year for the 2002-2007 period is 2001, for the 2008-2010 period it is 2007, and for the 2011-2015 period it is 2010. Data source: EU KLEMS 2017 release, available at www.euklems.net.

sis period, significant labour market reforms in the early 2000s, together with a strong focus on integrating the manufacturing sector into global value chains (van Ark *et al.*, 2013b), helped the economy to recover relatively rapidly from the crisis years. In 2011-2015, GDP increased at 1.5 per cent per year compared to 1.0 per cent for the EU-12. Much of this recovery came from faster output growth in the manufacturing sector (2.5 per cent compared to 1.3 per cent for the EU-12 in 2011-2015). Strikingly, a large part of

the manufacturing growth advantage in Germany originated from a strong performance in hours worked. Germany was among only four European countries with a positive and by far the highest (0.9 per cent) contribution from total hours to manufacturing output growth (Bellman *et al.*, 2016). However, in 2011-2015 labour productivity as well as TFP growth rates in German manufacturing were still much lower than in 2002-2007, and not very different from the EU-12 average (Tables 1 and 3).

Chart 1: Share of Hours Worked in Manufacturing as % of Total Economy Hours Worked



Notes: Countries are ranked on the basis of the largest share of manufacturing working in 2002-2007.

Data source: EU KLEMS 2017 release, available at www.euklems.net.

The strongest contrast to Germany's manufacturing performance can be seen in France. While manufacturing output in France increased at about two thirds of the rate in Germany from 2011-2015, labour productivity growth was much better at 2.0 per cent compared to 1.2 per cent in Germany. This is mainly because working hours growth in manufacturing in France have contracted throughout the 2002-2015 period, and France has seen one of the lowest manufacturing share in total hours worked (Chart 1). Even though French manufacturing workers make a strong output contribution from skill improvements, as seen by the above average contribution from labour composition, TFP growth in French manufacturing was only 0.8 per cent per year in 2011-2015 versus 1.1 per cent in Germany (Table 3).

In the United Kingdom the manufacturing sector had already shrunk significantly before the crisis years. Manufacturing output grew at only 0.3 per cent in 2002-2007 versus 2.2 per cent for the EU-12. In terms of the share in total hours worked, the UK has had the smallest manufacturing sector across the EU-12 since the beginning of the crisis (Chart 1). Since the crisis, UK manufacturing output growth has somewhat

recovered but it has been clearly driven towards more labour intensive manufacturing activities, as the growth in hours worked increased while the growth of capital input has remained negative since then (Table 3).

The manufacturing sectors in Italy and Spain have suffered much more from the crisis than the other three large economies as they experienced the deepest cuts in output during the crisis. An important difference between the two countries, however, is that manufacturing output and labour productivity growth recovered much more strongly in Spain than in Italy. While both Italy and Spain made deep cuts in total hours worked, the manufacturing sector in Spain restructured much faster as total factor productivity increased at 2.4 per cent per year in 2011-2015 vis-à-vis 0.6 per cent in Italy (Table 3). However, despite below-average growth, there are signs that Italy does benefit more from its manufacturing sector to support its recovery than in many other economies. Notably Italy still has the third largest manufacturing sector (after Czech Republic and Germany) among the EU-12 (Chart 1), and (together with Spain) saw a better TFP growth rate in 2011-2015 compared to 2002-2007 (Table 3).

Table 4: Contributions to Value Added Growth in Market Services in 12 EU Member States, 2002-2007, 2008-2010, and 2011-2015 (percentage points per year)

MARKET SERVICES	EU-12	Austria	Belgium	Czech Republic	Denmark	Finland	France	Germany	Italy	Netherlands	Spain	Sweden	United Kingdom
2002-2007													
GROSS VALUE ADDED GROWTH	2.6	3.0	3.0	5.0	3.2	3.0	2.4	1.6	1.3	2.5	3.9	4.1	4.0
Contribution of													
Labour input growth	1.0	0.9	0.8	1.1	1.2	1.3	0.9	0.4	1.1	0.8	2.8	1.1	1.2
Total hours worked	0.8	0.7	0.5	0.6	0.7	1.3	0.7	0.5	1.0	0.6	2.7	0.3	0.6
Labour composition	0.2	0.2	0.3	0.6	0.5	0.0	0.2	-0.1	0.1	0.2	0.1	0.8	0.6
Capital input growth	1.1	0.9	1.3	1.7	0.8	0.0	1.2	1.1	1.1	0.1	2.0	1.6	1.0
ICT capital	0.4	0.2	0.5	0.4	0.3	0.3	0.4	0.6	0.1	0.3	0.6	0.5	0.4
Non-ICT capital	0.7	0.6	0.8	1.3	0.4	-0.4	0.8	0.5	0.9	-0.1	1.4	1.2	0.6
Total factor productivity growth	0.5	1.2	0.9	2.1	1.3	1.7	0.3	0.1	-0.9	1.5	-0.9	1.4	1.8
2008-2010													
GROSS VALUE ADDED GROWTH	-0.8	0.6	0.7	-0.8	-1.1	-0.5	0.1	-1.4	-1.1	-0.4	-0.5	1.0	-1.6
Contribution of													
Labour input growth	0.1	0.3	0.7	1.0	0.2	0.0	0.8	0.3	-0.4	-0.1	0.3	1.1	-0.4
Total hours worked	-0.2	-0.2	0.3	0.6	-0.9	0.1	0.3	-0.2	-0.4	-0.5	-0.2	0.8	-0.9
Labour composition	0.4	0.5	0.3	0.4	1.1	-0.1	0.5	0.4	0.0	0.4	0.5	0.2	0.5
Capital input growth	0.5	0.3	0.6	3.0	0.8	-0.1	0.7	0.9	0.2	0.0	0.8	1.4	0.1
ICT capital	0.2	0.1	0.3	0.2	0.2	0.1	0.3	0.5	-0.1	0.2	0.2	0.4	0.1
Non-ICT capital	0.3	0.2	0.3	2.9	0.6	-0.2	0.4	0.4	0.2	-0.2	0.6	1.0	-0.1
Total factor productivity growth	-1.5	0.1	-0.6	-4.9	-2.1	-0.5	-1.4	-2.5	-0.9	-0.3	-1.5	-1.5	-1.3
2011-2015													
GROSS VALUE ADDED GROWTH	1.6	0.9	1.1	1.2	1.8	0.9	1.4	1.8	-0.6	1.4	0.6	2.9	3.0
Contribution of													
Labour input growth	0.7	0.5	0.7	0.2	0.8	0.4	1.1	0.4	-0.4	0.7	0.1	0.6	1.9
Total hours worked	0.5	0.4	0.4	0.1	0.5	0.2	0.5	0.3	-0.4	0.4	-0.3	0.5	1.6
Labour composition	0.3	0.1	0.3	0.2	0.3	0.3	0.7	0.1	0.0	0.3	0.4	0.1	0.3
Capital input growth	0.4	0.5	0.2	2.5	0.0	0.0	0.5	0.4	-0.2	-0.1	0.5	0.8	0.5
ICT capital	0.2	0.1	0.2	-0.1	0.2	0.1	0.3	0.2	0.0	0.2	0.2	0.2	0.2
Non-ICT capital	0.2	0.4	0.1	2.5	-0.2	-0.2	0.2	0.2	-0.2	-0.3	0.2	0.6	0.4
Total factor productivity growth	0.4	-0.1	0.1	-1.5	1.0	0.5	-0.2	1.0	0.0	0.8	0.1	1.5	0.5

Notes: For EU-12 composition, see Table 1. Italy, Czech Republic and Sweden exclude 2015, and the EU aggregate for 2011-2015 therefore only includes the average growth rate for those three countries from 2011-2014 instead of 2011-2015. All rates of change are expressed in log terms so that the growth rates are fully additive. The base year for the 2002-2007 period is 2001, for the 2008-2010 period it is 2007, and for the 2011-2015 period it is 2010. Data source: EU KLEMS 2017 release, available at www.euklems.net.

Services sector performance

In market services, the United Kingdom has seen the best growth performance of the five large economies in the EU-12. While the financial sector was especially hurt during the crisis, output growth in market services recovered to 3.0 per cent on average in 2011-2015, well above the EU-12 average of 1.6 per cent. However, total hours worked accounted for as much as half of market services output growth from 2011-2015 (Table 4). The weakness of labour productivity growth in UK services has been widely discussed, with the most important explanation

being the high absorption capacity in Britain's services sector for low-productivity jobs (Barnett *et al.* 2014; Bryson and Forth, 2016).

Market services output has recovered slightly more in Germany than in France in 2011-2015, at 1.8 per cent and 1.4 per cent respectively. However, contrary to conventional wisdom, France saw a higher contribution from labour input to market services growth, especially because of much stronger skill improvements in services sector jobs (Askenazy and Erhel, 2016). In contrast, German labour market reforms in the early 2000s may have been more favorable to

low-skill jobs. On the other hand, TFP growth in market services was much stronger in Germany than in France in 2011-2015, at 1.0 per cent and -0.2 per cent respectively (Table 4). Germany's market services sector may also have benefitted from the economy's integration into global value chains (van Ark *et al.*, 2013b)

In contrast to France, Germany and the United Kingdom, Italy and Spain have seen a much slower recovery in market services. Italy was even the only country with a negative output growth in market services in 2011-2015. The contributions of labour input to output growth were also still negative from 2011 to 2015 in Italy and just above zero in Spain compared to a positive growth contribution of 0.7 per cent for the EU-12 average. Total factor productivity growth in market services in Italy was flat from 2011 to 2015 and only 0.1 per cent in Spain (Table 4).

The small European economies

Among the seven smallest economies in the EU, a distinction can be made between those economies that have relatively large manufacturing sectors (Austria, Czech Republic, Finland and Sweden) and those that have relatively large market services sectors (Belgium, Denmark and the Netherlands). These differences are determined by international specialization patterns.

Large manufacturing sectors

Among the small economies with relatively large manufacturing sectors, Finland suffered by far the hardest hit during the global recession, as it experienced a major collapse in manufacturing output and productivity. To a large extent this development reflects the demise of its communication equipment industry which flourished during 1990s and early 2000s. The share of manufacturing in total hours worked dropped strongly during the crisis after which it did not recover (Chart 1), and manufacturing output

growth shrank dramatically by 7.2 per cent per year from 2008 to 2010. Finland is now significantly restructuring its manufacturing sector even though TFP growth in the sector remained negative until 2015 (Table 3).

Swedish manufacturing, which has also heavily relied on technology production, saw a much more moderate drop in manufacturing output during the crisis and was able to keep the productivity slowdown at bay. However, the recovery since 2011 has been slow, and Sweden saw one of the largest drops in its manufacturing employment share among the EU-12 economies (Chart 1).

In contrast, Austria and especially the Czech Republic retained their strength in manufacturing. The Czech manufacturing sector has by far the largest share of total hours in the EU-12 economies at more than 25 per cent while Austria has 15 per cent just behind Germany and Italy (Chart 1). While both countries saw a large drop in manufacturing labour productivity growth during the crisis, Austria saw a quick recovery when labour productivity returned to 2.1 per cent per year on average in 2011-2015. In contrast to Austria, the Czech Republic saw a much stronger recovery in total manufacturing hours worked since 2011, while labour and TFP growth dipped even below Austria's. These differences in growth dynamics largely stem from both countries' contribution to and specialization in the value chain network formed by Germany and other Central European economies (also including Poland, Hungary and Slovakia) which has functioned as a European stronghold since the crisis (van Ark *et al.*, 2013b).

Large market services sectors

Belgium, Denmark and the Netherlands have among the largest market services sectors in Europe in terms of employment share, which signals the high level of specialization in business and consultancy services in those econo-

mies. However, the three economies responded quite differently during the crisis. Whereas the market services sector in Belgium saw a significant amount of labour hoarding during the crisis, the Danish and Dutch services sector rapidly adjusted labour input to meet the challenges posed by the crisis. This led to positive contributions (Belgium) versus negative contributions (Denmark and the Netherlands) of labour input to output growth, and the opposite for labour and total factor productivity which saw higher growth rates for Denmark and the Netherlands than in Belgium (Table 4). Those divergent adjustment effects for labour and productivity contributions are typical of recovery periods. Meanwhile none of the countries has seen a recovery in market services labour productivity (0.5 per cent in Belgium, 1.3 per cent in Denmark and 1.0 per cent in the Netherlands in 2011-2015) to anywhere near their pre-crisis performance (2.3 per cent in Belgium and Denmark and 1.8 per cent in the Netherlands in 2002-2007).

Conclusions and a Forward Looking Perspective

The analysis of the latest sector-level growth and productivity data from the EU KLEMS database show that the global financial crisis (2008/09) and the Euro Area recession (2011/12) have significantly damaged the growth performance of European economies across the board. Except for Germany, none of the countries in our EU-12 group have recovered to growth rates anywhere near to what they were in the decade before the crisis. The slowing growth trend is driven by a triple combination of a modest recovery in employment growth, stagnant growth in capital input growth and a weakening in the TFP growth trend. Slow productivity growth which was already visible in most market services sectors before the crisis has broadened to the goods producing sector for most Euro-

pean economies after the crisis. The manufacturing sector was particularly hard hit by crisis, and has only partially recovered effects since the crisis.

We conclude that the global financial crisis and the Euro Area recession may have accelerated the demise of the manufacturing sector in Europe which has been losing much terrain in terms of output, investment and productivity growth. In addition, growth in total hours worked in manufacturing has hardly begun to recover by the end of the latest period in our analysis, which stops in 2015. It may of course be argued that, as the recovery has been ongoing since 2016, a further improvement in manufacturing productivity growth may have occurred since then. However, recent estimates of manufacturing labour productivity growth from the International Labour Comparisons program at The Conference Board show that growth rates for 2016 have been about the same as in 2011-2015, namely at 1.5 per cent (The Conference Board 2017b).

At the same time the services sector has increased its importance in the economy, and recovered slightly better from the crisis. Total hours worked recovered strongly in 2011-2015, and the output contribution of capital input growth in market services was in fact stronger than in manufacturing for the aggregate EU-12. Finally, TFP growth in market services, while still below that in the manufacturing sector, has recovered to the pre-crisis growth rates while this is not the case as yet for manufacturing TFP growth. However, both output and labour productivity growth rates in market services in 2011-2015 were still at about half of the 2002-2007 growth rates (Table 1).

Based on the analysis, it is fair to say that even with sector data covering the first seven years since the global financial crisis, the dynamics of the global crisis and their impact seem still to be in full swing. It is still too early to make a final

Table 5: Projections of Sources of GDP Growth in Europe, Measures as Contribution of Factor Inputs Quality and Quantity and TFP Changes to GDP Growth, 2002-2026

	2002-2007	2008-2010	2011-2016	2017-2021	2022-2026
GDP growth	2.3	-0.5	1.1	1.7	1.2
<i>Quantity</i>	<i>1.5</i>	<i>0.4</i>	<i>0.9</i>	<i>0.7</i>	<i>0.3</i>
Capital Quantity	1.1	0.8	0.6	0.5	0.5
Labor Quantity	0.4	-0.5	0.2	0.2	-0.2
<i>Quality</i>	<i>0.7</i>	<i>-0.9</i>	<i>0.2</i>	<i>1.0</i>	<i>0.9</i>
Capital Quality	0.4	0.3	0.2	0.2	0.1
Labor Quality	0.2	0.1	0.1	0.2	0.2
<i>Total Factor Productivity</i>	<i>0.1</i>	<i>-1.3</i>	<i>-0.1</i>	<i>0.6</i>	<i>0.5</i>

Notes: Europe includes European Union-28 as well as Switzerland, Iceland, and Norway.

Data source: The Conference Board Global Economic Outlook 2017, available at (<https://www.conference-board.org/data/globaloutlook/>). See also Erumban and de Vries (2016).

judgment on whether output and productivity growth can recover to the pre-crises growth rates or whether we will experience slower trend growth as predicted by many.

However, the triple weaknesses in employment, investment and productivity growth suggest that medium-term factors may still be predominant in explaining slow growth in Europe. Beyond the temporary cyclical impact from the recessions related to weak demand, the slow medium-term forces can be a sign of weakening innovation and technological change as companies hold back on new investment due to longer term concerns about demand and investment. This could point at the possibility of "secular stagnation" due to a persistent shortfall in demand and an erosion of supply-side factors as established by the long-term slowdown of potential output growth (Teulings and Baldwin, 2014).

In addition, the low interest rate policy which has been implemented by the European Central Bank might have caused increased misallocation of resources to low-productive firms. This would especially be harmful in times during which scale-dependent technologies such as communication technology require flexibility across a larger economic space. Limited scale

effects in Europe, related to fragmented markets and limited impacts from ICT utilization might have played a larger role than in the United States especially during the first decade of the century (Timmer *et al.*, 2010).

It is also possible that there is a lull in the emergence of productive technology applications. As is not uncommon with General Purpose Technologies, productivity growth during the installation phase of the New Digital Economy (which represents the combined shift to mobile technology, cloud storage and computing and ubiquitous internet access) has gone together with increased business spending on technology assets and human capital, without immediate effects on output and productivity growth. There is accumulating evidence that businesses are still in their early days of turning the opportunities offered by the New Digital Economy into significant productivity gains (van Ark, 2016b; van Ark *et al.*, 2016). The recent improvement in aggregate productivity growth — while largely cyclical — could also become a driver for a stronger technology impact on productivity.

Growth projections for the aggregate economy (Table 5), based on The Conference Board Global Economic Outlook show the challenges

ahead (The Conference Board 2016; Erumban and de Vries, 2016). A recovery in Europe to an average GDP growth rate of 1.7 per cent in 2017-2021 is heavily dependent on faster TFP growth. The latter might in part be driven by a recovery from lost terrain during the past two decades and a positive impact from new technology implementation on growth. Such a turnaround in TFP growth would be especially welcome in light of a weakening growth in labour supply as a result of an aging population in most European economies. The decline in the labour contribution to growth in the 2020s may in fact be offset by capital-intensive output growth driven by technological change. However, this will also be dependent on the ability of the European economies to shift to a larger output contribution from labour quality as measured by the average educational attainment level of the workforce, and an increased intensity of ICT relative to non-ICT capital. The latest EU KLEMS growth and productivity measures presented in this article show the need for significant action in the policy environment, as described above, to meet the challenges of future growth in Europe.

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The Role of Capital Accumulation in the Evolution of Total Factor Productivity in Spain

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ABSTRACT

GDP growth in Spain was strong for much of the last half century, whereas the country's productivity performance during these years has been mediocre. The reasons for this situation have frequently been analysed with the focus on labour productivity. But, as this article highlights, the evolution of capital productivity should also be taken into account when looking for explanations for poor productivity performance. This article analyses the sources of growth in the Spanish economy, in comparison with major economies, and takes into account the effects that the improvements in the measurement of inputs (labour and capital) have on TFP estimates. Once problems are identified and the role played by labour and capital is evaluated, the paper analyses the possible causes for the negative results in terms of productivity in Spain and what policies can be considered to improve it.

For much of the last half century, GDP growth in Spain has been strong, while productivity growth has been mediocre. The reasons for this situation have frequently been the subject of analysis, with the focus on labour productivity. Nevertheless, the abundant data available on trends in physical and human capital deserves attention, particularly during the later stages of expansion (1995-2007) and the economic crisis (2008-2013).² This article analyses this topic,

examining the impact of measurement improvements on estimates of labour and capital inputs. These improvements capture changes in quality, which can increase new productive services, with implications for both labour and capital growth.³ These changes are already incorporated into the estimates developed within the framework of the EU KLEMS and WORLD KLEMS research programs.⁴

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 - 2 The capital stock database on the Spanish economy was created by the BBVA Foundation and the IVIE. The most recent estimates are found at http://www.fbbva.es/TLFU/microsites/stock09/fbbva_stock08_index.html. An analysis of the results is provided by Serrano, Pérez, Mas and Uriel (2017).
 - 3 See Jorgenson, Ho and Stiroh (2005a, 2005b), OECD (2009), Jorgenson and Schreyer (2013) and Hulten (2006).
 - 4 The WORLD KLEMS project aims to promote and facilitate the analysis of growth patterns and evolution of productivity throughout the world, based on growth accounting. To do this, one of its objectives is to offer users databases with the necessary variables to carry out these analyses. Within this framework, the EU KLEMS project is dedicated to analysing and collecting data for European countries. See <http://www.worldklems.net/> and <http://www.euklems.net/> for more information on these two initiatives.

When we measure the sources of growth taking into account the composition of labour and capital (that is, considering labour and capital services instead of hours worked and net capital stocks), part of technical progress is embodied in both factors and the exogenous part of technical progress, which is called total factor productivity (TFP) and computed as a residual, is reduced. The exercise is important for clarifying the origin and scope of efficiency improvements in economies, and especially for reviewing the traditional interpretation of productivity problems in Spain. The low or negative growth rates in TFP are almost always attributed to poor labour performance (lower contribution of workers to growth than what would be expected based on their educational attainment), labour market malfunctioning and low educational results (elevated high school drop-out rates as well as low PISA scores). This study underlines why capital productivity should also be considered.

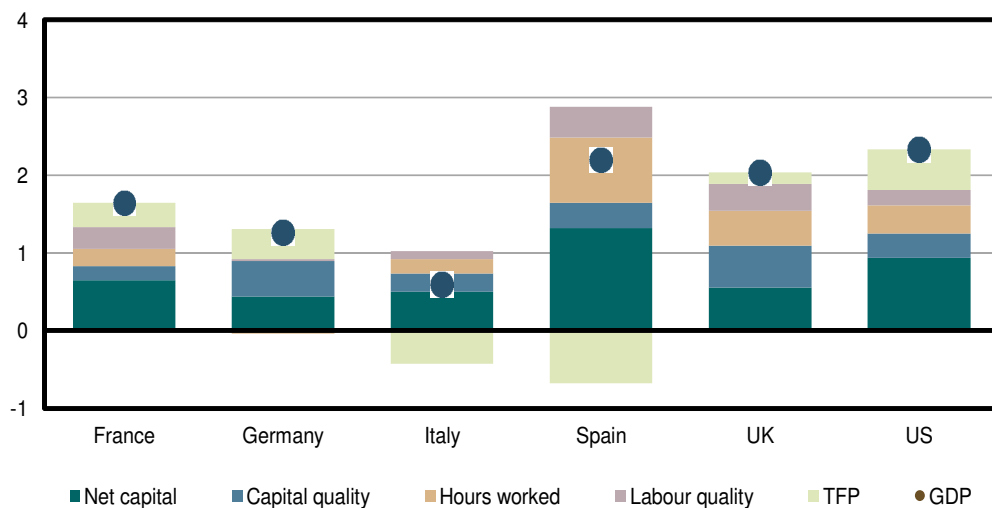
Capital productivity in the Spanish economy has not received a great deal of attention, with only a few exceptions.⁵ However, for more than

two decades the available capital series have shown that the trajectory of capital productivity is indeed worrying, as the series have illustrated a generally decreasing trend. This fall is accentuated when productive capital (capital services) is used for the calculation of capital productivity instead of net capital, as changes in the composition of capital stock by asset type are acknowledged.

This article analyses the sources of growth in the Spanish economy to answer three questions. First, what role does the orientation of investments and capital productivity play in the evolution of TFP in Spain? Second, what are the causes of the negative evolution of capital productivity? Third, what productivity improvement policies should be considered in Spain? And how can the investment orientation, as well as labour market reforms, contribute to them?

The article contains five sections. Section 1 analyses (in a comparative perspective) how the sources of growth have evolved in Spain and the intensity of physical and human capitalization processes. Section 2 studies the trajectory of

Chart 1: Contributions to GDP Growth in Major European Countries and the United States, 1995-2012 (average annual percentage points contribution)



Source: EU KLEMS (2012), Jorgenson and Vu (2016), The Conference Board (2015) and authors' estimates.

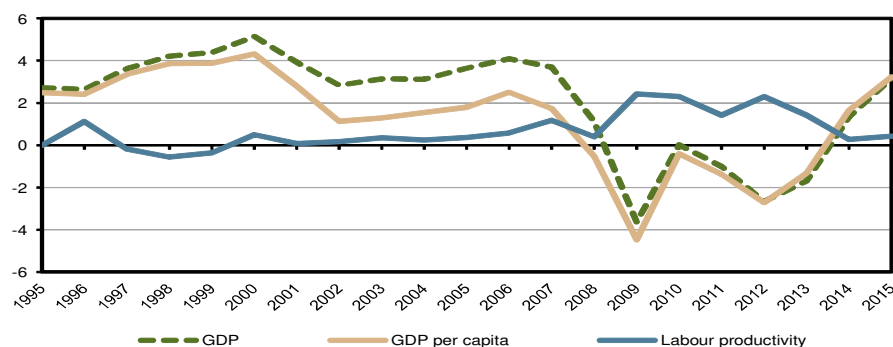
5 See Pérez and Benages [2014], Pérez *et al.* [2011]; and Timmer *et al.* [2010] for an international perspective.

Table 1: Contributions to GDP Growth in Major European Countries and the United States, 1995-2012 (percentage point contributions per year)

	France	Germany	Italy	Spain	United Kingdom	United States
GDP	1.65	1.27	0.60	2.20	2.04	2.33
Net capital	0.65	0.44	0.50	1.32	0.56	0.94
Capital quality	0.18	0.45	0.24	0.33	0.54	0.31
Hours worked	0.22	-0.04	0.19	0.84	0.45	0.36
Labour quality	0.28	0.02	0.10	0.40	0.35	0.20
TFP	0.31	0.39	-0.43	-0.68	0.15	0.52

Source: EU KLEMS (2012), Jorgenson and Vu (2016), The Conference Board (2015) and authors' estimates.

Chart 2: GDP, GDP Per Capita and Labour Productivity in Spain, 1995-2015 (per cent change)



Source: INE (2016) and authors' estimates.

TFP and its determinants. The possible causes of the slowdown in TFP are explored in section 3, while section 4 analyses the factors explaining the negative trajectory of capital productivity. The fifth and last section reflects on the implications of the different hypotheses considered for the orientation of productivity improvement policies.

Sources of Spanish Growth

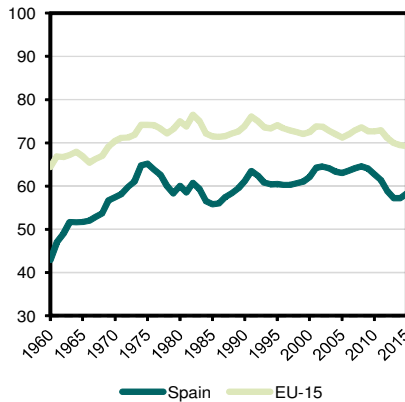
Compared to the main European countries (Germany, France, the United Kingdom and Italy), Spain's economic growth has been strong in the last decades. Indeed, Spain is the only country that equals the United States in terms of the growth rate of real GDP. But what is different about Spanish growth in comparison with the other reference countries is the very different composition of its sources. This is the case in three respects: a) the more intense accumulation

of net capital; b) the intensity of labour factor contributions to GDP, both in terms of hours and quality improvements: and c) like Italy (but with greater intensity), the sharp decline in TFP, which has been more than half a percentage point a year for nearly two decades.

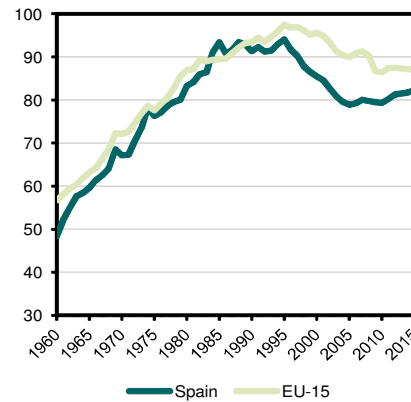
The most common interpretation of the productivity trajectory in Spain, provided by Chart 1 and Table 1, focuses on the evolution of labour productivity defined as output per hour worked. Chart 2 offers this perspective, showing annual growth rates from 1995 to 2015 for gross domestic product (GDP), GDP per capita and labour productivity defined as output per hour worked. In this trajectory there are three trends which stand out: a) GDP growth and GDP per capita evolved in a similar way at the beginning of the period, but between 2000 and 2009 they diverged, as a result of the significant population growth arising from the intense immigration in

Chart 3: GDP Per Capita and Labour Productivity in Spain and the EU-15 Relative to the United States, 1960-2015 (United States = 100)

Panel A: GDP per capita



Panel B: Labour productivity



Source: BBVA Foundation-IVIE (2017), European Commission (2016), World Bank (2016), EU KLEMS (2012), The Conference Board (2015) and authors' estimates.

the first decade of this century; b) the growth rates of GDP and GDP per hours worked dropped sharply from 2007, reflecting an intense W-shaped crisis which saw the economy experience negative growth rates at two different points between 2009 and 2013; c) hourly labour productivity growth followed a less irregular trajectory than that of GDP, but was usually between 0 and 2 per cent, a moderate improvement given the important capitalization processes of those two decades.

The trend in output per hour worked in Spain is weak when compared to that of the more developed countries and the higher income levels of these economies is taken into account. Panel A in Chart 3 confirms that since 1960 Spanish GDP per capita has always been in the range of 45 per cent to 65 per cent of that of the United States and roughly 10 percentage points below the EU-15 average.⁶ This Spanish delay fostered an intense convergence process in labour productivity with the United States and to a lesser degree with the European Union

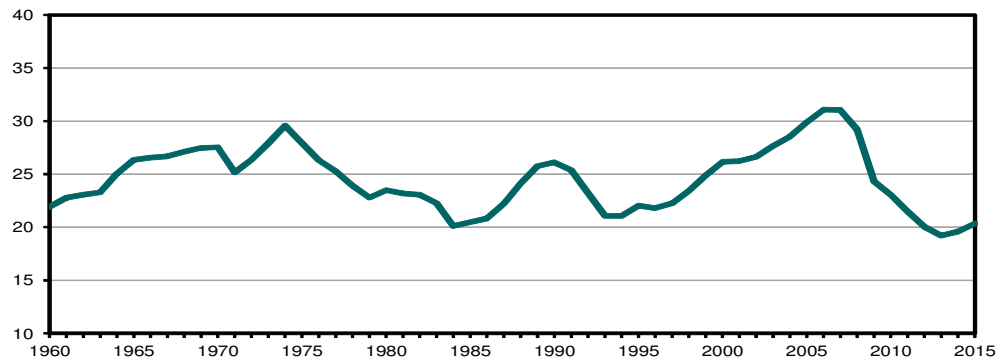
from the beginning of the 1960s until Spain joined the European Union (EU) in 1986. After 1986 convergence ended with the United States as it did with the EU-15 a decade later.

The last cycle of positive growth in Spain began in 1995 and turned out to be a period of divergence in labour productivity with Europe, and even more so with the United States. This divergence slowed down with the onslaught of the crisis but the disadvantage compared with the American economy remained at levels similar to those of 1980, putting labour productivity once again at 80 per cent of the US level. The gap with the EU-15 is currently small, just over 5 per cent, but Europe has also accumulated labour productivity disadvantages in comparison with the United States since 1995 (Chart 3, Panel B).

The stagnation in the convergence of GDP per capita in Spain with respect to the reference economies derives from a combination of sources of growth which failed to simultaneously bring about improvements in employ-

6 EU15 comprised the following 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom.

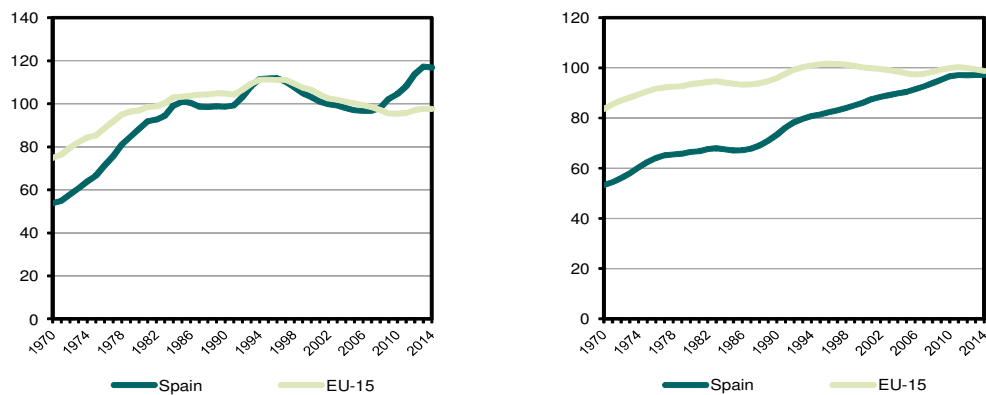
Chart 4: The Spanish Investment Effort, 1960-2015 (gross fixed capital formation/GDP)



Source: BBVA Foundation-IVIE(2017) and INE (2016a).

Chart 5: Net Capital Stock Per Employed Person and Per Capita in Spain and the EU-15 Relative to the United States, 1970-2014 (United States= 100)

Panel A: Net Capital Stock Per Employed Person Panel B: Net Capital Stock Per Capita

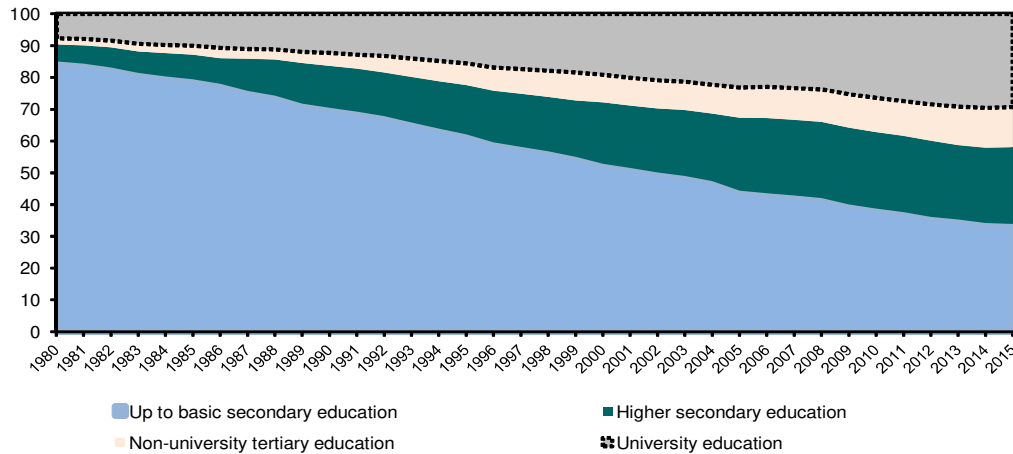


Source: BBVA Foundation-IVIE (2017), European Commission (2016), EU KLEMS (2012), The Conference Board (2015) and authors' estimates.

ment and labour productivity. On the contrary, labour productivity often improves when employment is destroyed, and when employment grows labour productivity stagnates and diverges from that of other countries. This evolution of labour productivity is striking for two reasons. First, the investment effort of the Spanish economy has been strong, with the gross fixed investment/GDP ratio always above 20 per cent, even exceeding 25 per cent between 2000 and 2007 (Chart 4). Second, because of this intense process of accumulation, the capital endowments per worker have continuously improved, to the point that they are not below those of the United States and EU-15 (Chart 5).

The high intensity of gross fixed capital formation which has taken place over several decades has multiplied by almost six times Spanish capital endowments in the last fifty years and by four the ratios of capital per worker. The net capital endowments per worker in Spain were low half a century ago in relation to those of the EU-15 and the United States, but they have since converged completely with those of these economic areas, even surpassing that of the United States (Chart 5, Panel A). Compared with the United States and the EU-15, the Spanish disadvantages in capital endowments per capita are also very small if not nonexistent (Chart 5, Panel B).

Chart 6: Educational Attainment of the Employed Population in Spain, 1980-2015 (per cent of total employed population)



Source: Encuesta de Población Activa (EPA), Instituto Nacional de Estadística, and authors' estimates.

Growth theory predicts that increasing capital endowments per worker will improve labour productivity by allowing workers to develop their productive capacity, relying on more equipment until a stationary state is reached. In this sense, the intense stock accumulation in Spain since 1995 would predict strong increases in labour productivity which, to date, have not been seen. Reaching similar levels of capital per worker to the EU or the United States but not converging in labour productivity implies that resources are used less efficiently in Spain. This less efficient labour factor would serve (given a certain level of wages) to slow down employment growth.

The rate of net capital accumulation is not the only variable to be considered when analyzing the path of labour productivity: changes in the composition of labour and capital stock are also relevant, since these changes affect the productive potential of both factors. Changes in the composition of factors are ways in which technical progress is embodied, thereby reducing the

Solow residual which measures disembodied technical progress. The data now available makes it possible to assess more accurately past changes in the quality of factors⁷ and how embodied technical progress is greater and disembodied technical progress (TFP) is lower.

Changes in the composition of productive resources in Spain are significant. First, accumulated educational improvements have substantially improved the level of educational attainment of the working-age population. As shown in Chart 6, the employed population over the 1980-2015 period has gone from most workers generally having only basic studies to most workers now having formal education beyond the compulsory minimum, and up to 40 per cent of those employed having a university degree or vocational training.

This progress in education means that labour services per hour increase, on account of the quality improvements which come with having more qualifications. The importance of this trend for labour productivity can be estimated

7 See the available databases on human capital and capital services (Jorgenson (2009), Jorgenson and Vu (2016), Jorgenson, Ho, and Samuels (2016), EU KLEMS (2012 and 2016) and the databases which are part of the WORLD KLEMS initiative). For Spain, see those developed by the IVIE: Bancaja Foundation and IVIE (2014) and BBVA Foundation and IVIE (2017).

Chart 7: Labour Productivity in Spain, 1980-2014 (1980 = 100)



Source: European Commission (2016), EU KLEMS (2012), The Conference Board (2015), World Bank (2016) and authors' estimates.

based on the data on wage differences according to education levels. Growth in labour input (estimated by correcting hours worked in proportion to changes in the quality reflected by wages) is greater than that calculated without making such a correction. Consequently, when human capital improves, the equivalent amounts of simple or basic labour used are greater and progress in labour productivity is slower if the capacity to generate value from human capital does not progress sufficiently.

The above-mentioned is what occurs in Spain, to the point that the increase in labour productivity measured as output per hour worked (not corrected by quality improvements) becomes stagnant in terms of output per unit of labour services. Then, when we include also the improvements in their quality (using the salaries paid to workers with different skill levels as index of quality) the evolution of labour productivity worsens. Almost since Spain joined the EU until the onset of the crisis (nearly two decades), labour productivity in the Spanish economy barely improved once the productive potential of the salaries attributed to the most skilled workers was taken into account (Chart 7).

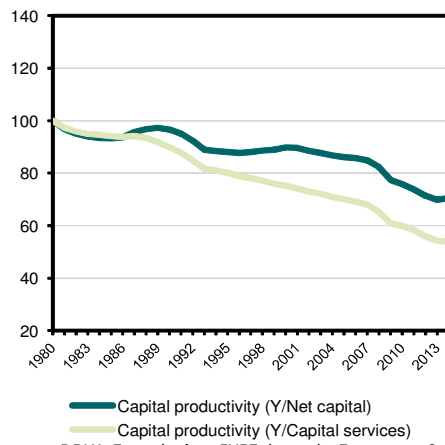
Almost since Spain joined the EU in 1986 until the onset of the crisis (almost two decades), labour productivity in the Spanish economy barely improved once the productive potential of the salaries attributed to the most skilled workers was taken into account (Chart 7).

In terms of the performance of capital productivity, Spain does not fulfil the old hypothesis of Harrod neutral technical progress, according to which the capital/output ratio (and its inverse, capital productivity) tends to be constant. This ratio has been continuously increasing for 25 years in the Spanish economy, which is equivalent to a continuous decline in capital productivity. This fall is even more intense if, instead of calculating it using net capital, we consider changes in the composition of capital and the different capacity of each asset to produce services.⁸ Given that there have been quality improvements in capital stock, by reducing the weight of less productive assets such as housing, productive capital has grown more than net capital, and productivity of productive capital (per unit of capital services) has fallen more than that of net capital (Chart 8). If we compare this evolution with that in the United States, a clear pro-

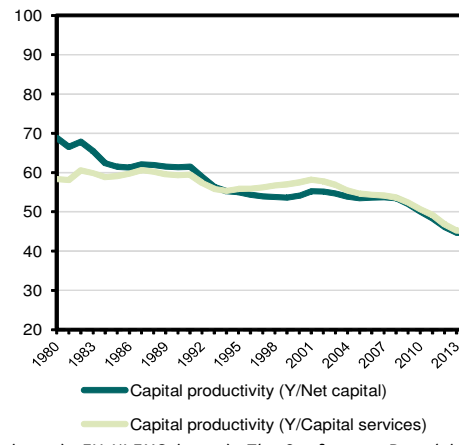
⁸ See OECD (2009) for a detailed explanation about the differences between net and productive or quality-adjusted capital and the methods for calculating both.

Chart 8: Capital Productivity in Spain, 1980-2014

Panel A: Spain = 100 in 1980



Panel B: United States = 100



Source: BBVA Foundation-IVIE (2017), European Commission (2016), EU KLEMS (2012), The Conference Board (2015), World Bank (2016) and authors' estimates.

cess of divergence in capital productivity is observed, with the capital productivity in the United States more than twice the figure for Spain in 2014 (Chart 8, Panel B).

The path of capital productivity in Spain is so negative (in the case of productive capital productivity, it recorded a decline close to 50 per cent) and continuous (occurring uninterruptedly over several decades) that it deserves to be reflected upon. It also deserves to be examined as to whether it is an exceptional case at the international level. As for the first question, a partial productivity measure such as capital productivity or labour productivity is an imperfect indicator of efficiency because it depends on the endowments of other factors. For this reason, its decline does not necessarily mean a slowdown in efficiency per se because the intensification in capital use could be explained by a type of technological progress biased towards capital, given that this is very advantageous and replaces labour. In this case, Harrod-neutral technical change is not fulfilled and improvements in labour productivity alone do not guarantee

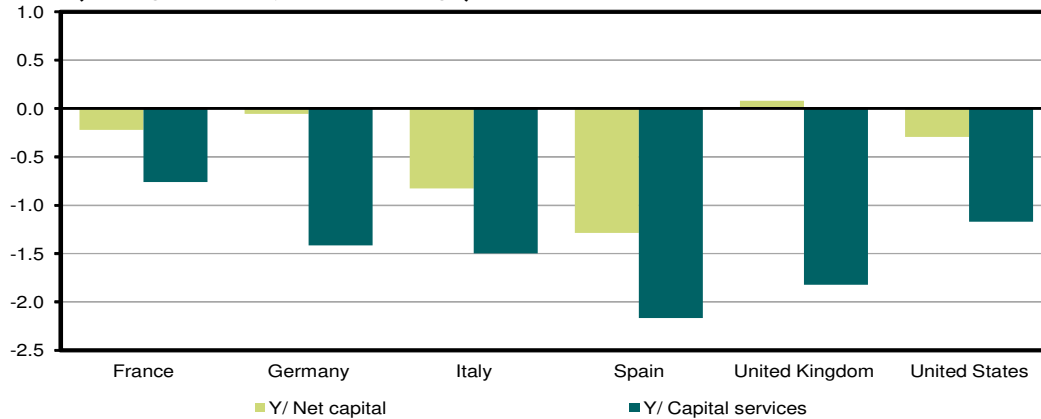
improvements in TFP, as they could be offset by the decline in capital productivity.⁹ This possibility is confirmed in an economy such as Spain's where labour productivity is stagnant (when human capital is considered) and capital productivity is decreasing.

Concerning the evidence of trends in capital productivity over relatively long periods, Chart 9 shows that growth rates differ when measured in terms of net capital or capital services. The productivity of net capital in France, Germany, the United Kingdom and the United States hardly changed between 1995 and 2012, and thus with such data we can say that the fulfilment of the hypothesis of a constant capital/output ratio has been fairly exact. However, the hypothesis is not fulfilled in Italy and Spain, where in both cases the capital/output ratio increases or, in other words, capital productivity decreases.

However, when we consider changes in the composition of capital and use productive capital as a measure of the existing stock and the ability to produce services from accumulated

⁹ According to Harrod's definition, neutral technical progress is one which leaves capital-output ratio unchanged. Thus, according to Harrod's neutrality of technical progress, labour productivity will increase whereas capital productivity remains constant.

Chart 9: Capital Productivity in Major European Countries and the United States, 1995-2012 (average annual per cent change)



Source: BBVA Foundation-IVIE (2017), European Commission (2016), EU KLEMS (2012), The Conference Board (2015), World Bank (2016) and authors' estimates.

capital, Harrod's hypothesis of neutrality is not fulfilled in any of the countries studied and the slowdown in capital productivity occurs across the board, as can be seen in Chart 9. Improvements in the measurement of capital, by incorporating part of technical progress into capital and quantifying a flow of capital services, indicate that the greater productive potential attributed to capital accumulated as a result of the increasing investment toward more productive types of assets does not lead to a proportional increase in the value added generated. In other words, productive capital increases more than output, and thus if there are to be efficiency improvements, (partial) labour productivity has to increase sufficiently to compensate for the decrease in (partial) capital productivity.

Efficiency: Total Factor Productivity

In a Cobb-Douglas production function, where Y is GDP, L is labour, K is capital, α and β the respective income shares of the two factors of production and A is TFP:

$$Y = AL^\alpha K^\beta \quad (1)$$

the variable that indicates whether efficiency improvements are achieved is the growth rate of A . TFP can be expressed as the product of labour and capital productivity raised to their respective share of income:

$$A = \left(\frac{Y}{L}\right)^\alpha \left(\frac{Y}{K}\right)^\beta \quad (2)$$

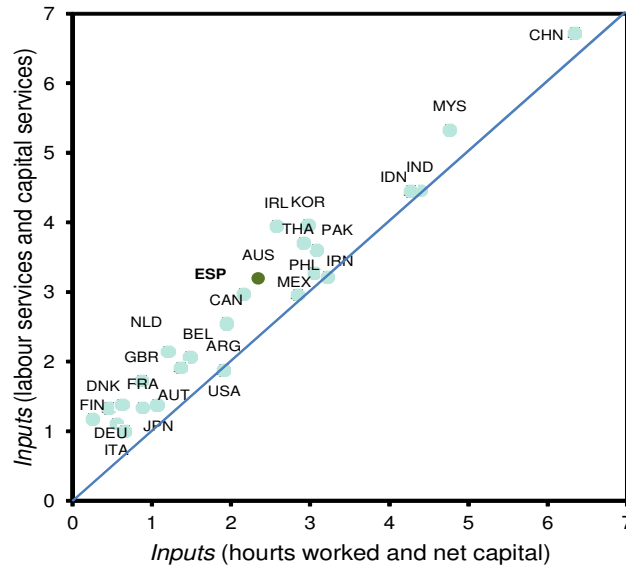
Generalizing the Cobb-Douglas production function to a translog function, which allows the input shares to vary through time and taking logarithms and differences with regard to time, the growth rate of TFP can be expressed as the sum of labour and capital productivity growth rates, weighted by the average of their share in income in (t) and $(t - 1)$:¹⁰

$$\begin{aligned} \Delta \ln A_t &= 0.5(\alpha_t + \alpha_{t-1}) \times \\ &\Delta \ln \left(\frac{Y_t}{L_t}\right) + 0.5(\beta_t + \beta_{t-1}) \times \\ &\Delta \ln \left(\frac{Y_t}{K_t}\right) \end{aligned} \quad (3)$$

In the absence of drastic changes in income shares, if capital productivity is relatively constant, TFP follows the path determined by

¹⁰ For a more extensive explanation see Jorgenson, Gollop and Fraumeni (1987) and Jorgenson, Ho and Stiroh (2005b).

Chart 10: Inputs Contribution to GDP: Effect of Quality Improvements: An International Perspective 1985-2012 (average annual per cent per year)



ARG: Argentina; AUS: Australia; AUT: Austria; BEL: Belgium; CAN: Canada; CHN: China; DEU: Germany; DNK: Denmark; ESP: Spain; FIN: Finland; FRA: France; GBR: United Kingdom; IDN: Indonesia; IND: India; IRL: Ireland; IRN: Iran; ITA: Italy; JPN: Japan; KOR: South Korea; MEX: Mexico; MYS: Malaysia; NLD: Netherlands; PAK: Pakistan; PHL: Philippines; THA: Thailand; USA: United States.

Source: BBVA Foundation-IVIE (2017), European Commission (2016), Asian Productivity Organization (2015), EU KLEMS (2012), The Conference Board (2015), OECD (2016), World Bank (2016) and authors' estimates.

labour productivity. And similarly, if labour productivity is relatively constant, TFP follows the path determined by capital productivity. This is the scenario in which we have been in Spain since the mid-1980s, as shown in Chart 7.

In sum, *ceteris paribus* the productivity of one of the two factors, a higher (lower) productivity of the other leads to a larger (smaller) increase in TFP. But since this last variable is calculated from the previous ones in expression (3), the estimation criteria of the first ones are decisive for the values of TFP and their meaning. Thus, labour and capital estimates have embodied part of the technical progress into the factors by acknowledging changes in the composition of labour and capital which have led to improvements in their quality. As a consequence of these improvements, the growth rates of estimated

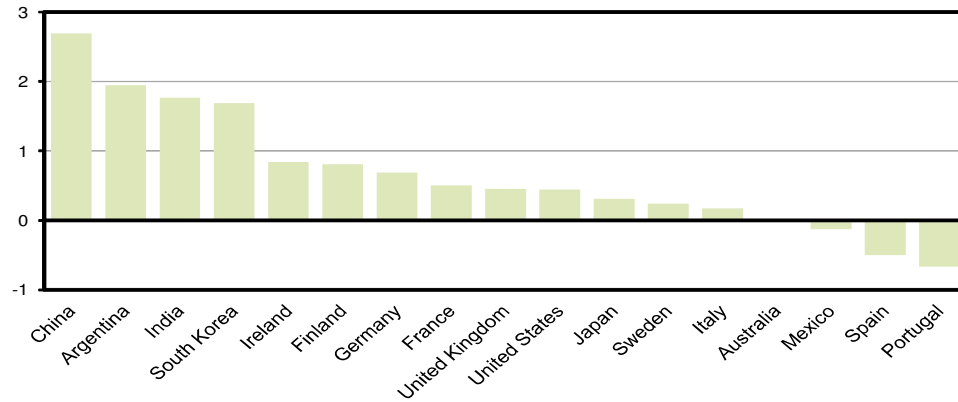
labour and capital endowments have increased according to the metrics designed to calculate the productive services of both factors.¹¹ The outcome of this measurement improvement is that the growth rates in the productivity of factors are lower and the growth rates in TFP have also decreased.

Chart 10 shows the contribution of labour and capital to output growth across a broad set of countries between 1985 and 2012. On the x-axis is the contribution of inputs to output growth when labour is measured in hours worked and capital is measured as net capital, i.e. without including quality improvements in the estimates. On the y-axis the factors are based on labour and capital services, that is quality adjusted labour and capital. In all countries the quality-adjusted input growth rates are above

11 See Jorgenson (1966, 2017), Pérez (2016), Timmer *et al.* (2010) and OECD (2009).

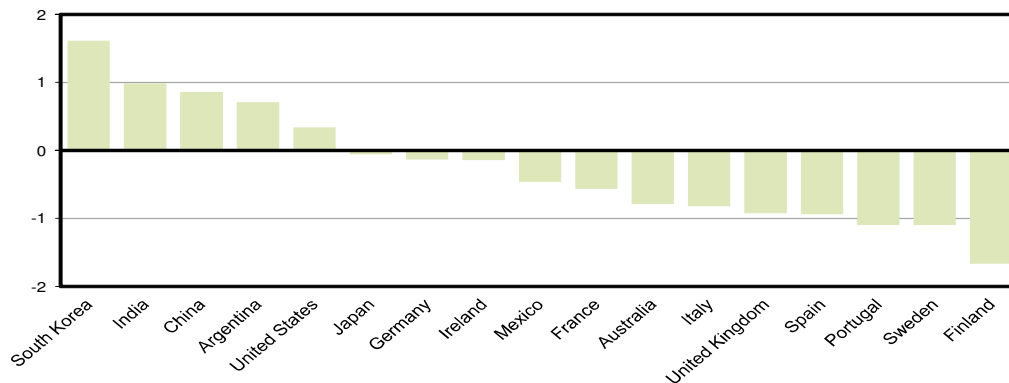
Chart 11: An International Comparison of Total Factor Productivity Growth, 1985-2012 and 2007-2012 (average annual rate of change)

Panel A: 1985-2012



Note: For China, India, Indonesia, Iran, Malaysia, Mexico, Pakistan, Philippines, South Korea and Thailand the period is 1989-2012. For Argentina the period is 1989-2010.

Panel B: 2007-2012



Note: For Argentina the period is 2007-2010.

Source: BBVA Foundation-IVIE (2017), APO (2015), European Commission (2016), EU KLEMS (2012), Jorgenson and Vu (2016), OECD (2016), The Conference Board (2015) and authors' estimates.

the 45 degree line, indicating that they exhibit faster growth than unadjusted inputs. The vertical distances to the 45 degree line indicate the magnitude of the contribution of quality improvements in inputs to growth.

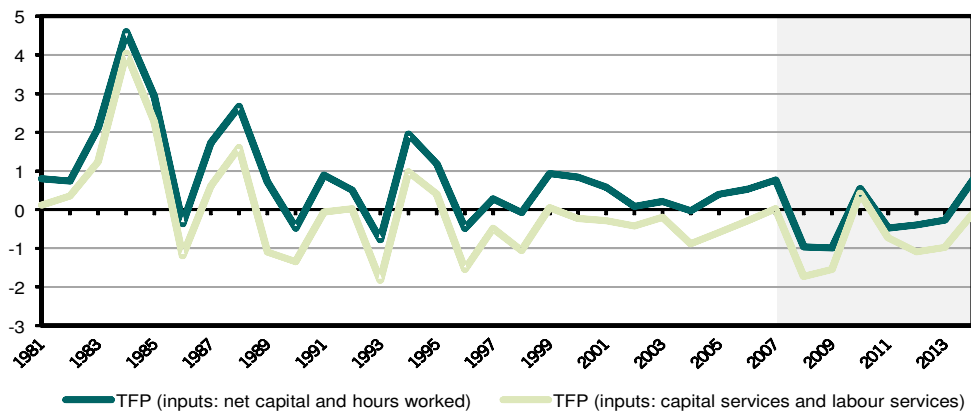
The larger increases in inputs accounted for by considering the quality improvements of factors do not explain all the output growth, and therefore improvements in total factor productivity continue to account for a share of GDP

growth.¹² This can be seen in Panel A in Chart 11 for a selection of 17 countries whose statistics make this estimate possible over a period of almost three decades. But there are some exceptions to this general trend: in Mexico, Spain and Portugal¹³ the growth derived from increases in the productive services of inputs surpasses that of the product, so that when the technical progress embodied into factors is computed there is a fall in TFP.

¹² See Oulton (2016) for a summary of the effects that measurement changes in inputs can have on TFP.

¹³ See Pinheiro Alves (2017) for more details on the slowdown in productivity growth in Portugal and its main causes.

Chart 12: Total Factor Productivity Growth in Spain, 1981-2014 (per cent change)



Source: BBVA Foundation-IVIE (2017), European Commission (2016), EU KLEMS (2012), The Conference Board (2015) and authors' estimates.

Details of the TFP trajectory in Spain are presented in Chart 12, which shows annual growth rates from 1981 to 2014 for TFP, first estimated without quality improvements in labour and capital (hours worked and net capital), and then with such improvements. The first estimate shows smaller increases in inputs, which leads to improvements in TFP over most of the period. In this case, there are negative changes in TFP in specific years, which become frequent after the crisis started in 2008. On the other hand, by considering quality improvements in labour and capital, the estimated contributions of inputs quite clearly explain GDP growth in most of the years. Consequently, the growth rates of TFP are generally negative since 1986, the year of Spain's entry into the EU.

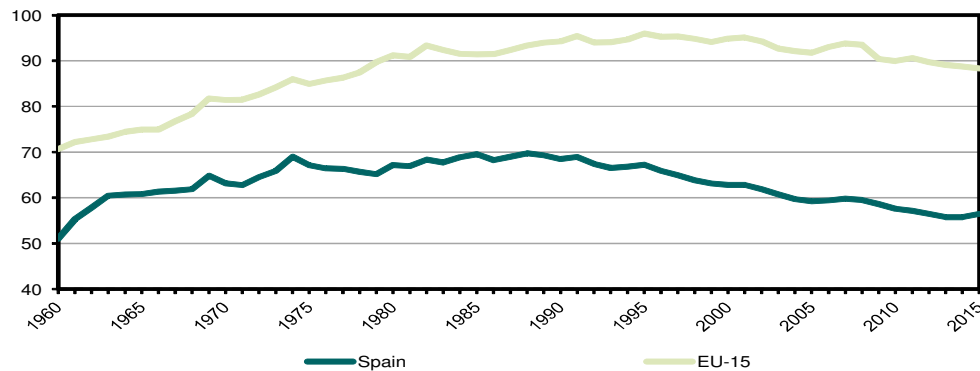
There can be various explanations for the negative trajectory of total factor productivity in a given year or period (the first of which can be excess capacity arising from a fall in demand). In fact, during the five-year period 2007-2012, where most developed countries were hit by the

economic crisis, the slowdown in TFP of many economies can be explained by underutilization of installed capital and employed workers,¹⁴ as can be seen in Panel B in Chart 11. But when a longer period of time is considered, as seen in Panel A, these economies show improvements in their TFP, i.e. they improve their productive efficiency.

A different problem arises when there are continuous declines in TFP over the last three decades, as in Spain. A trajectory such as the one observed in Chart 12 means that the productive capacity of the services providing the labour employed and the capital increases greatly, due to the investment effort and the creation of employment, as well as to the quality improvements of both factors. However, this capacity is systematically under-used. In other words, it does not generate enough value added to take advantage of the productive potential of the factors, and therefore the efficiency of the economy does not improve but rather declines.

14 In the case of labour, the problems of underutilization occur if firms do not automatically adjust their workforce when demand falls, due to their interest in retaining human capital or strict labour legislation. In the case of capital, rigidity is greater because the estimates of services derived from capital endowments are not corrected for excess capacity. Although rented capital can be disposed of by the user in a period of recession, macroeconomic estimates continue to include it.

Chart 13: The Level of Total Factor Productivity in Spain and the EU-15 Relative to the United States, 1960-2015 (United States = 100)



Source: BBVA Foundation-IVIE (2017), European Commission (2016), EU KLEMS (2012), The Conference Board (2015) and authors' estimates.

Given that this problem is not present in other economies, the relative efficiency of the Spanish economy decreases in comparison with that of the major economies. This is confirmed by Chart 13, which shows the levels of TFP in Spain and the EU-15 during the last half-century, using the United States as the benchmark. Until the mid-1990s, Europe converged significantly with the United States in efficiency, cutting its total factor productivity level gap with the United States from 25 percentage points to just 5 points. However, in the 21st century the gap widened once again and in recent years the level of TFP in the EU-15 has been below 90 per cent of that of the United States.

Spain shares certain characteristics with the European TFP trajectory, but with several more negative features. It started from a significantly lower TFP level — in 1960 it barely reached 50 per cent of the United States level and was 20 percentage points below the European level. Its trajectory of convergence in TFP was similar to the European one until the arrival of the oil crisis in the mid-1970s. Subsequently, TFP convergence weakened to stagnation in the early 1990s and diverged continuously thereafter, moving away from the United States and from the EU-15. The end result is that in more than

half a century the Spanish economy has barely reduced its total factor productivity gap with the US economy and has widened it in relation to Europe's.

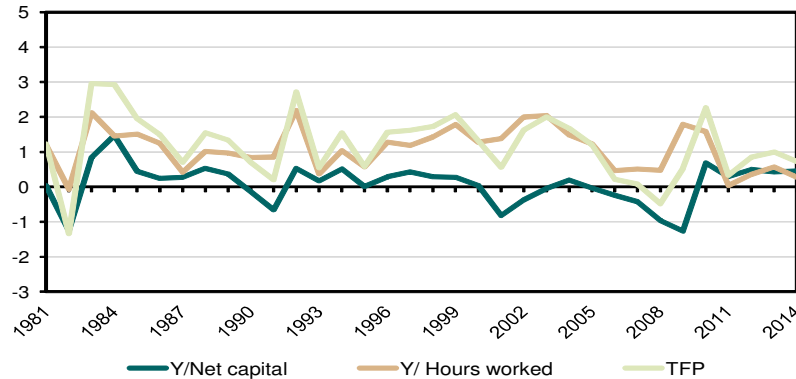
Causes of the Negative Evolution of TFP: Low Productivity of Labour or Capital?

The trajectory of TFP in Spain was not solely caused by excess capacity during the crisis, but rather is a structural problem. The most common interpretation focuses on the performance of labour productivity, although the low productivity of some investments seems to be a very relevant factor. The reason for the fall in capital productivity is that certain projects are never sufficiently productive, which is equivalent to suffering the consequences of underutilization of capacity permanently and not only in unfavourable situations.

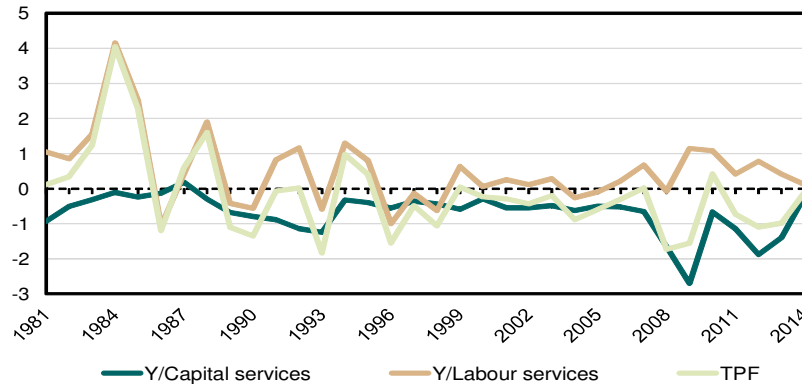
To explore the significance of labour productivity and capital productivity trajectories in explaining TFP growth rates, let us consider as a whole the differences between Spain and the United States. Recall that, according to expression (3), when capital productivity is relatively constant the evolution of TFP follows the path

Chart 14: Contributions of Capital Productivity and Labour Productivity to TFP Growth in the United States and Spain, 1981-2014 (per cent change)

Panel A: United States



Panel B: Spain



Source: BBVA Foundation-IVIE (2017), European Commission (2016), EU KLEMS (2012), The Conference Board (2015), Jorgenson and Vu (2016), OECD (2016), World Bank (2016) and authors' estimates.

determined by labour productivity. Chart 14, Panel A illustrates that this is approximately the case of the United States, whose TFP shows almost the same improvement as labour productivity.

To better observe the association in Spain between the evolution of TFP and the productivity of one of the factors, let us consider the human capital and capital services in Panel B of Chart 14. TFP and labour productivity evolve together in the early years of the series, but they soon diverge with TFP below labour productivity. The reason for this situation is that capital productivity growth rates are generally negative, and this accumulation of inefficient capital leads

to a slowdown in TFP growth. In addition, the change in partner which we can observe in the trajectory of TFP should also be highlighted: until the end of the twentieth century TFP evolved alongside labour productivity, but in the twenty-first century it distanced itself and followed more the capital productivity path, given that human capital productivity progressed very little during the last expansion.

Table 2 sets out the productivity contributions of productive capital and labour services in the two economies studied. Calculations of the decomposition of expression (3) are made for the period 1980-2014 and for the two sub-periods before and after 2000. In Spain, the average

Table 2: Contributions of Capital Productivity and Labour Productivity to TFP growth in Spain and United States, 1980-2014 (percentage points per year)

		1980-2014	1980-2000	2000-2014
Spain	TFP	-0.17	0.14	-0.60
	Y/Capital services	-0.69	-0.50	-0.97
	Y/Labour services	0.53	0.64	0.36
United States	TFP	0.53	0.48	0.60
	Y/Capital services	-0.37	-0.47	-0.23
	Y/Labour services	0.90	0.95	0.83
Differences	TFP	-0.70	-0.34	-1.21
	Y/Capital services	-0.32	-0.03	-0.74
Spain - USA	Y/Labour services	-0.37	-0.31	-0.47

Source: BBVA Foundation-IVIE (2017), European Commission (2016), EU KLEMS (2012), The Conference Board (2015), Jorgenson and Vu (2016), OECD (2016), World Bank(2016) and authors' estimates.

annual growth rate in TFP was slightly negative (-0.17 per cent) over the period as a whole, and the main cause was the negative contribution of capital productivity. Productivity performance worsens by moving to the second sub-period in the case of the two components and also for TFP. On the other hand, TFP significantly improved on average annually in the United States during the whole period (0.53 per cent per year) and in the two sub-periods, with no apparent worsening in the second. There were also declines in capital productivity over the whole period, but they were lower than in Spain and accompanied by much larger improvements in the productivity of labour services, which are corrected to take into account human capital improvements.

The lower part of the table shows that the negative differences between Spain and the United States in TFP over the entire period were caused by lower labour and capital productivity, both factors contributing almost equally. When the sub-periods are considered, negative differentials were larger in the 21st century in all factors, although the most significant deterioration occurred in capital productivity which, in the most recent decades, accounted for 60 per cent of the decline in Spanish TFP in comparison with that of the United States. It could therefore be said that the worst results in Spain

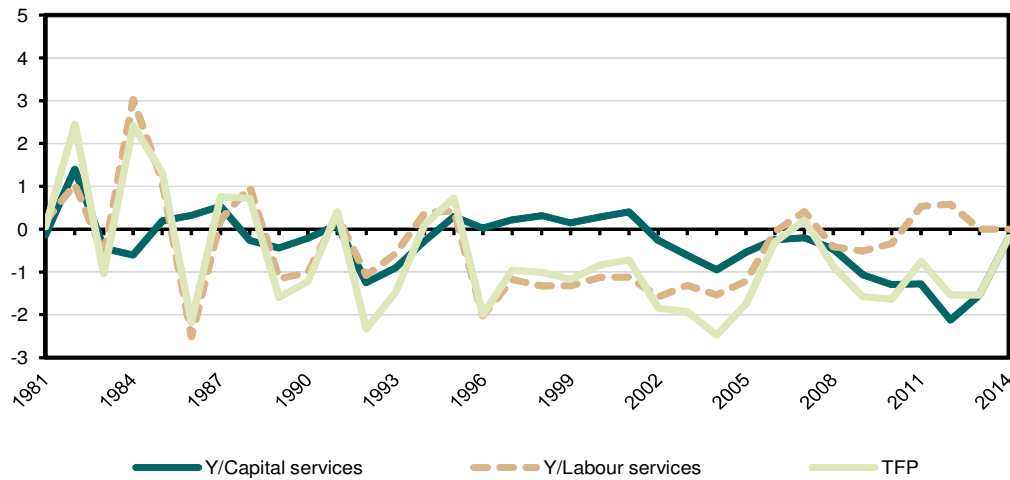
up to the year 2000 were due to the slower progress in labour productivity, as is usually pointed out in the common interpretation of the productivity problems in our economy. Up until that date, the difference in the contributions of capital productivity was insignificant. However, after the year 2000 there are productivity disadvantages in both labour and capital, with the latter being the most important factor.

Chart 15 compares the yearly trajectories of these differences. The relative slowdown in TFP in Spain with respect to the United States is the norm throughout the period. But while this difference is clearly explained over most of the period by the negative differentials of Spain in labour productivity contributions, in the 21st century it is the differentials in capital productivity contributions which explain the relative losses of efficiency in the Spanish economy and the trajectory of the differential in TFP, especially from the onset of the crisis.

Why Has There Been a Capital Productivity Decline in Spain?

The increase in the capital-output ratio (and the consequent fall in capital productivity) does not necessarily imply a slowdown in efficiency. The substitution of labour for capital and the consequent improvement in labour productivity

Chart 15: Differences in Contributions of Capital Productivity and Labour Productivity to TFP Growth in Spain and the United States, 1981-2014 (percentage points)



Source: BBVA Foundation-IVIE (2017), European Commission (2016), EU KLEMS (2012), The Conference Board (2015), Jorgenson and Vu (2016), OECD (2016), World Bank (2016) and authors' estimates.

can lead to a decrease in the use of factors in relation to value added and thus, an increase in TFP. However, in Spain this has not been the case, since labour productivity barely improved (in fact, it did not do so at all when quality improvements are considered), while capital productivity clearly decreased, and thus TFP declined. In these circumstances, one can question the reasons for the productivity trajectories of each of the factors.

The possible causes of the modest progress in labour productivity in Spain have often been analysed, stressing, in many cases, that they are related to education quality, the functioning of the labour market or the use of human capital by companies.¹⁵ However, it seems also necessary to consider the possible causes of the slowdown in capital productivity, which have been much less studied.¹⁶ This section puts forward the following three hypotheses:

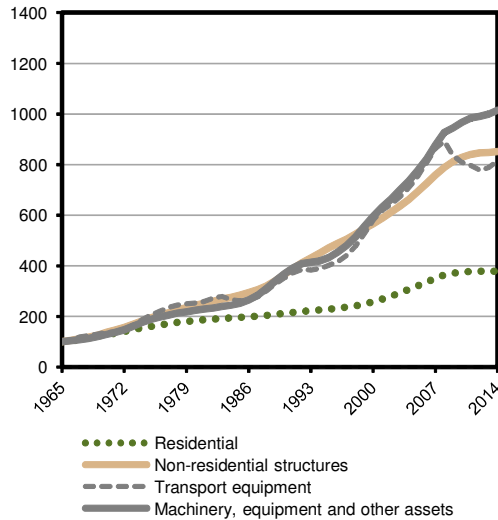
- Capital productivity declines because the intensity of real estate investment (particularly residential) has reduced investment in other assets and the weight of these assets in productive capital.
- Capital productivity declines because there has been unproductive overinvestment in non-residential real estate assets (industrial buildings, commercial premises, infrastructure) in many sectors, arising from the accumulation processes in these assets being driven by short-term profitability and not by productivity.
- Capital productivity is low because the composition of the productive fabric does not foster its use, due to the excessive weight of traditional sectors, the low weight of large firms and the importance of micro enterprises, and the low investment in essential intangible assets to make the other factors productive.

¹⁵ See Serrano (2010); Hernández and Serrano (2012), among many others.

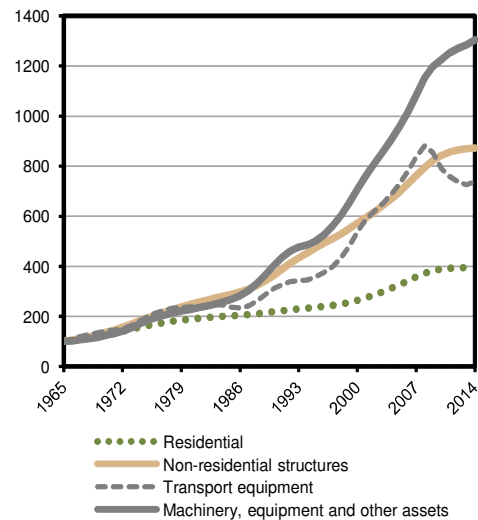
¹⁶ Approaches to the issue of capital productivity can be found in Pérez and Benages (2014), Mas *et al.* (2013), and Pérez and Robledo (2010).

Chart 16: Index of Capital Stock by Asset Type in Spain, 1965-2014(1965=100)

Panel A: Net Capital Stock



Panel B: Productive Capital Stock



Source: BBVA Foundation-IVIE (2017).

First hypothesis: Crowding out of machinery and equipment

The hypothesis that the intensity of residential investment or other assets produced by the construction sector has prevented the accumulation of other more productive physical assets (such as machinery and different types of equipment) cannot go very far since the empirical evidence does not support it. The capital stock series confirm that there was a great deal of real estate investment, but also show that the accumulation rate of the most productive assets has been even stronger than that of real estate assets, both residential and non-residential (Serrano *et al.*, 2017 and BBVA Foundation-IVIE, 2017).

Panel A in Chart 16 shows that throughout the whole of the last half century as well as in the expansion that began in 1995, net capital accumulated in machinery and equipment grew more than non-residential structures and much more than residential structures. If one takes into account the changes in composition of each of the aggregates represented in the chart, as does productive capital, the growth rate of machinery and equipment has been even stronger. Thus,

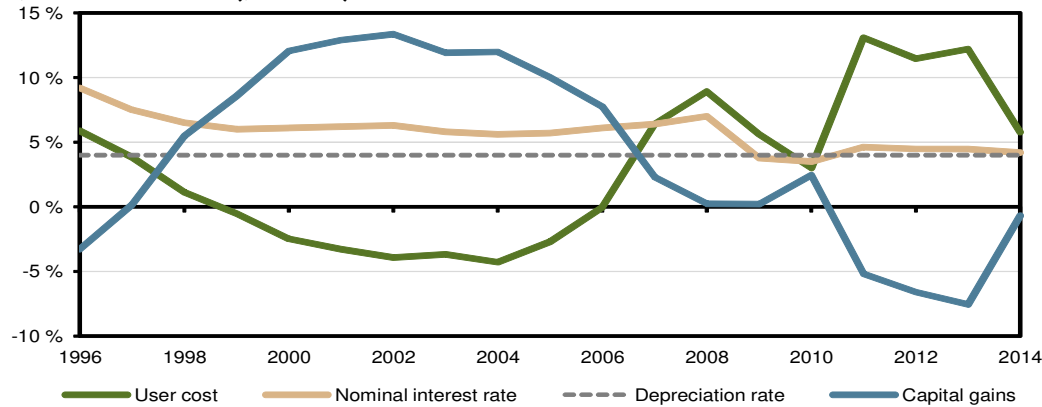
the reason why the aggregate capital productivity did not advance cannot be a lack of potential generator of services by the accumulated assets, but rather that for some reason this potential has not been realized in the form of value added. Thus, the investment effort has been partially wasted and the productivity of capital has been affected by it.

Second hypothesis: Unprofitable investments in real estate assets

The second explanation for the negative trajectory of capital productivity in Spain relates to the under-use of the capital assets. Firms make investments without expecting returns on projects through productivity improvements. Rather, they invest on the expected profit from the revaluations of the assets.

When the expected capital gains are high, the user cost of capital can be negative. This situation is more likely when interest rates and depreciation rates are low — as is the case with assets with long service lives such as real estate. If the user cost is negative, investments can be profitable in the short term even if they are tem-

Chart 17: User Cost of Private Non-residential Real Estate Capital and its Components in Spain, 1996-2014 (per cent)



Note: In this figure the non-residential real estate capital includes land.

Source: Alonso and Marqués (2006), Sánchez, Sánchez and Urtasun (2008), BBVA Foundation-IVIE (2017), IPC (INE, several years) and authors' estimates.

porarily unproductive.¹⁷ Under these conditions, if investors (and their funders, mainly banks) work with relatively short horizons in which drops in asset prices are considered unlikely, the volume of such profitable but unproductive investments can be high, as well as the excess capacity accumulated because of them.

The hypothetical situation described may have occurred in Spain in certain periods when real estate investments were driven by the housing bubble in which land prices grew at very high rates. The excess capacity accumulated during that period had a lasting impact because the service lives of real estate assets are very long.

We examine the data to assess whether the orientation of investment decisions in real estate assets are in accordance with the logic described, with a focus on non-residential construction.¹⁸

Chart 17 shows the evolution of the variables which affect the user cost of capital during the last expansion in the Spanish economy and the subsequent crisis. It shows that interest rates were low, as were depreciation rates, while increases in asset prices were considerable for a decade, generating guaranteed expectations of considerable revaluation. Consequently, the user costs of these capital assets were very low from 1997 to 2007, to the point of being negative for much of that period.¹⁹ Investments in these assets over the course of those years grew at a high rate and represented a significant part of total investment, putting in place capacity which was only partially used because the depreciation of real estate assets is very slow.

However, the evaluation of investment decisions cannot be made solely in the short term when the service life of an asset is long and the long-term profitability expected of an invest-

17 On the arithmetic of the user cost and the key contribution of Jorgenson to the measurement improvement of capital values, see Jorgenson, Ho and Stiroh (2005b), Jorgenson, Gollop, and Fraumeni (1987), Timmer *et al.* (2007, 2010) and OECD (2009).

18 Investments that are mostly related to family decisions are excluded.

19 The capital user cost of all assets in the economy was not negative during those years, but positive and increasing (from 8 per cent to 14 per cent) due to the increase in the average depreciation rate of a capital stock in which assets with shorter lives have a greater weight. This composition shift was related to the falling prices of certain assets, in particular those related to ICT.

ment (which turns out to be unproductive) is negative, except when the capital gains are consolidated because the price levels reached by real estate assets do not fall.²⁰ For this expectation to be fulfilled, the non-depreciating share of the real estate assets (land) must be revalued to compensate for the fall in value of the depreciating part of the asset (that is, the building or structure), even if it is depreciating slowly.

This appears to have been the expectation in Spain, a country with a tradition of high inflation and intense urbanization during the last half century. Based on that experience, many people (including many professionals) believed that real estate assets never went down in price and were considered a safe haven. Their long useful lives served as a protection against occasional episodes of decreasing prices, allowing people to wait until prices rose again. However, the ability of real estate assets to retain their real value while not being productive (such as gold) is a hypothesis not always supported by the data from previous periods, not even in the case of Spain.²¹

The impact of unproductive real estate investments is not limited to the construction and real estate sectors, as real estate assets make up an important share of the capital formation in many sectors, which use industrial buildings, commercial premises, and industrial and commercial infrastructures in their production processes. In addition, the equipment and facilities which accompany these assets as a condition of their

use is also important, in that overinvestment and overcapacity of real estate assets also mean overinvestment and low utilization of related assets, which are also not used productively.

The hypothesis that the effects of unproductive investments in real estate assets have spread to many other sectors is supported by the poor productivity gains encountered in many sectors. In this respect the evidence can be synthesized with the help of a Harberger diagram (Harberger, 1998) shown in Chart 18. It represents sector contributions to TFP growth in the Spanish economy, ordered from the highest to lowest growth rate of the sector's corresponding TFP. The first of the panels shows the final phase of the expansion while the second shows the years of crisis. The x-axis represents the share of each sector in GDP and the y-axis its contribution to TFP growth. The curve represents the accumulation of these contributions, rising while sector TFP is positive, and falling once the contributions of sectors with negative TFP growth have been incorporated.

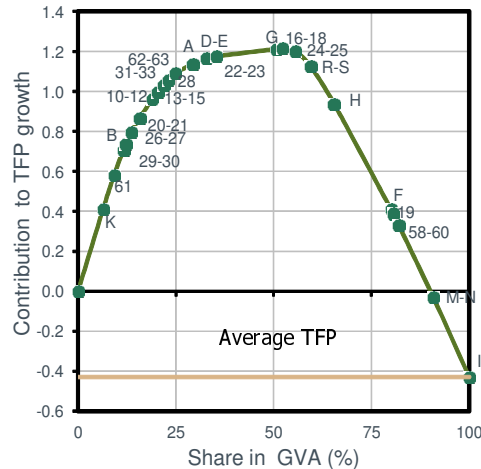
In the period of expansion (2000-2007), the average annual growth rate of aggregate TFP was negative (-0.4 per cent per year). Of the 24 (market) sectors considered, eight (representing 65 per cent of gross value added or GDP) showed negative contributions to the aggregate TFP. Among them, hotels and restaurants, professional, scientific, technical and administration activities, construction, and transport and storage, stood out for their weight in GDP and

20 It is difficult for measurements of capital productivity to estimate certain components of the user cost, such as capital gains. These estimates reflect different assumptions which can affect the results. If the user cost is computed from the capital gains in the past (reflecting adaptive expectations), then during the boom years possible future losses will not be captured. Under these conditions, the user cost could be negative (as we have seen in Chart 17) and any investment project could be considered profitable, even if it were not productive. If we assume that we are in equilibrium (user cost equal to the marginal productivity of capital) and the cost of capital is calculated from the gross operating surplus (i.e. endogenous rate of return), it will be impossible to observe negative user costs, even if they exist and are the cause of unproductive investments. Third, if the evolution of the income shares of factors of production found in the National Accounts do not only reflect changes in their productivity, but also other influences of a different nature (linked to labour market regulation or intense competition), our measures of productivity will be affected.

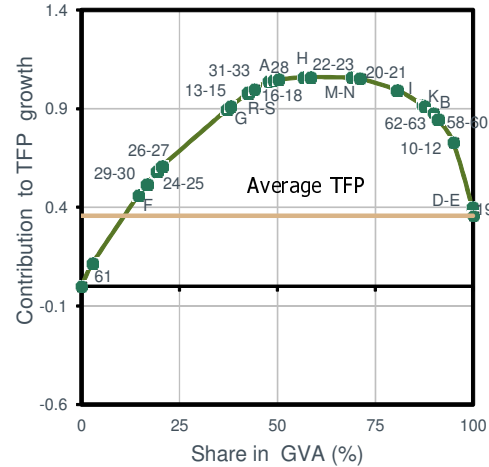
21 See, for example, the analysis of the Spanish case carried out by the International Monetary Fund (IMF, 2009).

Chart 18: Harberger Diagrams for Market Economy TFP Growth in Spain, 2000-2007 and 2007-2014

Panel A: 2000-2007



Panel B: 2007-2014



Sector codes: A: Agriculture, livestock, forestry and fisheries; B: Extractive industries; D-E: supply of electricity, gas, steam and air conditioning; Water supply, sanitation activities; 10-12: Food, beverage manufacturing and tobacco industry; 13-15: Textile industry, garment making and leather and footwear industry; 16-18: Wood and cork industry, paper industry and graphic arts; 19: Oil coke and refining; 20-21: Chemical industry and manufacturing of pharmaceuticals; 22-23: Manufacture of rubber and plastics products and other non-metallic mineral products; 24-25: Metallurgy and manufacture of metal products, except machinery and equipment; 26-27: Manufacture of computer, electronic and optical products; Manufacture of electrical equipment and equipment; 28: Manufacture of machinery and equipment n.e.c.; 29-30: Manufacture of transport equipment; 31-33: Manufacture of furniture; Other manufacturing industries and repair and installation of machinery and equipment; F: Construction; G: Wholesale and retail trade; Repair of motor vehicles and motorcycles; H: Transport and storage; I: Hospitality; 58-60: Cinematographic editing and activities, video and television programs, sound recording and music publishing; Programming and broadcasting activities; 61: Telecommunications; 62-63: Programming, consultancy and other activities related to information technology; Information services; K: Financial and insurance activities; M-N: Professional, scientific and technical activities; Administrative activities and ancillary services; R-S: artistic, entertaining and entertainment activities; Repair of household articles and other services.

Note: Residential capital and labour quality is not taken into account in the estimate of TFP. The market economy excludes the non-market sectors (Real estate activities, Public Administration, Education, Health and Household activities as employers of domestic personnel or as producers of goods and services for their own use).

Source: EU KLEMS (2012), BBVA Foundation-IVIE (2017), INE (2016) and authors' estimates.

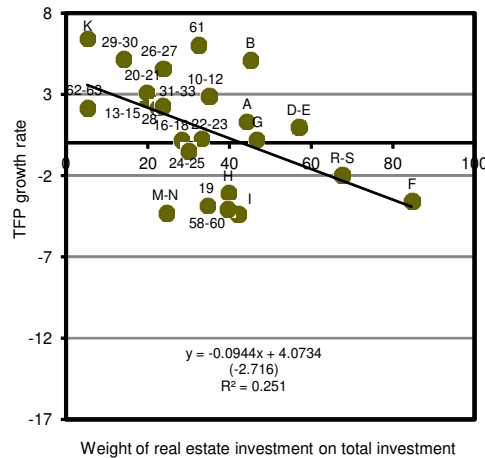
the significant slowdown in total factor productivity. During this period, industries representing only a third of the market economy improved their TFP, at an average rate of 2 per cent per annum: in general, industrial activities and the advanced tertiary sector. The negative performance of TFP by industries is correlated with the greater concentration of their capital in real estate assets. Thus, the hypothesis that when real estate assets were revalued some of the investments were most likely guided by short-term profitability criteria, regardless of capital

productivity, appears to be supported by the evidence.

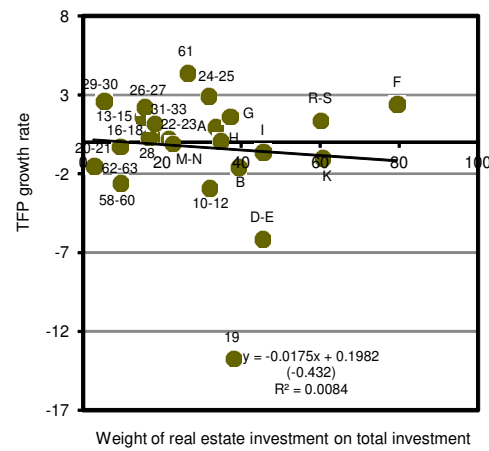
Panel B in Chart 18 shows that, after the boom, when there are no longer incentives to accumulate capital in real estate, the industries with negative TFP reduce their weight in GDP. The sectors with negative contributions (energy and extractive industries, manufacture of food products and beverages, publishing and film activities, financial activities and chemical industry) do not correspond to activities which accumulate more real estate capital. Falls in TFP could be related to a slowdown in demand

Chart 19: Real Estate Investment and TFP Growth in Spain, 2000-2007 and 2007-2014

Panel A: 2000-2007



Panel B: 2007-2014



Note: See the sector codes in Chart 18.

Source: BBVA Foundation-IVIE (2017), INE (2016) and authors' estimates.

or excess capacity in all types of facilities and/or assets.

Chart 19 shows that the relationship between the intensity of real estate investment and TFP growth by industry was negative and statistically significant during the real estate boom (Panel A), but was no longer significant in the years thereafter (Panel B).

Third hypothesis: Unproductive business fabric

The negative trajectory of productivity in Spain reflects that a large part of capital and labour is used by companies that are unproductive due to their specialization in traditional activities, their small size and their organizational weaknesses. But in this area, it must be said again that the problems regarding the low use of resources not only affects labour but also capital, reducing the potential profitability of the investment effort.

There is abundant evidence regarding the characteristics of the productive fabric and its implications for productivity.²² In Spain, a large part of the nation's human resources is managed

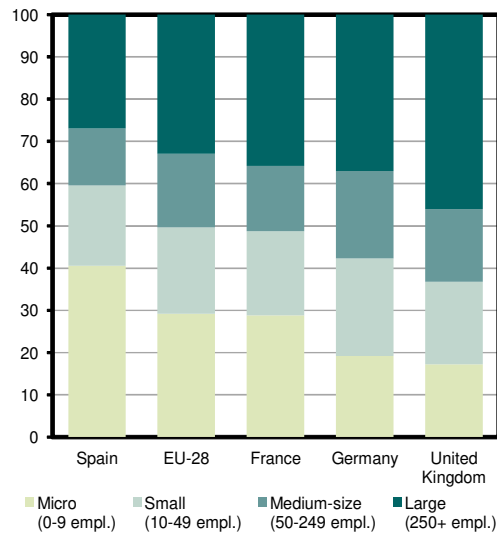
by very small companies: in 2015 40 per cent of employees were employed in micro-enterprises with less than 10 workers, while those percentages are less than half in Germany and the United Kingdom (Chart 20, Panel A). The disadvantage of having such small business units for labour productivity is confirmed in Panel B of Chart 20, which shows that larger firms generate more value added per person employed in all countries. In the Spanish case, this handicap is more severe, since micro enterprises are very unproductive, both in comparison with other countries as well as with large Spanish companies.

One of the underlying causes of lower productivity of smaller enterprises is that they are often managed by persons with a lower level of skills. This is due both to the educational profile of the owners and to the fact that in micro-enterprises the management is often not professional, which usually entails having higher education. The fact that there is less human capital in the management of small firms in an important part of the productive fabric, has consequences for the specialization of companies, the jobs they offer, the

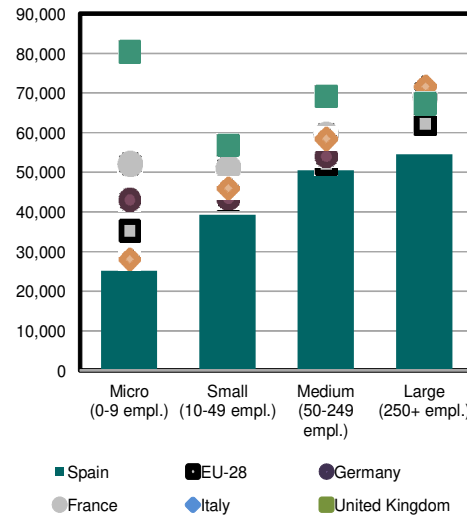
²² See Pérez *et al.* (2012) and Reig (2016), and the bibliography cited there.

Chart 20: International Comparisons of Employment and Labour Productivity by Business Size Class, 2015

Panel A: Employment by Business Size Class (Per Cent)



Panel B: Labour Productivity by Business Size Class (Euros Per Person Employed)



Note: Data refer to the market sector, excluding agriculture and the financial sector.
Source: European Commission (2016).

use of human capital, and the orientation and exploitation of investments in physical and also intangible assets.

This last issue is particularly relevant because intangible capital is made up of a wide variety of assets which are accumulated, to a great extent, because of the activities of skilled workers, and are therefore closely related to the use of human capital.²³ Their productivity potential stems from operating as catalysts for productivity gains. Intangibles allow for a better use of other assets by encouraging the development of product and process innovations and improving the efficiency of organizations. In business units and territories where there are more intangible resources, the owners of these particular assets and also the remaining assets obtain better

returns, reflecting overall productivity improvements.²⁴

To sum up, insufficient investment in intangibles can lead to a low productive use of tangible capital if lack of the former generates low value added. If firms do not have the appropriate intangible assets, their managerial, organizational and innovative capacity will be weaker, investment effort is at greater risk of not being well directed and not achieving full advantage, and the value added generated is more likely to be lower. Thus productivity suffers.

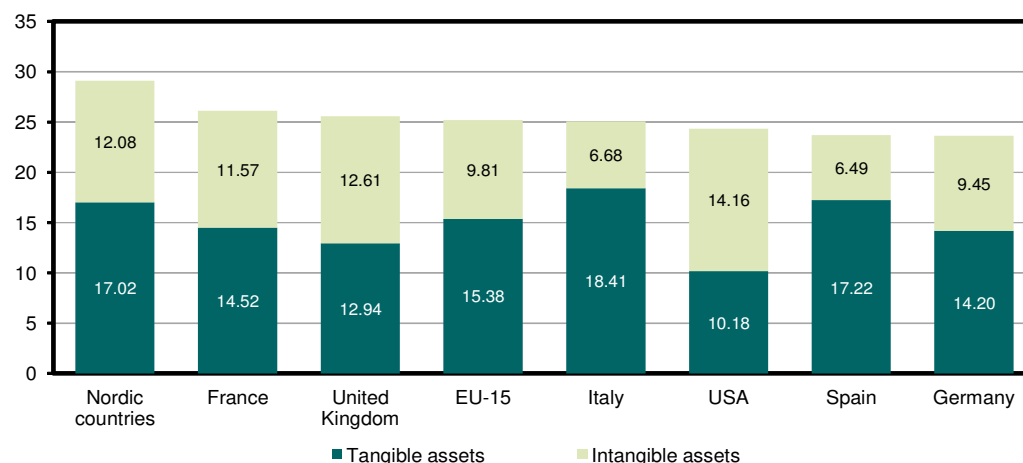
According to evidence on the investment in these types of intangibles related to company skills, the level in Spain is low (Mas and Quesada, 2014). Over the 1995-2010 period, the Spanish economy invested 70 per cent of its private investments in tangible assets and only 30

23 Intangible assets can be grouped into three broad categories: software and databases, investments in R&D and innovative property, and investments in economic competencies (company training, organizational capital, brand, advertising, etc.). See Corrado *et al.* (2012, 2014) and for the Spanish case, Mas and Quesada (2014).

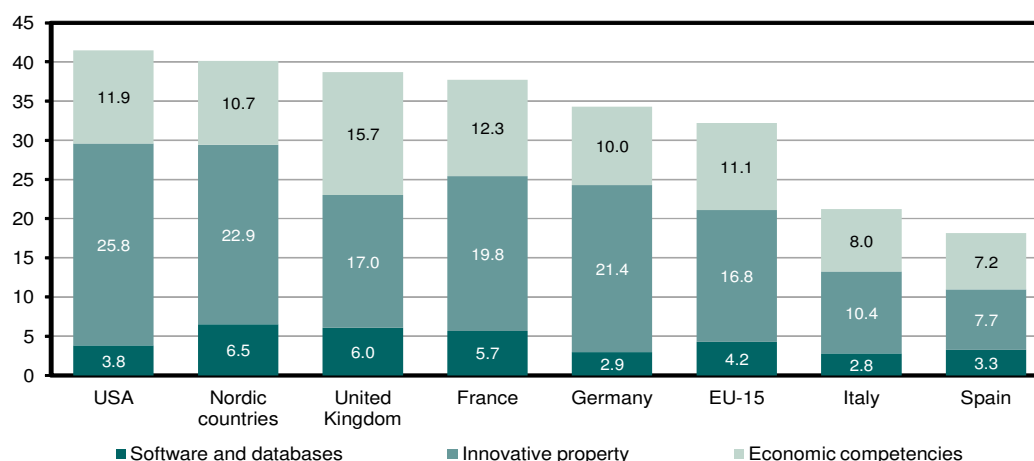
24 On the externalities/spillover effects of well-used knowledge, see Moretti (2012).

Chart 21: International Comparisons of Intangible Assets in the Market Sector, 1995-2010 (per cent of gross value added)

Panel A: Tangible and intangible assets (GFCF/GVA)



Panel B: Intangible capital stock over GVA by type of asset



* Nordic countries: Sweden, Finland and Denmark. ** EU-15 does not include Greece, Luxembourg and Portugal.

Source: INTAN-Invest (2014), BBVA Foundation-IVIE (2017), INE (2016) and authors' estimates.

per cent in intangibles. In contrast, over half of market sector investment in the United States was in intangible assets (Chart 21, Panel A). During this period, tangible relative capital endowments in Spain became similar to those of the developed countries, but those of intangible assets were much lower (Chart 21, Panel B). In all likelihood, this characteristic is one of the keys to explaining the poor capacity of the Spanish economy to take full advantage of its investments and reflects weaknesses in the productive

fabric along with the smaller size of the majority of Spanish companies.

The implications that the business structure has for productivity have been receiving increasing attention from the literature, thanks to the greater wealth of data available on the capital used. First, capital stock statistics by asset type and sector have improved, thanks to projects associated with the WORLD KLEMS initiative. Second, microeconomic or firm-level data are available which, while not allowing computation of the effect of composition by asset type (as we

do with sectors and countries), do provide data on the net capital for millions of companies. This set of information provides evidence corroborating the hypothesis of lower capital productivity levels in smaller firms, as well as those in service sectors (especially traditional ones) compared with manufacturing (Dabla-Norris *et al.*, 2015 and IMF, 2016).

The fundamental conclusion of these recent studies is that the potential TFP gains of many companies are significant in that they are far from the best practices observed. But the lower productivity levels of smaller firms are due to their characteristics, and therefore as long as the largest share of capital and labour is concentrated in Spain in these units, the productivity of both factors will be diminished.²⁵ The improvement of these results requires an increase in company size that leads to productivity gains and a higher rate of investment in intangible assets.

Implications of Capital Productivity Analysis

At the beginning of this article we posited three questions: what role does the orientation of investments and capital productivity play in the evolution of TFP in Spain? What are the causes of the negative evolution of capital productivity? What productivity improvement policies should be considered in Spain and how can investment contribute to them?

The answers to the first two questions can be summarized as follows. The orientation of investments plays an important role in the unsatisfactory evolution of TFP in Spain, since

it has generated excess capacity and the limited use of a significant share of the capital stock. The negative evolution of capital productivity results from the fact that the generation of value added based on the investment effort made has been less than its potential, due to the misallocation of resources related to two occurrences: First, many investment projects have been guided by short-term profitability deriving from the expected capital gains from the revaluation of assets, rather than the medium and long-term productivity of assets; Second, many units that manage the resources are too small to be efficient and do not have certain assets which are necessary to be productive, mainly intangible assets.

Based on these two conclusions, the answer to the third question on how to ensure that the accumulation of quality employment and the expansion of capital endowments does not lead to a slowdown in TFP as in the past is as follows. Improvements in TFP depend on the ability of capital and labour to generate more value per unit used of equal quality factor. Therefore, the objective should be to achieve synergies between both and this is, most likely, the only way in which growth can be productive.

In this sense, human capital productivity can contribute to improving capital productivity by improving how it is used in companies. To achieve this, educational skills must be improved, so that education is more effective: reducing school failure and dropout rates, improving educational performance and investing in life-long learning.²⁶ The second way forward is to improve the use of human capital in

25 It should be noted, however, that microeconomic studies use data on capital (book values) and labour (employees, hours) which do not incorporate quality of factors, as do recent sectoral and macro studies. This has two consequences: average TFP improvements are overestimated; and TFP differences between large and small firms could be overestimated if larger firms use higher quality resources than smaller firms.

26 In the case of Spain there are lights and shadows in this area. On the one hand, it is noted that the state spends little on employee training and that companies spend little on education, especially small ones, which are the majority. On the other hand, the spending of medium and large companies on training within the company has grown strongly. See Pérez and Uriel (2016).

companies by placing better prepared managers in leadership positions, an objective that is conditioned by the size of the company and the decision of the owners to improve in the professionalization of their management.

Furthermore, in order to improve capital productivity, the misallocation of investments must be reduced, which can then contribute to improving labour productivity by allowing labour to be better used in companies. There are several ways forward in this direction: increasing the size of companies and improving the quality of their management, extending the time horizon in decision-making; transforming a financial system which invests primarily in real estate guarantees focusing on the short term, to one which caters to the productivity of long-term projects; and fostering an institutional environment which favour the achievement of these objectives, enhancing resource allocation.

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Sources of Productivity and Economic Growth in Latin America and the Caribbean, 1990-2013

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ABSTRACT

This article examines growth experiences of 23 Latin American and English-speaking Caribbean countries from 1990 to 2013. We carry out three types of exercises. The first exercise for the 23 countries in the region uses the traditional methods to measure capital, labour, and efficiency or total factor productivity (TFP). The second exercise focuses on the Latin American countries only. The labour measure (L) is improved through the introduction of a quality adjustment to hours worked, while the capital measure includes capital services. The exercises reveal that as the input measures improve, the efficiency measure (TFP), which is usually positive and statistically explains a large share of observed growth, becomes increasingly negative for all groups of countries and all sub-periods. The only exception is the boom period of 2003–2008. A third exercise uses the LA-KLEMS database to disaggregate the data into nine industries. For each industry, we identify three characteristics of the labour factor and eight types of capital assets. The disaggregated data are only available for Argentina, Brazil, Chile, Colombia, and Mexico. Based on this more disaggregated analysis, we put forward hypotheses on the factors that determine growth and discuss implications for public policies.

In this article, we address recent efforts to quantitatively measure what pushes our economies towards growth and, ultimately, towards development. These studies use a growth accounting framework to identify elements that could guide public policies in terms of promoting measures that sustainably increase growth

rates in 23 economies of Latin America and the English-speaking Caribbean (LAC).

In the international literature on growth accounting, the discussion is generally structured around an approach that can be expressed as follows (Caselli, 2004):

$$\text{Income} = F(\text{inputs, efficiency})$$

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That is, income or production, generally measured in per capita terms, is a function of certain inputs (usually some measure of capital and labour) and the efficiency with which those inputs are used (namely, total factor productivity, or TFP). TFP is a measure of the shift in the production function (of an economy, production facility, or economic sector) at a given level of capital and labour. Intuitively, we could say that it measures the movement of the production function over and above what can be explained by the capital and labour inputs. Many factors can cause this shift or “addition”: technical innovations, organizational or institutional changes, demand fluctuations, changes in the allocation of capital and labour, scale effects, and changes in labour intensity, as well as measurement errors (Hulten, 2001).

TFP is often associated with technological progress, but this is a mistake. To illustrate, consider a change in a productive process based on a consultant’s recommendation. The consultant will (ideally) be paid the present value of the innovation, in which case the innovation (or the part paid for it) will be accounted as an input. However, if the same innovation is made by an employee who (in the extreme case) receives no additional payment whatsoever for having discovered the innovation, the innovation will be included in TFP and thus will not be recorded in the firm’s economic accounts. The same happens with most R&D spending, which tends to be associated with TFP when, in fact, we are simply not measuring R&D correctly. Further examples include free inputs or inputs that are not recorded in the economic accounts. One of these, which we consider below, is the quality of macroeconomic policies.

This leaves us with two alternatives. We can try to improve the estimation of the input content, or we can take the more difficult path of trying to determine what explains efficiency. As Maddison (1987: 651) states, “Growth account-

ing of this type cannot provide a full causal story. It deals with “proximate” rather than “ultimate” causality and registers the facts about growth components; it does not explain the elements of policy or circumstance, national or international, that underlie them, but it does identify which facts need more ultimate explanation.”

LA-KLEMS has been working in conjunction with the Groningen Growth and Development Centre, the Valencian Institute of Economic Research, and Harvard University through the World KLEMS Initiative, led by Dale Jorgenson, to develop a database that allows a better identification of the proximate causes of economic growth in Latin America. The work has resulted in a consistent statistical database, known as the LA-KLEMS database for Latin America. Like the EU-KLEMS database for Europe, LA-KLEMS identifies and measures five inputs: capital (K), labour (L), energy (E), materials (M), and services (S).

The project collected data on 23 LAC countries from 1990 to 2013, with the sample period broken into four sub-periods: 1990–1997, 1997–2003, 2003–2008, and 2008–2013. The first sub-period covers the economic recovery following the region’s “lost decade” of the 1980s, which was characterized by a strong macroeconomic adjustment and a significant decrease in investment, especially public investment. This sub-period ended with the Russian and Asian financial crises, which pushed the world economy into a recession. Given that the LAC region only started recovering from the recession in 2003, the second sub-period spans the recession years from 1997 to 2003. Towards the end of this sub-period, a new boom cycle began, with a substantial increase in commodity prices.

The third sub-period encompasses the boom in commodity prices from 2003 to 2008 and ends with the Great Recession of 2008–2009, detonated by the subprime crisis in the United States. Due to better management of the eco-

nomie boom, such as the building up of reserves, a number of LAC countries were able to withstand the international recession through countercyclical policies. Finally, the 2008–2013 sub-period comprises the recovery of the world economy and the slowdown in China from double-digit growth rates to a “new normal,” which appears to be between 6 per cent and 8 per cent in annual terms. Commodity prices are expected to remain low in the medium term, while interest rates are returning to more normal levels, making access to credit more difficult and more costly.

Based on the data availability, we designed three types of exercises. The first covers 23 countries in the region, including 18 from Latin America (LA) (from Mexico to Argentina, plus the Dominican Republic) and five from the English-speaking Caribbean (Bahamas, Barbados, Belize, Jamaica, and Trinidad and Tobago). For this group of 23 countries, we use traditional measures of capital, labour, and TFP.

The second exercise focuses on the 18 Latin American countries only. We improve the labour measure (L) by introducing a quality adjustment to hours worked (namely, years of education), while the capital measure includes a capital services measure. We are thus able to measure flows in the same way we measure labour and output shares. Finally, the third exercise uses the LA-KLEMS database to disaggregate the data into nine industries. For each industry, we identify three characteristics of the labour factor (sex, age, and level of education) and eight types of capital assets. The disaggregated data are only available for five countries: Argentina, Brazil, Chile, Colombia, and Mexico.

The exercises reveal, as discussed in detail below, that as the input measures improve, the efficiency measure (or TFP), which is usually positive and statistically explains a large share of observed growth, becomes increasingly negative for all the groups of countries and in all sub-

periods. The one exception is the boom period of 2003–2008, when, because of high growth rates, the contribution of TFP decreases but remains positive. This result is consistent with the findings of other studies, which show that TFP displays a procyclical behaviour: since the capital stock does not adjust quickly, in a period of low growth the increase in idle capacity tends to be reflected in a decrease in productivity.

To explore what is happening in these results, we performed an exercise on the five countries for which disaggregated data are available (Aravena and Hofman, 2014). For these countries, it is possible to determine the contribution of the five productive factors used in the KLEMS approach (capital, labour, energy, materials, and services) in nine industrial branches. Based on this more disaggregated analysis, we extract hypotheses on the factors that determine growth and that can be addressed through public policies.

We find that while the growth rates of the capital stock (K) are not far below more industrial countries, investment rates (capital accumulation) are much lower, and the improvement of the quality-adjusted labour input is lower than recorded in the high-growth Asian countries. In addition, dispersion indicators on labour productivity and TFP by economic sector in our countries are much higher than in developed countries, whereas the dispersion of capital per labour unit is not so different, pointing to problems in the allocation of investment. Thus, our relatively low long-term growth rates could be associated with a slower accumulation process, as well as TFP-related factors such as a misallocation of productive resources across firms or industries. This would support the Hsieh-Klenow hypothesis, which argues that “the misallocation of inputs across firms and industries may be an important determinant of differences in residual TFP, but it remains to be seen what the

forces behind the misallocation are” (Hsieh and Klenow, 2010).

The rest of this article is organized as follows. The first section discusses the development of the LA-KLEMS database and presents the results of the aggregate exercise for the 23 LAC countries. The results are presented separately for the improved L and K measures and for each of the sub-periods identified above. This section also describes the empirical regularities for the LAC region and for each of the three subgroups of countries: the English-speaking Caribbean, Mexico and Central America, and South America. The second section presents the more detailed study of Argentina, Brazil, Chile, Colombia, and Mexico, countries for which it is possible to disaggregate the data into nine industries and differentiate the contribution of the different components of capital to analyse the consequences for TFP. Section 3 provides a comparative analysis of the five countries vis-à-vis developed countries. Section 4 concludes with some hypotheses on the factors that could help explain the TFP residual. Based on these hypotheses, we make some policy suggestions that could help improve TFP in Latin America and the English-speaking Caribbean. We thus hope to contribute to the design of policies aimed at increasing the long-term growth rates of the economies in Latin America and the English-speaking Caribbean.

The Contribution of Productivity to Growth in Latin America: Growth Accounting

The basic growth accounting framework allows us to measure the contribution of increases in inputs and efficiency to output growth. The analysis starts with a production

function which defines gross domestic product (GDP) as a function of total factor productivity (TFP) and factor inputs (capital and labour).

Methodology

We use three approaches to estimate GDP growth contributions. In the first, which is used in studies based on the “traditional” growth accounting framework, the capital stock is taken from the gross capital formation series at constant prices,² while employment is introduced as the total number of actual hours worked. We calculate GDP growth contributions for 18 Latin American countries and five Caribbean countries using this approach.

In the second approach, based on the recommendations of SNA (2008), hours worked are structured according to education level (primary, secondary, and tertiary) and adjusted for their respective rates of return. As an additional innovation, capital is disaggregated and estimated based on the available capital stock over time.³ Once the capital stock has been estimated, we calculate the respective cost of use, which is then used to aggregate the different types of assets into a capital services index. This approach is used to estimate GDP growth contributions for 18 Latin American countries.

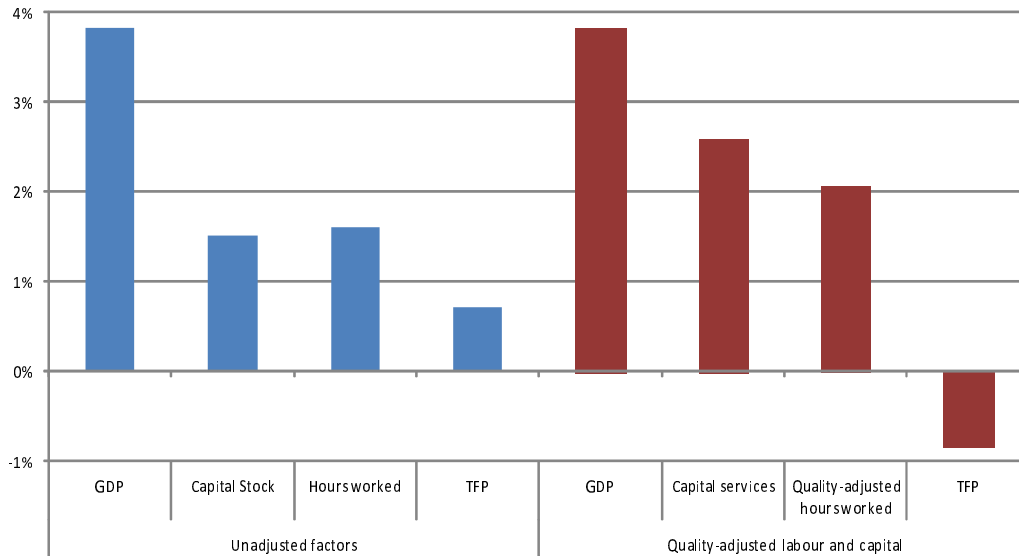
Finally, the third approach draws on the LA-KLEMS database to disaggregate the data into nine economic industries.⁴ For each industry, we identify three characteristics of the labour factor (sex, age, and level of education) and eight types of capital assets. These disaggregated data are only available for Argentina, Brazil, Chile, Colombia, and Mexico. We estimated the residual TFP series for each approach by subtracting the weighted sum of the growth of capital and labour inputs from GDP growth, where the

2 Known as the perpetual inventory method. See Hofman (2000).

3 Aravena and Fuentes (2013) perform the same calculation for the determinants of labour productivity.

4 On the LA-KLEMS database, see Aravena and Hofman (2014).

Chart 1: Sources of GDP Growth in Latin America, Traditional versus SNA-2008 Based Growth Accounting, 1990–2013 (average annual percentage point contribution)



Source: Authors' estimates.

weights are the share of each input in income in the national accounts.⁵

Main Results

When we compare the capital estimates in which the asset aggregation is based on the respective cost of use with the estimates from the traditional method, we find that capital services account for a larger contribution to GDP growth than the traditional estimates. In other words, the traditional approach underestimates the contribution of capital or investment, because the quality adjustment increases the contribution of capital.

A comparison of the decomposition of the determinants of GDP under the two methods, (Chart 1), shows that the traditional method generates a larger increase in TFP, relative to the adjusted methodology. This is because in the second exercise, the contribution or — in other words — the explanatory power of capital and

hours worked, adjusted for human capital, is greater.

In particular, the contribution of hours worked increases in all countries, except for Argentina, after the quality adjustment (as a comparison of the results in Table 1 and Table 2 show). This rise is mainly due to the increase in years of education since the rates of return are fairly stable. At the same time, the results suggest that when the market value, rather than the user's cost of capital, is used as a weight in the aggregation of assets, the contribution of capital to the productive process is underestimated, and thus the residual (TFP) is overestimated.

The positive effect of the capital adjustment is especially favourable in higher-growth countries (Bolivia, Chile, Colombia, El Salvador, Panama, and, to a lesser extent, Costa Rica and Peru). This suggests that not only the amount, but also the quality of investment as reflected in this case in the adjustment that takes into account the

⁵ Given that it is not possible to distribute mixed income, it was allocated to labour payments. The data are from Aravena and Fuentes (2013).

Table 1: Latin America and the Caribbean: Contributions to GDP Growth, According to the Traditional Method of Growth Accounting, 1990-2013 (average annual percentage point contribution)

	GDP	Capital stock	Hours worked	TFP
Argentina	3.9	1.0	1.0	2.0
Bolivia	4.0	1.6	3.6	-1.2
Brazil	2.5	0.9	1.2	0.4
Chile	4.9	2.3	0.8	1.8
Colombia	3.6	1.2	1.4	1.0
Costa Rica	4.6	2.4	1.3	0.9
Ecuador	3.3	1.6	1.2	0.5
El Salvador	4.2	1.8	1.5	0.9
Guatemala	3.7	1.4	1.8	0.4
Honduras	3.5	1.6	2.2	-0.4
Mexico	2.8	1.6	0.8	0.4
Nicaragua	3.1	0.5	2.8	-0.2
Panama	6.0	2.9	1.6	1.6
Peru	4.4	1.4	1.9	1.1
Paraguay	3.1	1.4	1.9	-0.3
Dominican Rep.	4.9	1.9	1.7	1.2
Uruguay	3.4	0.7	0.7	2.0
Venezuela	2.8	0.8	1.4	0.7
Latin America	3.8	1.5	1.6	0.7
Bahamas	1.5	1.1	1.0	-0.6
Barbados	0.9	0.1	0.5	0.3
Belize	4.1	1.6	2.0	0.5
Jamaica	0.7	1.0	0.6	-0.8
Trinidad and Tobago	4.5	0.0	1.3	3.2
Caribbean (1990-2012)	2.3	0.8	1.1	0.5

Source: Authors' estimates.

capital composition and especially the use of ICT is an important source of productivity (TFP). Moreover, the aggregate analysis of the 18 countries shows that in all cases, there was a favourable (and fairly similar) contribution of higher-quality labour.

The estimation of TFP suggests that it is procyclical: its contribution is positive in countries with high GDP growth, but negative when GDP decreases sharply. The pattern of contraction and “resurrection” of TFP during contractionary and expansionary periods, as documented in previous studies, has given rise to the hypothesis that these large variations in estimated TFP derive not from technological factors, but rather

from financial frictions (Calvo, Izquierdo, and Talvi, 2006). They could also reflect changes in factor utilization. For example, during an economic slowdown (expansion), there could be a reduction (increase) in hours worked, such that the economy produces less (more) with the same capital endowment. The labour market structure could also be part of the explanation. Given that there is little unemployment insurance in LAC countries, during economic downturns the unemployment rate does not increase as much as in developed countries. Instead, people are employed in less productive activities. This phenomenon could partially explain the procyclicality of TFP.

Table 2: Latin America: Contributions to GDP Growth, According to the SNA-2008 Method of Growth Accounting, 1990-2013 (average annual percentage point contribution)

	GDP	Capital services	Quality-adjusted hours worked	TFP
Argentina	3.9	1.7	0.9	1.4
Bolivia	4.0	3.0	4.0	-3.0
Brazil	2.5	2.3	2.0	-1.8
Chile	4.9	3.6	1.2	0
Colombia	3.6	3.1	2.1	-1.6
Costa Rica	4.6	3.2	1.8	-0.5
Ecuador	3.3	1.2	1.5	0.6
El Salvador	4.2	3.6	1.9	-1.2
Guatemala	3.7	2.5	2.4	-1.2
Honduras	3.5	4.0	2.8	-3.3
Mexico	2.8	2.4	1.2	-0.8
Nicaragua	3.1	1.6	3.5	-2.0
Panama	6.0	3.5	2.0	0.6
Peru	4.4	2.2	2.4	-0.3
Paraguay	3.1	2.5	2.3	-1.8
Dominican Rep.	4.9	3.8	2.1	-1.0
Uruguay	3.4	1.5	1.1	0.9
Venezuela	2.8	0.9	1.9	0
Latin America	3.8	2.6	2.1	-0.8

Source: Authors' estimates.

Observations on the Growth Accounting Results

This section provides five observations on the the growth accounting results presented in the previous section.

- *The GDP growth cycle is similar in Latin America*

GDP growth follows the same cycle in Mexico and Central America and in South America. In contrast, the English-speaking Caribbean recorded an increase in its growth rate in the 1997–2003 sub-period. Overall this region followed the trend in developed countries more closely than did Latin America. The subregion with the highest GDP growth rate was Mexico and Central America from 1990 to 2013 (Chart 2).

- *Capital plays a key role in the GDP growth process*

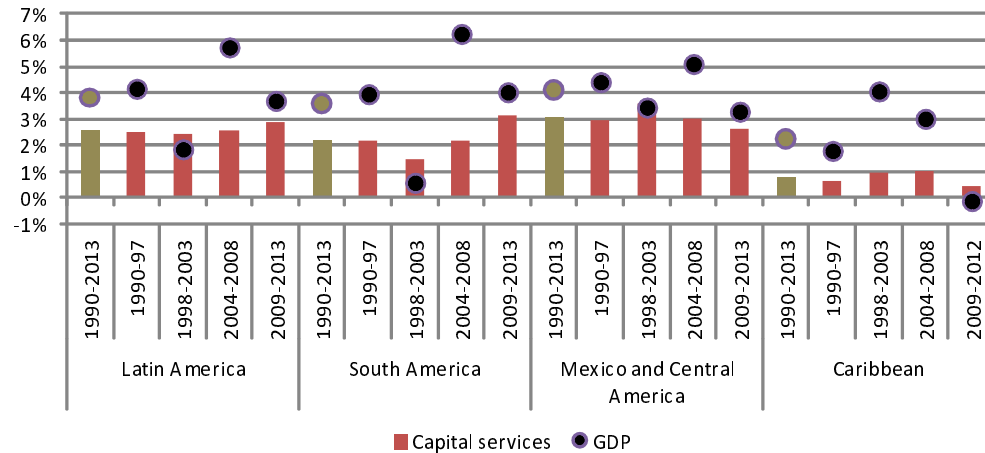
Capital services play a key role in the GDP growth process in Latin America, contributing

68 per cent of average growth in the region in 1990–2013 (Chart 2, Panel A). The difference in the regions' growth dynamics lies in labour and TFP, which contribute 54 per cent and –28 per cent, respectively to GDP growth. If the growth contribution of TFP in the Latin American economies was zero, the contributions of capital and labour would be 56 per cent and 44 per cent, respectively. By sub-period, in Latin America the capital contribution is stable at around 2.5 percentage points of GDP growth, which rises to 2.9 percentage points in the last period (2008–2013). The analysis by subregion reveals that the capital contribution was the most volatile in South America, due to a drop in 1997–2003 followed by a strong increase in 2008–2013 (Chart 2).

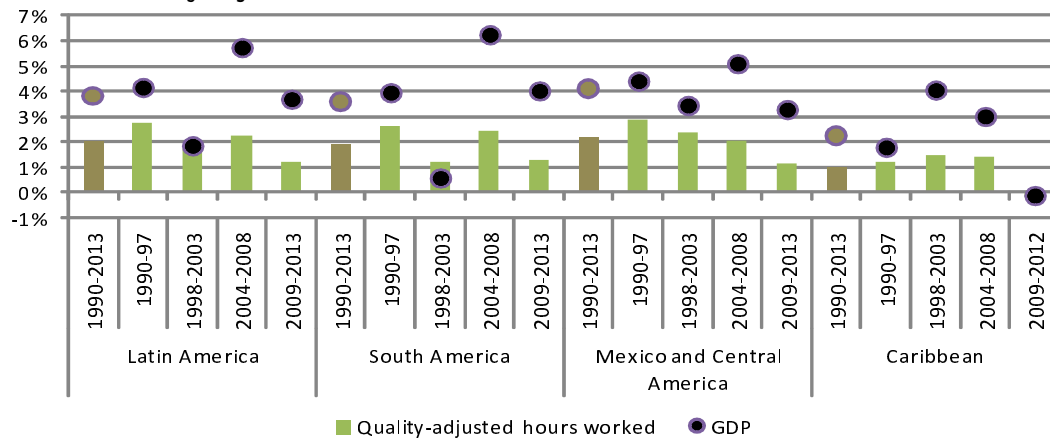
In South America, the contributions of capital and labour are similar, with the exception of the last period, when the capital contribution is nearly three times the labour contribution. In

Chart 2: Sources of GDP Growth in Latin America, SNA-2008 Based Growth Accounting by Subregion and Period, 1990–2013, (unweighted average of percentage point contribution)

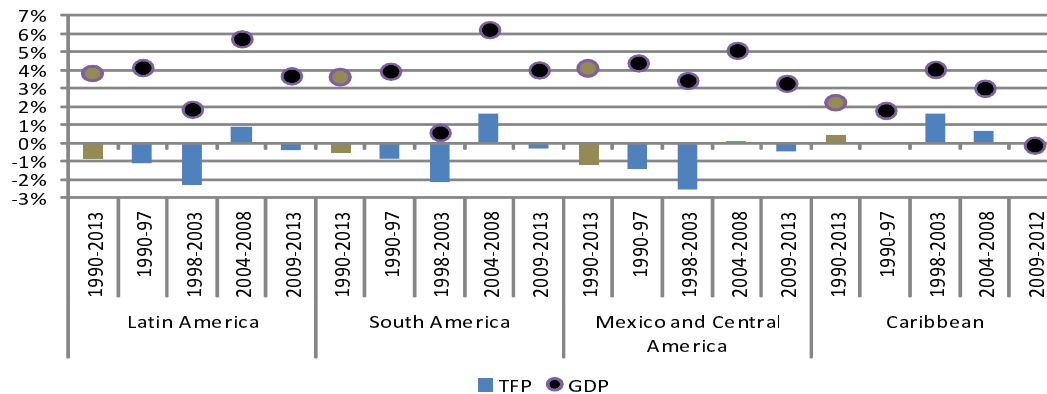
Panel A: Capital Services and GDP



Panel B: Quality Adjusted Hours and GDP



Panel C: TFP and GDP



Note: The estimates for the Caribbean are obtained through the traditional method of growth accounting. (Net capital stock and total hours worked).

Source: Authors' estimates.

contrast, in Mexico and Central America, the capital contribution always exceeds that of labour. The labour contribution was higher than capital in only four countries in 1990–2013: namely, Bolivia, Ecuador, Nicaragua, and Venezuela (Table 2).

In the English-speaking Caribbean, the contribution of capital to GDP growth is lower, ranging from 0.5 to 1.0 percentage point. This is an underestimation, however, since the data for this region do not allow the disaggregation of the capital stock into capital services.

- *Labour influences the regional growth process*

The contribution of labour is different between groups of selected countries, with a procyclical pattern in South America and the English-speaking Caribbean and a continuous decline in Mexico and Central America, due to both a smaller increase in employment in three countries (El Salvador, Guatemala, and Nicaragua) and a smaller share of wages in GDP throughout most of the subregion. The labour contribution is mainly due to an increase in total hours worked, which accounts for 77 per cent of the total (Chart 2).⁶ The human capital component accounts for over 25 per cent of the total contribution in seven of the 18 countries of Latin America, where Costa Rica is the only Central American country in the group of seven. The GDP contribution of labour is generally less than that of capital, both across countries and over time (Charts 1 and 2).

- *The growth contribution of total factor productivity is negative and procyclical*

The only period in which TFP has a positive GDP contribution is 2003–2008, when the two Latin American subregions recorded higher GDP growth rates. The TFP performance was systematically worse in Mexico and Central

America than in South America (Chart 2). The GDP growth contribution of TFP in Latin America was the most negative in 1997–2003. This is the same period in which the growth contribution of TFP was highest in the English-speaking Caribbean, at about 40 per cent, reflecting its procyclical nature. The analysis of the evolution of productivity in the sample of countries tends to confirm that TFP is procyclical, and it is the main determinant of the difference between higher or lower economic growth (Chart 2).

- *The increase in the capital contribution generates higher total factor productivity*

The countries with a positive TFP contribution are those that also recorded increases in the contribution of capital to GDP growth (Chart 3). That is, the greater investment and the more intensive use of capital increase TFP and thus growth.

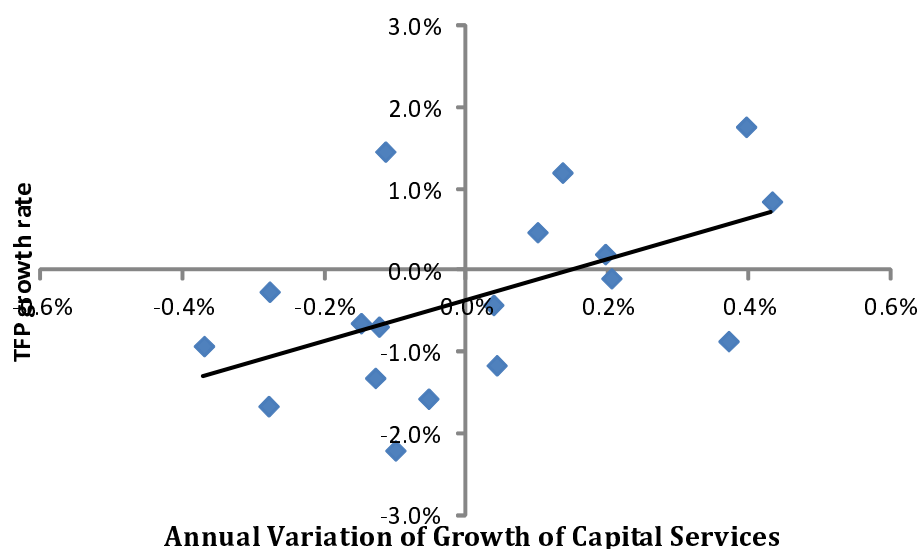
Sectoral Analysis of the Determinants of Productivity

Thus far, we have looked at the evolution of productivity at the aggregate level. This section analyses economic growth, productivity, and their determinants for nine industries in five countries (Argentina, Brazil, Chile, Colombia, and Mexico) in the 1990–2012 period. The exercise draws on the new LA-KLEMS database.

The database provides the employment, capital services, and production series by sector. In the case of employment, the database includes factors associated with the change in the composition of the labour force, while for capital, it includes the effects of the speed of the investment shift towards information and communication technologies (ICTs) in recent years.

6 The contribution of labour to GDP growth is the sum of the contributions of actual hours worked and human capital.

Chart 3: Relationship between TFP Growth and Annual Variation of Growth of Capital Services in Selected Latin American Countries, 1990-2013



Source: authors' estimates.

- *Sectoral growth is highest in the tertiary sector*

Chart 4 shows that the growth rate of the tertiary sector (services) was higher, on average, than the primary and secondary sectors, with the exception of Brazil where the primary sector (agriculture, livestock, and mining) had the highest average growth rate, followed by services.⁷ For the five countries analysed, the unweighted average economic growth rate in 1990–2012 was 3.7 per cent. Chile had the best performance in the period, at 5.0 per cent.

Surprisingly, the industry output data in Table 6, found later in the article, show that the transport and communications industry had the highest sectoral growth rate in all five countries. The lowest-growth industry was manufacturing in Argentina, Brazil, Chile, and Colombia.

In Mexico, total average growth was low. These results could be explained, in part, by the

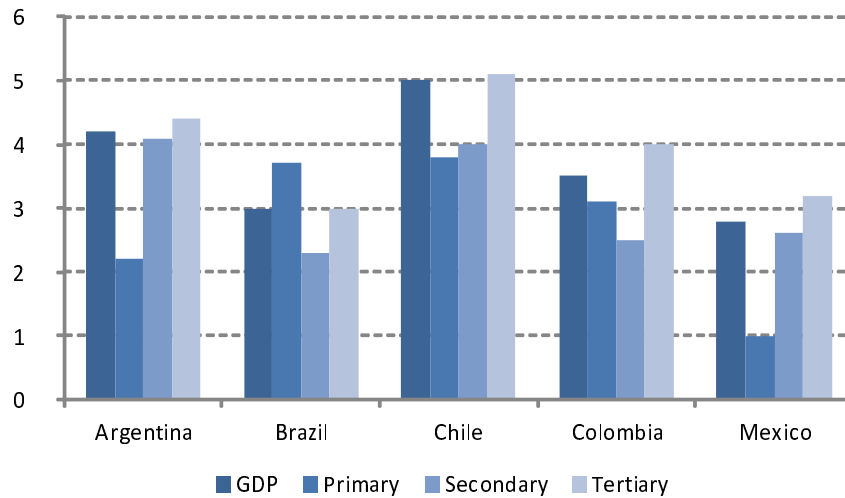
macro- and microeconomic policies in the countries of the region. For example, from a macroeconomic perspective, real exchange rate fluctuations can generate uncertainty about the expected returns in industries with strong international competition. In terms of microeconomics, market failures or regulations can impose costs that act as a wedge or tax, distorting relative prices and reducing the return on investment in the industry (Restuccia and Rogerson, 2013).

The finding that manufacturing is the least dynamic industry in Latin America, while the services industry is the most dynamic, raises a number of important questions.⁸ How can policies be designed to accelerate growth? If the problem stems from the misallocation of capital due to the way the sector and the markets operate, what measures can be adopted to reverse the

7 Primary sector: agriculture, livestock, forestry and fishing and mining; secondary sector: manufacturing, electricity, gas and water and construction and tertiary sector: trade, restaurants and hotels, transport and communications, financial, business and community services, social and personal services.

8 Of course, the service sector is very heterogeneous and some service sector industries are not dynamic, as shown in Table 6.

Chart 4: Total and Sectoral GDP Growth: Primary, Secondary and Tertiary Sectors in Argentina, Brazil, Chile, Colombia and Mexico, 1990-2012 (average annual rate of change)



Source: authors' estimates.

misallocation? Or must the future growth of Latin America and the English-speaking Caribbean be based on non-manufacturing industries? The answers are not obvious and require more detailed research.

- *Latin American countries are characterized by low investment, relative to both developed countries and other emerging regions*

In 1990–2013, investment in Latin America was equivalent to around 20 per cent of GDP, versus about 35 per cent in developing Asia. The low investment rates have made it impossible to achieve higher growth rates in Latin American economies.

Like the rest of the region, the five countries generally saw a reduction in the investment rate in the late 1990s and early 2000s, in part due to the Asian crisis of 1998–1999 and/or the slow-down of 2001–2002. By the end of 2010, however, all of the countries recorded the strongest investment effort of the last 20 years, with the exception of Chile (Table 3). The highest rates were in Argentina (25.4 per cent) and Brazil

(24.7 per cent), while the rest of the countries were above 20 per cent.

One of the major advances of the LA-KLEMS database is the inclusion of estimates of ICT gross fixed capital formation. The database includes three ICT assets — office and computing equipment, communication equipment, and software — for Argentina, Brazil, Chile, Colombia, and Mexico. Table 3 shows the disaggregation of gross fixed capital formation into ICT and non-ICT assets. As the table shows, the share of ICT assets as a percentage of real GDP is largest in Brazil, at twice the rate of Colombia, the country with the second-highest share of ICT assets. Chile has made the biggest improvement in ICT investment, moving up from the lowest level in the sample in 1995 to quickly overtake Argentina and Mexico. In the full sample period, meaning the average for every year from 1995 to 2010, ICT investment accounted for around 7 per cent of the total investment effort in Argentina, Chile, and Mexico, versus

Table 3: Disaggregation of Gross Fixed Capital Formation in Argentina, Brazil, Chile, Colombia, and Mexico, by Type of Asset (percentage of real GDP)

	1995			2000		
	Total	ICT	Non-ICT	Total	ICT	Non-ICT
Argentina	19.1	1.2	17.9	17.2	1.8	15.4
Brazil	22.2	4.0	18.2	21.0	3.9	17.1
Chile	26.0	0.3	25.7	22.1	1.3	20.8
Colombia	19.3	2.0	17.3	12.7	1.6	11.0
Mexico	18.2	1.0	17.2	21.5	1.9	19.6

	2005			2010		
	Total	ICT	Non-ICT	Total	ICT	Non-ICT
Argentina	23.2	1.6	21.6	25.4	1.4	24.0
Brazil	20.0	4.1	15.9	24.7	4.9	19.7
Chile	23.9	1.5	22.4	24.0	2.1	22.0
Colombia	18.3	2.6	15.7	20.2	2.0	18.1
Mexico	21.4	1.4	19.9	22.5	1.7	20.8

Note: The investment rates presented here are not official statistics from the countries' national accounts, because the ICT investment series were deflated using hedonic price deflators. For details, see Aravena and Hofman (2014).

Source: Authors' estimates.

12 per cent in Colombia and 19 per cent in Brazil.

Table 4 disaggregates non-ICT investment by type of asset. The largest investment share is non-residential construction in Chile, Colombia, and Mexico, and residential buildings in Argentina for the years 1995, 2000, 2005 and 2010. Only Brazil concentrates investment in non-construction assets, namely, other machinery and equipment. Residential investment is still significant, however, at only slightly less than other machinery and equipment.

Given that investment incorporates technological progress, the allocation to different types of assets is relevant. In terms of the size of productive non-ICT investment (excluding residential investment) as a share of the total, the countries can be classified in three levels: in

Argentina, just 60 per cent of total investment is allocated to productive investment; in Brazil and Mexico, 70 per cent; and in Chile and Colombia, 80 per cent.⁹ The latter two countries also have a higher contribution of capital to GDP and have recorded the largest improvements in productivity.

By economic sector, gross capital formation was highest in the tertiary or services sector in 1990–2010 in all five countries, followed by the secondary and then the primary sector (Table 5). More specifically, Argentina and Brazil have a large share of investment in manufacturing and a very low share in electricity, gas and water (EGW), while Chile, Colombia, and Mexico split the bulk of investment between manufacturing, mining, and community and personal services, with a substantial share for EGW as

9 Residential construction is the non-productive investment as only investments that add to the capital stock that is used in the production process are considered "productive" here.

Table 4: Gross Fixed Capital Formation in Argentina, Brazil, Chile, Colombia, and Mexico, by non-ICT Assets, 1995, 2000, 2005 and 2010 (percentage of real GDP)

	1995					2000				
	Total non-ICT assets	Residential buildings	Non-residential construction	Transport equipment	Other machinery and	Total non-ICT assets	Residential buildings	Non-residential construction	Transport equipment	Other machinery and
Argentina	17.9	7.2	4.9	2.0	3.8	15.4	6.3	4.5	1.8	2.8
Brazil	18.2	5.1	4.0	3.4	5.6	17.1	5.4	4.2	2.2	5.2
Chile	25.7	6.5	8.7	2.3	8.1	20.8	4.6	8.5	1.6	6.1
Colombia	17.3	2.1	11.4	1.0	2.8	11.0	1.9	5.6	1.0	2.6
Mexico	17.2	4.6	5.4	1.3	5.9	19.6	6.0	6.3	2.5	4.9
	2005					2010				
	Total non-ICT assets	Residential buildings	Non-residential	Transport equipment	Other machinery	Total non-ICT assets	Residential buildings	Non-residential	Transport equipment	Other machinery
Argentina	21.6	8.8	5.2	3.0	4.5	24.0	9.7	4.9	3.4	6.0
Brazil	15.9	4.4	3.5	2.5	5.6	19.7	5.0	3.9	3.8	7.0
Chile	22.4	4.6	8.8	2.4	6.6	22.0	3.8	9.5	1.7	7.0
Colombia	15.7	3.7	7.2	1.7	3.0	18.1	4.0	8.8	2.1	3.1
Mexico	19.9	6.5	6.6	2.1	4.8	20.8	6.5	7.2	1.9	5.3

Source: Authors' estimates.

well (Table 5). The investment shares of transport and communications are similar. Trade, restaurants and hotels has a notably larger weight in Argentina than in the other countries.

- *Investment in non-ICT capital explains most of the increase in total value added, as well as the growth of the fastest-growing industry: transport and communications*

In four of the five countries, investment largely accounts for the growth of total value added, as well as the growth of the most dynamic industry, namely, transport and communications (Table 6). The one exception is Brazil, where the labour contribution, especially hours worked, explains the largest share of total value added

growth, including value added in the transport and communications industry.

- *In terms of labour, the largest contribution to the growth of value added came from hours worked, and the industries that contributed the most were services (mainly trade and financial and business services) and construction*

The total contribution of labour essentially derives from hours worked, with a much smaller contribution from job quality. In manufacturing, hours worked grew very little in four countries and fell in Mexico. Job quality improved in all industries in four of the countries. Only Colombia recorded a negative contribution from the change in the composition of employment—and only in some industries. In the primary sector,

Table 5: Distribution of Total Gross Fixed Capital Formation in Argentina, Brazil, Chile, Colombia, and Mexico, by Industry, 1990-2010

	Argentina	Brazil	Chile	Colombia	Mexico
Agriculture, livestock, forestry, and fishing	6.6	6.3	4.8	4.7	5.6
Mining	2.0	3.9	15.7	16.7	11.0
Manufacturing	27.3	34.9	15.5	15.8	21.9
Electricity, gas, and water	0.6	2.9	8.3	16.0	10.2
Construction	2.3	5.4	1.8	1.7	5.7
Trade, restaurants, and hotels	16.0	6.4	8.6	6.4	9.2
Transport and communications	15.9	11.1	14.9	14.3	13.3
Financial and business services	6.4	4.9	10.6	4.5	5.1
Community, social, and personal services	23.1	24.3	19.8	19.9	18.0
Total	100	100	100	100	100

Source: Authors' estimates.

there was generally a very low or negative contribution from hours worked. The improvement in the quality of labour compensated this negative contribution in all countries with the exception of Colombia.

The results for TFP are less clear, although the aggregate effect on growth was negative in all economies. Even in the case of transport and communications, TFP was positive and significant only in Argentina.

Again, in four of the five countries analysed, the industries with the lowest TFP growth were those with the largest capital contribution to the growth of value added: the mining industry in Argentina and Brazil; electricity, gas, and water in Chile; and transport and communications in Colombia. In Mexico, these two factors do not coincide. This could be an indication that the problem of low value added growth in the countries of the region is due not only to low investment, but also to the allocation of investment, as discussed earlier.

Comparative Analysis of the Determinants of Labour Productivity

In order to formulate hypotheses about how Latin American economies perform relative to more developed economies, we designed a comparative exercise using seven of the largest industrialized countries: France, Germany, Italy, Japan, Spain, the United Kingdom, and the United States. The comparison analysed labour productivity over the 1995–2007 period. The main results are presented below.

- *The growth rate of labour productivity varies significantly among both the Latin American and developed countries*

The highest growth rates of labour productivity over the 1995–2007 period are found in two Latin American countries, such as Chile (2.6 per cent per year) and Colombia (2.0 per cent) followed by certain benchmark countries, Japan (2.1 per cent), the United Kingdom (2.1 per cent), and the United States (2.0 per cent) (Table

Table 6: Sources of the Growth of Value Added in Argentina, Brazil, Chile, Colombia, and Mexico, by Economic Sector, 1990-2009 (average annual percentage points contribution)

Argentina (1993–2008)						
	Value added	Hours worked	Job quality	ICT capital	Non-ICT capital	TFP
Total	3.1	1.1	0.5	0.6	1.6	–0.7
Agriculture, livestock, forestry, and fishing	3.0	–0.1	3.1	0.0	1.2	–1.2
Mining	2.7	0.7	0.9	0.2	9.2	–8.4
Manufacturing	2.4	0.0	0.2	0.5	1.3	0.4
Electricity, gas, and water	5.1	0.4	0.5	0.7	1.3	2.2
Construction	3.8	1.7	0.4	0.2	–1.7	3.2
Trade, restaurants, and hotels	2.7	0.6	0.2	1.0	0.6	0.4
Transport and communications	6.4	1.9	0.3	0.2	2.5	1.5
Financial and business services	3.1	1.2	0.1	1.3	3.3	–2.8
Community, social, and personal services	2.5	2.3	0.6	0.5	0.4	–1.3
Brazil (1996–2009)						
Total	2.6	1.8	1.0	0.8	0.4	–1.4
Agriculture, livestock, forestry, and fishing	3.5	–0.8	1.0	0.3	0.6	2.4
Mining	3.9	1.1	0.8	2.7	1.6	–2.4
Manufacturing	1.1	1.3	0.7	1.1	0.2	–2.2
Electricity, gas, and water	2.9	0.3	0.5	1.4	1.2	–0.6
Construction	2.0	2.0	0.8	0.2	0.8	–1.8
Trade, restaurants, and hotels	2.5	2.2	1.0	0.2	0.1	–1.1
Transport and communications	4.0	1.5	0.6	1.2	0.7	0.0
Financial and business services	3.5	4.0	0.5	0.6	0.0	–1.6
Community, social, and personal services	2.6	1.3	1.6	0.9	0.6	–1.7
Chile						
Total	4.3	1.4	0.9	0.3	2.0	–0.3
Agriculture, livestock, forestry, and fishing	4.6	–0.9	0.9	0.1	–0.7	5.3
Mining	4.2	–0.1	0.7	0.3	4.3	–1.0
Manufacturing	3.3	0.2	1.2	0.2	2.1	–0.3
Electricity, gas, and water	4.1	0.3	0.1	0.4	6.2	–2.8
Construction	4.2	2.5	1.1	0.1	0.4	0.1
Trade, restaurants, and hotels	5.7	1.9	1.1	0.3	1.1	1.4
Transport and communications	6.8	1.7	0.9	0.4	3.7	0.0
Financial and business services	5.8	4.6	0.6	0.5	2.0	–1.9
Community, social, and personal services	3.3	1.3	1.5	0.3	1.3	–1.0

Table 6: Sources of the Growth of Value Added (continued)

Colombia						
	Value added	Hours worked	Job quality	ICT capital	Non-ICT capital	TFP
Total	3.2	2.3	0.4	0.5	2.5	−2.4
Agriculture, livestock, forestry, and fishing	1.9	−0.1	−2.1	0.0	2.5	1.6
Mining	3.6	0.6	0.2	0.7	9.4	−7.3
Manufacturing	1.9	1.2	0.8	0.1	3.0	−3.2
Electricity, gas, and water	2.3	−0.9	−1.0	0.0	10.4	−6.3
Construction	3.5	3.1	−1.0	0.0	1.3	0.1
Trade, restaurants, and hotels	2.4	3.2	1.6	0.3	1.4	−4.1
Transport and communications	4.4	2.3	1.7	4.2	3.4	−7.1
Financial and business services	3.6	4.9	1.4	0.3	1.1	−4.2
Community, social, and personal services	5.1	0.3	−1.1	0.1	1.7	4.1
Mexico						
Total	1.8	1.2	0.5	0.4	1.2	−1.4
Agriculture, livestock, forestry, and fishing	1.0	0.0	0.4	0.1	1.6	−1.0
Mining	0.4	−0.4	0.6	0.1	2.0	−1.9
Manufacturing	1.6	−0.1	0.4	0.2	1.1	0.0
Electricity, gas, and water	2.9	0.3	0.1	0.5	1.0	1.1
Construction	1.6	2.3	1.0	0.4	1.3	−3.3
Trade, restaurants, and hotels	1.6	3.5	1.1	0.8	0.9	−4.7
Transport and communications	3.9	1.1	0.7	0.6	1.1	0.5
Financial and business services	2.9	1.2	0.0	0.4	1.8	−0.5
Community, social, and personal services	0.5	1.1	0.1	0.4	0.5	−1.5

Source: Authors' estimates.

Notes: It should be noted that the numbers in the columns after value added refer to percentage point contributions to value added, not the growth rates of the variable. Value added = GDP-taxes.

7). At the other end of the spectrum are Italy (0.5 per cent) and Spain (0.7 per cent), together with Brazil (0.6 per cent) and Argentina (1.7 per cent).

The level of labour productivity (measured in 1995 PPP U.S. dollars) in Latin America is about a third the level of the benchmark countries. Labour productivity is especially low in Brazil and Colombia, while Argentina and Mex-

ico have the highest levels among the five countries in the region for which data are available. In most countries, the most productive industry is electricity, gas, and water. Three of the exceptions have substantial mining and oil and gas resources: namely, Chile, Mexico, and the United Kingdom. The fourth is Colombia, where the most productive industry is finance, insurance, and business services. Nevertheless,

Table 7: Comparison of Labour Productivity in Latin American Countries and Developed Countries, 1995 and 2007 (US\$ PPP dollars, 1995)

	France	Germany	Italy	Spain	United Kingdom	United States	Japan	Argentina	Brazil	Colombia	Chile	Mexico
Annual growth rate of labour productivity in the total economy												
1995–2007	1.53	1.55	0.51	0.67	2.06	2.02	2.10	1.68	0.63	2.04	2.56	1.21
Labour productivity in the total economy (value added/ hours worked) (US\$ PPP 1995)												
1995	25.59	25.76	23.95	22.76	20.71	25.80	19.88	10.97	6.27	6.60	7.79	10.02
2007	30.83	31.03	25.44	24.45	26.74	33.32	25.66	13.51	6.74	8.43	10.92	11.70
Standard deviation of the log of sectoral labour productivity												
1995	0.49	0.50	0.65	0.56	0.84	0.59	0.73	0.81	0.91	1.00	0.91	0.94
2007	0.58	0.54	0.68	0.71	0.79	0.69	0.86	0.61	0.86	0.93	0.85	0.94
Max-min ratio (nine industries)												
2007	6.49	6.46	7.88	10.56	9.40	12.01	20.58	5.53	14.68	12.13	12.87	14.19
Industry with the highest labour productivity in 2007 (US\$ PPP 1995)												
Industry	E	E	E	E	C	E	E	E	E	JtK	C	C
Labour productivity	124.05	102.09	118.26	176.83	151.12	163.52	190.95	51.05	42.26	43.12	72.93	46.17
Industry with the lowest labour productivity in 2007 (US\$ PPP 1995)												
Industry	AtB	AtB	AtB	F	F	F	AtB	GtH	AtB	GtH	AtB	AtB
Labour productivity	19.12	15.81	15.00	16.74	16.08	13.61	9.28	9.24	2.88	3.56	5.66	3.25

Source: EU-KLEMS (2011), LA-KLEMS (2013), and authors' estimates.

Notes: TOT = Total economy; AtB = Agriculture and fishing; C = Mining; D = Manufacturing; E = Electricity, gas, and water; F = Construction; GtH = Trade; hotels and restaurants; I = Transport and communications; JtK = Finance, insurance, and business services; LtQ = Personal, community, and social services.

electricity, gas, and water is the second-most-productive industry in Chile, Colombia, and the United Kingdom. At the other end, the least productive industry in most countries is agriculture and fishing.

These relationships are interesting because labour productivity determines the level of wages. Thus, sectors that are highly capital intensive — that is, with a high K/L ratio, such as electricity and mining — tend to have higher productivity and better wages.

- *The K/L ratio increased more in the industrialized countries than in Latin America*

The developed countries underwent a significant intensification of the K/L ratio between 1995 and 2007, with an average increase of around 32 per cent in the period (Table 8).

Although the five Latin American countries, as a whole, recorded a larger increase in the K/L ratio (72 per cent), this trend is mainly explained by strong growth in the ratio in Colombia and, to a lesser extent, Chile. In contrast, the intensification of capital was fairly modest in Argentina

(13 per cent), Brazil (15 per cent), and Mexico (19 per cent). In these three countries, the increase in the K/L ratio was only half that of the

Table 8: Comparison of Capital Per Hour Worked in Latin America and Developed Countries, 1995 and 2007 (1995 PPP dollars)

Panel A: K/L ratio

	France	Germany	Italy	Spain	United Kingdom	United States	Japan	Argentina	Brazil	Chile	Colombia	Mexico
Annual growth rate of the K/L ratio in the total economy												
1995–2007	2.49	3.48	2.33	2.56	3.97	3.71	3.45	1.82	0.79	6.05	15.5	1.64
Capital-labour ratio in the total economy												
1995	52.88	50.30	99.21	45.92	31.55	40.87	46.04	15.87	9.23	10.80	4.63	20.03
2007	62.18	66.28	113.47	57.39	45.99	60.02	65.37	17.99	10.58	21.83	29.89	23.81
Standard deviation of the log of the capital-labour ratio												
1995	1.03	1.02	1.24	1.02	1.60	1.45	1.30	0.55	1.17	1.40	1.91	1.73
2007	1.03	1.11	1.15	1.15	1.49	1.37	1.39	0.76	1.27	1.55	1.85	1.56
Max-min ratio (nine industries)												
2007	41.28	50.52	32.89	40.43	135.94	74.06	164.66	11.42	34.18	155.70	266.49	126.35
Industry with the highest capital-labour ratio in 2007												
Industry	E	E	E	E	C	E	E	C	E	E	E	E
K/L ratio	568.82	582.90	911.76	785.04	1113.84	888.16	1633.41	27.64	84.81	375.28	1446.56	645.86
Industry with the lowest capital-labour ratio in 2007												
Industry	F	F	F	F	F	F	F	F	GtH	F	GtH	AtB
K/L ratio	13.78	11.54	27.72	19.42	8.19	11.99	9.92	2.44	2.48	2.41	5.43	5.11

Panel B: Non-ICT K/L ratio

	France	Germany	Italy	Spain	United Kingdom	United States	Japan	Argentina	Brazil	Chile	Colombia	Mexico
Annual growth rate of the non-ICT K/L ratio in the total economy												
1995–2007	1.63	2.09	1.64	1.61	1.44	1.26	2.74	1.08	–1.03	5.23	15.7	0.79
Non-ICT capital-labour ratio in the total economy												
1995	50.88	47.93	96.91	43.65	29.46	37.78	43.93	15.22	7.96	10.72	4.19	19.39
2007	57.50	57.65	106.87	50.82	34.99	45.66	60.18	15.51	7.30	19.94	24.17	21.13
Standard deviation of the log of the non-ICT capital-labour ratio												
1995	1.04	1.04	1.25	1.03	1.63	1.48	1.31	0.54	1.24	1.41	1.91	1.74
2007	1.05	1.16	1.17	1.19	1.59	1.50	1.42	0.77	1.30	1.62	1.87	1.65
Max-min ratio (nine industries)												
2007	43.27	54.15	35.35	41.95	159.22	98.08	171.86	12.50	43.57	208.09	312.23	124.09
Industry with the highest non-ICT capital-labour ratio in 2007												
Industry	E	E	E	E	C	E	E	C	E	E	E	E
Non-ICT K/L ratio	540.25	559.55	900.28	755.59	1109.78	825.58	1600.0	26.97	60.29	367.47	1445.59	618.58
Industry with the lowest non-ICT capital-labour ratio in 2007												
Industry	F	F	F	F	F	F	F	F	JtK	F	GtH	AtB
Non-ICT K/L ratio	12.49	10.33	25.47	18.01	6.97	8.42	9.31	2.16	1.38	1.77	4.63	4.99

Panel C: ICT K/L ratio

	France	Germany	Italy	Spain	United Kingdom	United States	Japan	Argentina	Brazil	Chile	Colombia	Mexico
Annual growth rate of the ICT capital-labour ratio in the total economy												
1995–2007	7.72	10.75	8.80	8.85	13.86	12.82	8.18	8.90	7.96	27.23	14.01	11.92
ICT capital-labour ratio in the total economy												
1995	2.00	2.37	2.30	2.27	2.09	3.08	2.11	0.64	1.26	0.07	0.44	0.64
2007	4.68	8.63	6.60	6.57	11.0	14.36	5.19	2.48	3.28	1.89	2.35	2.67
Standard deviation of the log of the ICT capital-labour ratio												
1995	1.74	1.14	1.76	2.00	1.65	1.36	1.48	2.44	1.17	1.04	2.42	1.92
2007	1.51	1.18	1.25	1.68	1.66	1.21	1.64	1.98	1.39	1.08	2.49	1.46
Max-min ratio (nine industries)												
2007	164.8	24.92	82.45	219.45	208.15	30.32	159.05	439.72	54.34	32.88	1412.3	215.18
Industry with the highest ICT capital-labour ratio in 2007												
Industry	E	JtK	I	E	E	E	E	LtQ	C	E	I	E
ICT K/L ratio	28.57	23.96	25.07	29.45	58.12	62.58	33.40	3.40	44.23	7.81	19.73	27.27
Industry with the lowest ICT capital-labour ratio in 2007												
Industry	AtB	AtB	AtB	AtB	AtB	AtB	AtB	AtB	AtB	AtB	AtB	AtB
ICT K/L ratio	0.17	0.96	0.30	0.13	0.28	2.06	0.21	0.01	0.81	0.24	0.01	0.13

Source: EU-KLEMS (2011), LA-KLEMS (2013), and authors' estimates.

Notes: TOT = Total economy; AtB = Agriculture and fishing; C = Mining; D = Manufacturing; E = Electricity, gas, and water; F = Construction; GtH = Trade; hotels and restaurants; I = Transport and communications; JtK = Finance, insurance, and business services; LtQ = Personal, community, and social services.

in labour productivity.

Distinguishing between ICT and non-ICT capital contributions provides a way to assess the speed with which the Latin American economies have incorporated ICT capital relative to the developed countries. A comparison of the ICT K/L ratio in the five Latin American countries with the average of the industrialized group reveals that the gap between the two has decreased somewhat, from 3.8 to 3.2 times. However, when Chile is excluded from the Latin American group, the ICT-K/L gap was stable, given that the ratio increased by 27 times in Chile, versus about four times for the remaining countries. Thus, with a few exceptions, Latin America did not reduce the lag in the incorporation of ICT capital in the period under consideration.

The level of the capital/labour ratio (measured in 1995 PPP US dollars) for the five Latin American countries is a little more than a quarter (31 per cent) of the level in the benchmark

countries, and it is fairly stable. If Chile and Colombia are excluded, however, Latin America is seen to be lagging further and further behind the industrialized countries in terms of the K/L level. In other words, the productivity gap between Latin America and the developed countries will tend to widen in the absence of a strong and sustained effort.

- *The negative contribution of TFP was the main cause of low productivity growth in Latin America*

Table 9 presents the descriptive statistics on TFP. As expected, the TFP level is much lower in the Latin American economies (around half the level of the comparator countries). There is no common pattern in TFP by economic industry among the countries. The highest TFP levels are in electricity, gas, and water (France, Spain, and Argentina); manufacturing (Germany, United Kingdom, and the United States); mining and quarrying (Italy, Japan, and Chile); and finance and insurance (Brazil, Colombia, and

Table 9: Total Factor Productivity(TFP) in Latin America and Developed Countries, 1995 and 2007(United States = 100 in 1995)

	France	Germany	Italy	Spain	United Kingdom	United States	Japan	Argentina	Brazil	Chile	Colombia	Mexico
TFP, total economy												
1995	94.4	95.9	75.6	86.3	86.3	100.0	75.4	61.5	37.4	94.4	95.9	75.6
2007	99.6	100.8	71.4	79.5	92.8	109.7	78.0	66.7	33.0	99.6	100.8	71.4
Standard deviation of the log of TFP												
1995	0.2	0.3	0.3	0.2	0.3	0.2	0.4	0.8	0.7	0.2	0.3	0.3
2007	0.3	0.2	0.3	0.3	0.3	0.4	0.4	0.7	0.6	0.3	0.2	0.3
Max-min ratio												
2007	2.4	2.0	2.6	2.0	2.0	4.4	4.6	8.9	5.5	2.4	2.0	2.6
Sector with the highest TFP in 2007												
Sector	E	D	C	E	D	D	C	E	JtK	C	JtK	JtK
TFP	153.4	142.5	133.6	140.2	134.0	180.1	126.6	367.3	107.6	153.4	142.5	133.6
Sector with the lowest TFP in 2007												
Sector	AtB	AtB	AtB	LtQ	LtQ	C	AtB	LtQ	GtH	LtQ	GtH	E
TFP	64.9	70.0	51.2	70.2	66.9	40.7	27.5	41.5	19.6	64.9	70.0	51.2
Annual growth rate of TFP in the total economy												
1995-2007	0.5	0.4	-0.5	-0.7	0.6	0.8	0.3	0.7	-1.0	0.5	0.4	-0.5

Source: EU KLEMS (2011), LA KLEMS (2013), and authors' estimates.

Notes: AtB = Agriculture and fishing; C = Mining; D = Manufacturing; E = Electricity, gas, and water; F = Construction; GtH = Trade, hotels, and restaurants; I = Transport and communications; JtK = Finance, insurance, and business services; LtQ = personal, community, and social services.

Mexico). The lowest are in agriculture and fishing (France, Germany, Italy, and Japan); personal, community, and social services (Spain, United Kingdom, Argentina, and Chile); and trade, hotels, and restaurants (Brazil and Colombia).

- *Relative to the benchmark countries, the Latin America economies display greater dispersion of TFP*

As shown in Table 9, the dispersion of TFP is clearly higher in Latin America (around twice that of the developed countries) according to both measures (standard deviation and max/min). In fact, this is the variable where dispersion is clearly higher in the Latin American economies. This means that the differences in sectoral efficiency are very large in the Latin American countries. That is, most of the dispersion in labour productivity levels across sectors can be attributed to TFP.

Furthermore, TFP declined between 1995 and 2007 in two, Mexico and Brazil, of the five Latin American countries, increasing slightly in Argentina, Chile and Colombia. In contrast, TFP increased in five of the seven comparator countries, and the two countries with decreases — Spain and Italy — are the least developed countries in the group.

- *The intra-sectoral change in the productivity variables under consideration is the driver of growth in these economies. For labour productivity, the (inter-sectoral) structural change component has a larger positive impact in Latin America than in the benchmark countries*

The process of economic development involves not only growth per se, but also structural change, that is, inter-sectoral changes or changes in the distribution of production by industry.¹⁰

The algebraic shift-shares decomposition for the growth rate of labour productivity is given by equation 1.

$$\frac{VA_t}{L_t} - \frac{VA_0}{L_0} = \sum_j \theta_{j0} \left(\frac{VA_{jt}}{L_{jt}} - \frac{VA_{j0}}{L_{j0}} \right) + \sum_j (\theta_{jt} - \theta_{j0}) \frac{VA_{j0}}{L_{j0}} + \sum_j (\theta_{jt} - \theta_{j0}) \left(\frac{VA_{jt}}{L_{jt}} - \frac{VA_{j0}}{L_{j0}} \right) \quad (1)$$

Where θ_{jt} is the weight of employment of sector j in total employment in year t . The first term is the within component, the second refers to the structural change component and the third, and last, the dynamic component. The subscript 0 refers to the initial year, 1995. Even though this is the precise decomposition, the last term of the expression is of no direct economic interpretation since its sign can be either positive or negative depending on the simultaneous combination of positive (negative) structural change component combined with positive (negative) variations of the within component.

The standard practice is either to directly dismiss the dynamic component term (as in McMillan and Rodrik, 2012) or keep it without making any reference to its economic meaning. Here we have opted to show only the within and the structural change component. However, in order to make the decomposition exact after dropping the dynamic component, the total variation of labour productivity is broken down into the within and structural change components according to the weight of each component in the sum of these two. In the rest of the shift-shares analysis the procedure has been analogous. When changes in employment share are positively correlated with productivity levels, the structural change term will be positive

meaning that the structural change increases economy wide productivity growth.¹¹

Table 10 presents the shift-share decomposition between the within and the structural change components for the five variables analyzed, namely labour productivity, capital per hour worked—distinguishing between ICT and non-ICT capital—and TFP. The main results of the shift-share analysis are the following.

With a few exceptions, the main contributor to growth in both the Latin American and comparative samples, for all variables, is the intra-sectoral effect. The structural change component of labour productivity has, on average, a positive contribution, which is eight times higher in the Latin American economies than the comparator countries. Nevertheless, it is smaller than the intra-sectoral effect, and it is not uniform within the four Latin American economies, being very high Brazil and Argentina and low in Chile. In terms of the K/L ratio, including both the ICT and non-ICT K/L ratios, the structural change component is significant for Brazil, but not for the rest of the Latin American economies. Thus, the intra-sectoral component is the main determinant of K/L growth.

For TFP, the intra-sectoral component of change is negative in three Latin American countries, especially Brazil (Argentina is the exception). Thus, the main responsibility for the negative TFP contribution lies within each sector and is not the result of technology transfers in the form of labour reallocations from industries with above average levels of labour productivity to those with below average levels. This suggests that it is necessary to identify the bottlenecks to raising productivity within each sector.

10 Kuznets (1966) highlights the role of structural change in the distribution of economic growth; Maddison (1987) emphasizes the importance of structural change as a source of growth and productivity improvements.

11 For details on the methodology, see Aravena, Fernández, Hofman, and Más (2014).

Table 10: Shift-Share Analysis of the Sources of Labour Productivity Growth in Latin America and Developed Countries, 1995-2007 (percentage point contribution)

	Labour productivity growth rate			Capital / labour ratio			ICT capital / labour ratio			Non-ICT capital / labour ratio			TFP		
	Total	Intra-sectoral change	Structural change	Total	Intra-sectoral change	Structural change	Total	Intra-sectoral change	Structural change	Total	Intra-sectoral change	Structural change	Total	Intra-sectoral change	Structural change
France	1.53	1.46	0.06	2.49	2.78	-0.29	7.72	7.60	0.13	1.63	1.89	-0.27	0.45	0.45	0.00
Germany	1.55	1.37	0.18	3.48	3.36	0.13	11.03	10.67	0.36	2.09	2.02	0.08	0.42	0.40	0.02
Italy	0.51	0.36	0.16	2.33	0.21	2.12	8.03	7.73	0.29	1.64	-0.17	1.82	-0.47	-0.64	0.17
Spain	0.67	0.69	-0.02	2.56	3.06	-0.51	8.77	8.79	-0.02	1.61	2.09	-0.48	-0.68	-0.72	0.04
United Kingdom	2.06	2.22	-0.16	3.97	4.45	-0.48	12.51	12.42	0.09	1.44	1.86	-0.42	0.61	0.79	-0.19
United States	2.02	2.10	-0.08	3.71	4.10	-0.39	12.46	12.49	-0.03	1.26	1.56	-0.30	0.77	0.82	-0.05
Japan ^a	2.10	1.89	0.20	3.45	3.39	0.06	8.03	7.34	0.69	2.74	2.73	0.02	0.31	0.41	-0.10
Argentina	1.68	1.22	0.46	1.82	1.93	-0.11	8.90	8.60	0.30	1.08	1.64	-0.56	0.67	0.35	0.32
Brazil	0.63	0.10	0.53	0.79	0.53	0.26	7.56	7.04	0.52	-1.03	-1.92	0.89	-1.04	-1.28	0.24
Chile	2.56	2.34	0.23	6.05	6.23	-0.18	26.79	26.75	0.04	5.23	5.42	-0.18	0.46	-0.41	-0.06
Mexico	1.21	0.88	0.33	1.64	1.64	0.00	13.13	12.82	0.32	0.79	0.81	-0.02	-0.44	-0.30	-0.14

Source: EU KLEMS (2011), LA KLEMS (2013), and authors' estimates.

Notes: Japan 1995-2006.

Conclusions

This article has reviewed the empirical evidence on growth in Latin America and the English-speaking Caribbean during the 1990–2013 period. The study used the growth accounting paradigm, in the tradition of economists such as Solow (1956, 1957), Denison (1967, 1985), Jorgenson and Griliches (1967), and Maddison (1987). Depending on data availability, we presented three exercises to explain the immediate causes of economic growth in the region:

- A traditional method, in which we use easily available data on hours worked and the capital stock (inputs) and calculate a measure of efficiency (TFP) for a sample of 23 countries—five in the English-speaking Caribbean and 18 in Latin America;

- An improved method, in which we disaggregate labour into hours worked and a job quality measure and calculate capital not as the stock of capital but as the flow of capital services, an exercise for which data are available only for the 18 Latin American countries; and
- A method based on the World KLEMS database (called LA-KLEMS in the case of the region), which supports a finer measure and disaggregation of the inputs that might explain the growth of the total economy and of nine industries, where — for both the economy as a whole and for the nine industries — the labour factor is broken down into hours and quality, the capital factor (measured as capital services) into ICT capital and non-ICT capital, and the residual is

TFP, for the five largest economies in the region (Argentina, Brazil, Chile, Colombia, and Mexico).

The story told by the data is that because the traditional growth accounting method is too aggregated, it cannot measure the labour and capital inputs very well and thus leaves a large positive residual, reported as TFP. As the input measures are improved by disaggregating labour into hours worked and job quality and measuring capital as a flow of services, the TFP residual decreases and indeed turns negative. Interestingly, TFP improves — becoming less negative or even positive — when there is a cyclical increase in the utilization of resources, especially capital, as happened in the 2008–2013 sub-period.

The finding that TFP is negative, in general, for the 24-year period under analysis is confirmed by the more disaggregated exercise that looks at nine industries in five countries. The main exception to this pattern is Argentina, where five of the nine industries have a positive TFP, although TFP is negative for the economy as a whole.

The negative TFP growth indicates that some factors are interfering with the productive processes, creating a drag on the economy's growth that diminishes the capital and labour contributions. Identifying these factors requires the use of econometric exercises that are beyond the scope of this article.

Based on the data analysis, we presented a series of observations, or stylized facts, in the text. The region is facing a significant challenge in the short and medium terms with regard to stimulating economic growth. As policies are formulated to address this challenge, the most pertinent observations would appear to be the following.

- In Latin America, GDP in the different countries moves together and is strongly influenced by the commodity price cycle. In

the English-speaking Caribbean, the economic cycle depends fundamentally on the cycle in developed countries.

- Capital explains over half of the region's growth, but investment is very volatile, moving in line with export prices. The largest component of the capital contribution is non-ICT capital. However, the countries in the region invest less than their counterparts in the high-growth Asian economies.
- Investment is largely directed to non-tradable services industries and, in many cases, regulated industries with guaranteed profits. To the extent that investment is concentrated in protected, nontradable, or regulated industries, it is being allocated to industries with a lower long-term growth potential because, in general, these industries are less exposed to competition and therefore have less incentive to innovate.
- The contributions of labour and TFP to GDP growth are procyclical, which indicates that people work fewer hours or shift into less productive industries during economic downturns, resulting in idle capital. In the case of labour, the largest contribution comes from hours worked. To date, labour quality has contributed less.
- The dispersion of productivity among industries is much higher in the five LA countries than in the benchmark developed economies, which points to greater production inefficiencies in certain industries.
- Although long-term growth reflects a change in the sectoral composition of the economy, improvements in intra-sectoral productivity have a larger impact on growth and the development of productive sectors.

With regard to the policy challenges facing the region, the stylized facts point to some tentative recommendations.

- Countercyclical macroeconomic policies are critical for maintaining the level of installed

capacity utilization and thus for sustaining labour productivity and income.¹²

- Macroeconomic policies should place a strong emphasis on promoting and protecting investment.¹³ As the above exercises show, productivity and income cannot increase without an investment effort.
- Macroeconomic policies must also aim to safeguard the competitiveness of the tradable industries of the economy so as to be able to raise productivity in industries where competition and innovation are more likely to materialize.¹⁴ While some services, such as telecommunications, can contribute to the growth of productivity, it can be difficult to improve productivity in certain services. Moreover, once a certain production level has been reached, there may be limited opportunities to continue growing at high rates.
- Macroeconomic policies must further aim to improve labour productivity and TFP in key industries. This can take many forms, from identifying barriers to production and competition, in order to eliminate them, to improving workers' training, in order to raise labour productivity per unit of capital invested. The average productivity of Latin American economies is, at most, one-third of the level of the industrialized countries. One of the primary obstacles to growth in the region is access to credit for small and

medium-sized businesses (ECLAC, 2008 and 2012). Facilitating their access to working capital should thus be a central part of a strategy for strengthening growth.

That is not to say that there is a "recipe" for achieving and sustaining high growth rates. The experience of other regions suggests that the policy combinations that have allowed a small group of countries to achieve large leaps to higher income levels include a lot of "sweat and sacrifice" (namely, high investment rates and the postponement of current consumption). The available evidence for Latin America and the English-speaking Caribbean appears to confirm this hypothesis, although the existing low levels of productivity also offer opportunities to stimulate growth.

Much research remains to be done to answer some fundamental questions. What are the obstacles contributing to the consistently negative TFP growth? What is going on in the region's manufacturing industry, which traditionally was the high-growth sector of economies that are now developed? These economies have transitioned towards the services sector, and the Latin American economies show signs of doing the same. Finding ways to promote growth in this sector, which has a high employment absorption, could be a major advantage. Answering these questions will be key to raising living standards in the region.

12 Macroeconomic factors contribute to lower productivity when the utilized capacity of economies decreases. In periods of deceleration, a greater proportion of the capital invested is not used and with the same endowment of capital we obtain a smaller product. That is, the degree of "inefficiency" of the economy increases. In times of cyclical declines in production, the phenomenon of "misallocation" of productive resources increases. Capital is underutilized and labour is employed in activities where it is less productive. Lack of unemployment benefits forces workers to lower productivity activities, included informal activities.

13 Public investment in innovation in key industries for competitiveness is reduced in times of crisis.

14 The other industry that is an obvious candidate to raise productivity and economic growth is the manufacturing industry. However, this industry is uncompetitive both because of relative (and in some cases absolute) advantages of Asian countries in this industry and because of the adverse effect of cycles on exchange rate appreciation and the level of investment. The evidence points out that all efforts to reduce growth volatility are important. In this sense, the development of anti-cyclical fiscal capacities point in the right direction. In addition, it would seem desirable to strengthen efforts to isolate the impact of high commodity prices on the rest of the economy. For example, by strengthening policies and instruments to limit exchange appreciation.

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Argentina Was Not the Productivity and Economic Growth Champion of Latin America

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ABSTRACT

The Kirchner administration (2002-2015) claimed that under their leadership Argentina experienced record-breaking GDP growth. However, this article shows that Argentina's GDP growth was underwhelming. Statistical estimates produced by the new Argentine government support the ARKLEMS project's evidence that the Kirchner administration overstated growth. Distortions were large and discretionary and affected all industries, independent of the downward bias of the Consumer Price Index and the Wholesale Price Index. New stylized facts counter the claims of the Kirchner administration. First, real GDP growth in the 2002-2015 period was weaker than in the 1990-1998 period. Second, GDP only grew in the sub-period 2002-2007 because of the commodities boom. Third, GDP growth in Argentina was second lowest among ten Latin American countries in the 1998-2015 period. Fourth, GDP growth during the 2002-2015 period was extensive in nature, based on factor accumulation, not total factor productivity, so was not sustainable.

The commodities price boom at the beginning of the 21st century enabled Latin America to experience substantial GDP growth following the crisis that hit the region at the end of the 1990s. Metals, agricultural and energy commodities exported by Latin America showed strong price increases between 2002 and 2012. Favorable terms of trade and consistent monetary and fiscal policies resulted in substantial improvements of social and macroeconomic indicators in many Latin-American countries.

Argentina was a unique case within the region. GDP grew at Chinese rates from 2002 to 2007, taking advantage of tail winds from the export price boom and "advantages" from the recovery

effects following the worst recession of the last century, which lasted from 1998 to 2002.

In 2002, Argentina abandoned the Currency Board "Convertibility" regime: a fixed exchange rate of 1 Argentinean peso to 1 dollar that had been in place since 1991. What followed was a mega-devaluation of the domestic currency of 300 per cent in only three months. Wages increased only by 50 per cent, and income redistribution from savers to debtors exacerbated unemployment and poverty rates. The drastic depreciation of the Argentinean peso and the consequent improvement in terms of trade, however, ushered in a remarkable economic recovery from 2003 to 2007. But the social cost

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associated with placing half of the population under the poverty line generated institutional instability.

After the 2002 crisis, economic policy shifted dramatically. Trade openness, privatization, deregulation, and supply-side policies (promoted by the Washington consensus) were replaced with demand-driven policies. By 2005, these demand-driven policies as well as the administration's ambition to stay in power, began to generate substantial economic distortions: high fiscal deficits, restrictions on exports and imports; price and exchange-rate controls and high inflation.

The Kirchner administration (2002-2015) decided to hide inflation from 2007 to the end of their term in 2015 by manipulating the official Consumer Price Index (CPI), the Wholesale Price Index (WPI), and results from household and other surveys produced by the National Institute of Statistics and Census of Argentina (INDEC). Public opinion and academics analysts have estimated that the rate of increase of the CPI was considerably higher than officially reported. The former administration opened "a Pandora-Box" by distorting the measurement of the main macroeconomic and social indicators, such as GDP, the trade balance, the poverty rate, and measures of income distribution.

Based on the indicators that were politically manipulated by the Kirchner administration between 2007 and 2015 (referred to as the INDEK estimates in this article), the Kirchners spread several myths during their time in office:

- Argentina reduced poverty and increased real wages to Nordic European levels;

- Argentina had an impressive long-term positive trade balance; and
- Argentina experienced the highest economic growth in its history and was the growth champion of Latin America.²

The evidence of manipulation of official statistics motivated the development of alternative GDP estimations by the ARKLEMS project with the purpose of producing more accurate estimates of GDP for the Argentine economy.³ On December 2015, the new Macri administration ended political intervention at INDEC. The National Statistical Office then produced revised estimates of GDP which affirmed the ARKLEMS project's evidence of the Kirchner's statistical manipulation.

The objective of this article is to summarize the evidence of GDP tampering and its impact on Argentina's GDP profile during the 2007-2015 period.

The article has four sections. First, we present the background and main findings of ARKLEMS and new INDEC real GDP estimates and compare them with the earlier GDP estimates from the National Statistical Institute (INDEC). The second section discusses the realities of Argentina's economic growth record. Section three analyses the impact of these new estimates on Argentina's productivity growth. The final section concludes.

Background

Political interference with the statistical estimates produced by national statistical offices is a not a new phenomenon. Manipulating official data to show favorable political results, mostly on GDP, have been well documented for China,

2 See articles by *The Economist* (2012), *La Nación* (2013), and *Clarín-Economía* (2013) for more information.

3 ARKLEMS+LAND or ARKLEMS is a research project that measures the productivity and competitiveness of the Argentine economy. It is the Argentinean counterpart of the WORLD KLEMS Initiative led by Dale Jorgenson (Harvard University), Marcel Timmer (Groningen University) and Bart Van Ark (Conference Board and Groningen University). The ARKLEMS project is organized by a team of Argentine academics and researchers from the Centre of Studies of Productivity (CEP) at the University of Buenos Aires, specialists in national accounts and input-output analysis. The project is overseen by a prestigious academic committee.

by Maddison and Wu (2008) and Jorgenson and Vu (2001). Statistical offices in other countries have also experienced political intervention. Sturgess (2010) reports distortions related to the measurement of public debt and public finance indicators in Greece to show a fiscal deficit figure below the 3 per cent required to enter the Euro zone.⁴

There are two well-documented cases of CPI manipulation in Latin America by military regimes. Chile and Brazil's official CPI were manipulated to "manage" wage negotiations with trade unions during periods of high inflation as reported by Cortázar and Marshall (1980 and 1987) and Streb (2010). Lula, the former president of Brazil, as leader of the metallurgic labour union during the 1970s, began his political career by accusing the military regime of distorting the CPI, which was confirmed by the World Bank.

Historically, Argentina has been a leader in Latin America for the publication of reliable statistics, including national accounts. But INDEC experienced political intervention by the Kirchner administration starting in 2007. First CPI estimates were manipulated,⁵ then GDP estimates, followed by the quarterly Labour Force Survey and the National Household Expenditure Survey. Official GDP estimates were under suspicion after the media reported on the

ARKLEMS findings that official GDP growth was positively biased by discretionary manipulation (as described by Coremberg (2014)). Academics and public opinion began to use non-official estimations. Moreover, leading official institutions such as the Treasury and the Central Bank requested alternative estimations to track Argentine economic trends. In 2014, Congress began to publish an estimate of the CPI, and later of GDP, based on an average of alternative indicators.⁶

After ARKLEMS publicly released estimates of GDP by sector in 2013, public opinion recognized that the government would be overpaying GDP warrants as a result of the overestimation of GDP growth.⁷ The Kirchner administration responded by publishing a "new INDEK GDP 2004 base year series" in only one week, when, such statistical re-estimation usually takes no less than two years.⁸ The statistical office revised earlier estimates for real GDP growth in 2013 from 5 per cent to "new" estimates of 3 per cent to avoid payment of the 2013 warrants.⁹

The new administration ended the political intervention at INDEC in December 2015. Official revisions confirmed that all of the estimates in the official statistical system were manipulated in accordance with the political interest of the Kirchner administration.

4 The International Association of Research in Income and Wealth sent a letter in 2016 to the Greek government regarding the integrity and independence of official statistics and the prosecution of the former head of the Greek national statistical office. <http://iariw.org/ScannedLetter11-16-16.pdf>.

5 Argentine CPI distortion is reported in Cavallo (2012). An important and methodological consistent alternative CPI estimation was made by G. Bevaqua, former Director of CPI at INDEC. During the period of political intervention, there was an important involuntary "brain drain" from INDEC. The government fined consultants and experts who published inflation figures that showed official figures were being manipulated. The Argentinian court of justice has only recently dropped charges against the fined experts after more than eight years of court cases.

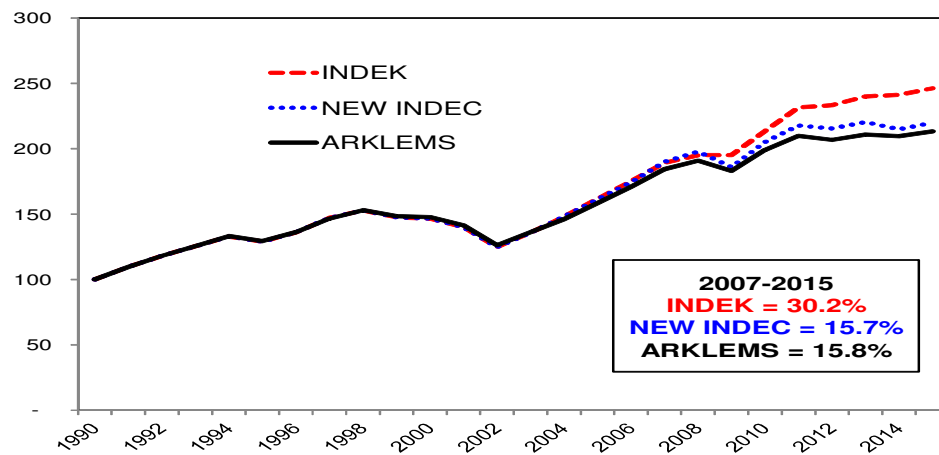
6 Alternative indicators had been estimated by academic institutions and consultants.

7 A GDP warrant is a financial instrument or bond that is directly linked to real GDP official figures. The warrant promises to pay a return, in addition to amortization, that varies with GDP growth. Argentina issued GDP warrants in 2005 after the debt restructuring of the 2002 default.

8 As pointed out before, INDEK revised the 1993 base series to a new 2004 base series. Both are quite similar as they were manipulated in the same way. This article reports manipulation of the INDEK 2004 base series. The political manipulation of the 1993 base series was reported in Coremberg (2014).

9 See Coremberg and Wierny (2014) and Morgan Stanley (2016).

Chart 1: Index of GDP in Argentina, 1990-2015, (1990=100).



Source: INDEK, new INDEC, ARKLEMS

The new INDEC administration has published the following warning about the use of its statistical series (<http://www.indec.gob.ar>): "The statistical series published since January 2007 and until December 2015 should be referenced with caution, except those that have already been reviewed in 2016 and its disclosure is expressly stated. The INDEC, within the framework of the powers conferred by Decree 181/15 and 55/16, ordered the investigations required to establish the standard of quality of the procedures of data collection, processing, development of indexes and dissemination."

Once the new administration was in power, INDEC decided to review and re-estimate the INDEK GDP series. This series was the only one recalculated during the period of statistical manipulation in response to the release of public and independent series not produced by INDEC.¹⁰ The rest of the official statistics series based on primary surveys, such as CPI based on the Household Expenditure Survey, could not be revised based on the original data because these data had been lost or destroyed.

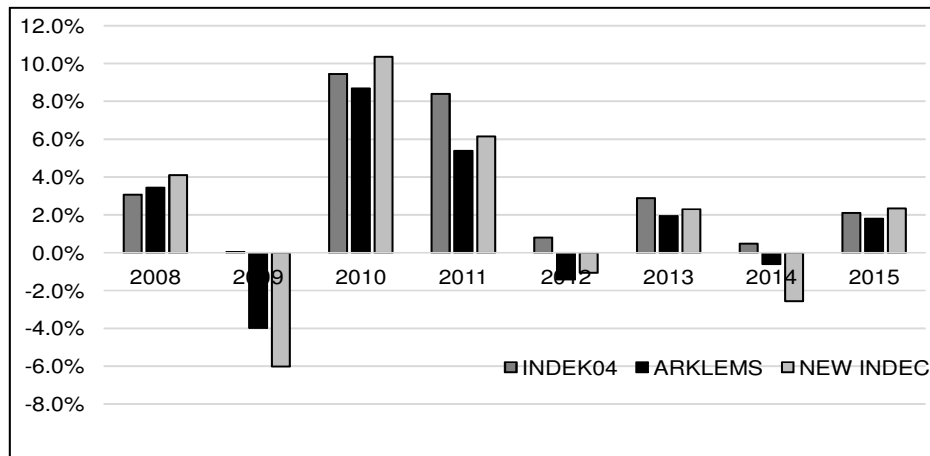
Main Findings

ARKLEMS produced estimates of real GDP in Argentina based on the traditional methodology used for national accounts in Argentina. Chart 1 compares the ARKLEMS estimates with the estimates produced by the national statistical office during the Kirchner administration (INDEK) and the revised estimates produced by this office under the new Macri government (INDEC). The chart shows clearly the political manipulation of the estimates.

ARKLEMS' estimates replicate almost exactly the official Argentine GDP growth from 1993 to 2007 (the first year of political intervention of the data). After that year, however, a significant gap appears. After 2007, the GDP INDEK series shows a significant positive gap in growth rates compared to the ARKLEMS GDP series. The new INDEC series, almost identical to the ARKLEMS estimates, confirms the statistical manipulation. It shows INDEK GDP growth was double the GDP growth reported by ARKLEMS and the new INDEC for the 2007-2015 period: 30.5 per cent "penciled-in rate" versus 15.7/15.9 per cent. Moreover, the ARKLEMS and INDEC show decreases in real

¹⁰ See Government of Argentina (1999) and Coremberg (2014) for detailed data sources.

Chart 2: Argentine GDP Growth, 2008-2015, annual rates



Source: INDEC, new INDEC, ARKLEMS.

GDP in 2009, 2012, and 2014, in contrast to increases in the INDEK series (Chart 2).

"Demythifying" Argentine GDP Growth

The "new" stylized facts have several implications for macroeconomic analyses and previous views about Argentine growth dynamics. It was commonly believed that:

- The strength of Argentine growth reflected a deflator issue. Argentine real GDP growth supposedly had an upward bias because value added at current prices was deflated with a biased Consumer Price Index.
- Argentina's economic growth during the commodities price boom was historically record breaking.
- Argentina was the Latin America growth champion with the highest growth rate of the region.

The Deflator Myth: Just Direct Manipulation

The most common methodological misconception in Argentina was that the upward bias in GDP growth was an indirect consequence of deflating nominal GDP by a CPI index in which

the rate of change exhibited a downward bias. But this is not the case.

The methodology for Argentina's GDP estimates is not to deflate nominal GDP by the CPI. Rather, GDP growth is based mostly on volume indicators. Nominal GDP is estimated by indexing GDP at constant prices to specific industry deflators. Table 1 summarizes the methodology for estimating real GDP by industry:

This methodology was adopted in traditional Argentine national accounts more than three decades ago at the detailed ISIC 4-5-digit industry level. The estimation of basic series, based on volume indicators (output or employment), and made directly or indirectly through commodity flow and income elasticity methods, are not undertaken by INDEC. Rather, they are carried out by other institutions based on representative public and private surveys (Coremberg (2014: Appendix)). As Table 1 shows, Argentine national accounts traditionally estimate real value added in most industries by Laspeyres volume index aggregation instead of deflating nominal values, except for financial intermediation.

We estimate the contribution of each industry to the GDP level gap in 2015 accumulated from the difference in the INDEK and the new INDEC real GDP growth rates between 2007

Table 1: Argentine GDP Growth: Traditional National Accounts Methodology by Industry

	Volume Indicators	Commodity Flow	Demand Function*	Employment Indicators	CPI Deflator
Agriculture, hunting, forestry and fishing	X				
Agriculture Services		X			
Mining and quarrying	X				
Electricity, gas and water supply	X				
Construction	X				
Manufacturing	X				
Trade		X			
Transport and storage		X			
Post and communication services		X			
Financial intermediation					X
Renting of m & eq and other business activities		X			
Hotels	X				
Restaurants		X			
Other community, social and personal services			X		
Private households with employed persons				X	
Public admin and defense; compulsory social security				X	
Education				X	
Health and social work				X	
Real estate activities	X				
Rental services of owner-occupied dwellings	X				

*(only unitary income elasticity)

Source: Government of Argentina (1999), INDEC (2001), Coremberg (2014).

and 2015 (Chart 3).¹¹ The contribution of each industry to the total gap is estimated by taking each industry-specific gap and weighing it by its share of GDP at basic prices.

Industries based on volume indicators account for most of the gap (72 per cent): trade (30 per cent), manufacturing (29 per cent), and positive gaps in construction, mining and services. Financial intermediation accounts for only 28 per cent of the total gap, the only sector where the CPI deflation method is applied.

The upward biases of the official INDEK GDP series are consequently not an indirect result of deflating nominal values by a down-

wardly biased CPI index. Instead, it was discretionary manipulation to internal non-public data sources and public series that produced the biased real GDP estimates.

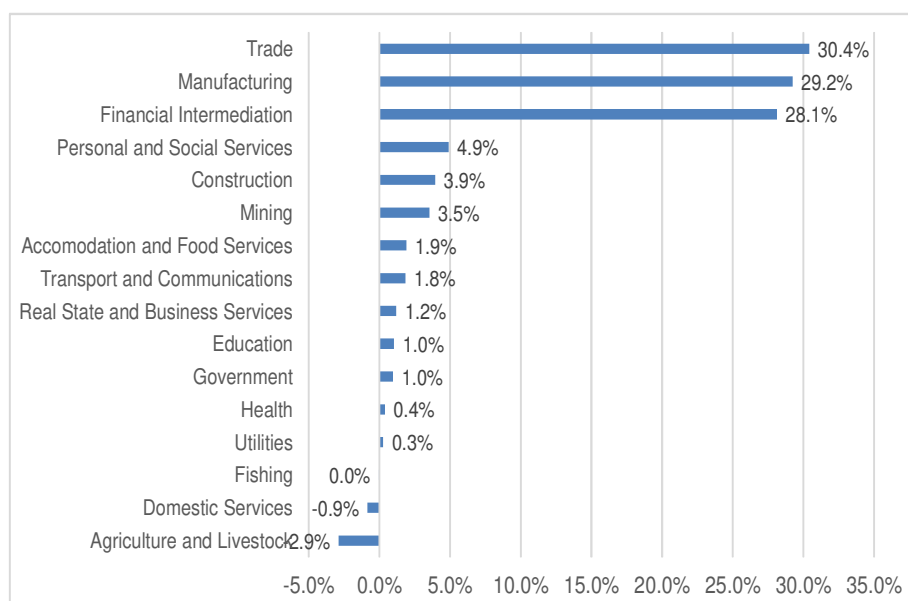
Argentina Did Not Experience Record GDP Growth

The Kirchner administration claimed that Argentina's growth during the commodities price boom was record breaking from a historical perspective. But this was not true.

The economic growth in Latin America and Argentina between 2002 and 2012 occurred after a profound economic depression during

¹¹ Similar results are found with the ARKLEMS series.

Chart 3: Industry Contributions to GDP Level Gap in 2015, (% of total)



Source: INDEK and new INDEC.

the 1998-2002 period. How much of the economic growth is actually due to the post-depression boom? By how much did GDP growth accelerate throughout the "Washington Consensus period" at the beginning of the 1990s? We conclude that the answers to those questions depend on the accuracy of the GDP series used.

The analysis of the GDP cycle is essential when studying whether an economy is recovering from a recession or a previous crisis and whether a growth acceleration process is beginning again. We identify GDP trends and short-run recoveries following Burns and Mitchell (1946) and Rostow (1965). Long-term GDP growth is calculated between GDP peaks.

Generally, GDP peaks coincide with an output level being near potential output, where all production factors are fully utilized. In general, the GDP growth between cyclical peaks is lower than during a recovery phase, because the former is based on productivity gains derived from innovation and other effects that shift the production possibilities frontier instead of

changes in capacity utilization, as explained by Coremberg (2008) and Jorgenson (2011).

We identify GDP cycles for Argentina according to the above method. Results are equivalent to GDP per capita cycle.

We distinguished two positive GDP phases in the medium run: 1990-1998 and 2002-2015. The 1998-2002 period represented the worst depression of the last century, worse than the 1930 crises. GDP peaks are for 1998 and the last year 2015. 1990 and 2002 represent troughs of the GDP cycle.

Table 2 shows GDP growth for selected periods for INDEK, ARKLEMS and the new INDEC series. We also report the sub-periods 2002-2007 and 2007-2015, considering that 2007 is the first year of INDEK political intervention.

The last growth episode from 2002 to 2015, measured by GDP, is similar to the previous positive phase in Argentine history (1990-1998). There was no GDP acceleration during the commodities price boom compared to the 1990s Washington consensus era. The new INDEC

Table 2: Argentine Real GDP Growth, Selected Periods, compound annual growth rates

	INDEK	NEW INDEC	ARKLEMS
1990-1998	5,4	5,4	5,5
1998-2002	-4,7	-4,7	-4,7
2002-2015	5,4	4,5	4,1
2002-2007	8,7	8,8	7,9
2007-2015	3,3	1,8	1,8
1998-2015	2,8	2,2	2,0

Source: INDEK, new INDEC, ARKLEMS.

series, as well as the ARKLEMS series, show a growth slowdown of 1 percentage point per year. GDP estimates show "Chinese rates," approximately 8-9 per cent annually, only during the period 2002-2007. But after 2007, Argentina suffered a significant GDP growth slowdown for every series.

As noted, there was no GDP growth acceleration in the period 2002-2015. The acceleration occurred only during the 2002-2007 period, but this period does not fulfill the rules put forth in Haussmann *et al.* for a sustainable growth episode.

Moreover, after 2007, the so-called "Chinese rates" were not sustainable, since GDP growth showed a substantial slowdown. Peak to peak, GDP grew only 2.2 per cent (0.7 per cent per capita) annual rate.

ARKLEMS GDP growth long-run series (Chart 4) show that there was no structural break of Argentina's long-run GDP growth as verified by econometric filters by Hodrik-Prescott, Kalman and others.¹² During the last century, there were several growth recovery episodes at Chinese rates experienced during different political regimes: Yrigoyen-Alvear (1917-1924), Frondizi (1959-1961), Illia (1963-1965), Menem (1990-1994) and Nestor Kirchner (2002-2007).

Argentina's GDP growth rate during the last commodities price boom between the 1998 and

2015 peaks, 2.0 per cent according to ARKLEMS estimates, was similar to the average growth rate (2.7 per cent) for the last century (1913-2015). These growth rates were around half of the long-term GDP performance of Australia and Canada (Maddison Project, 2015).

This fact demystifies the assertion that Argentina reached the growth rate of natural resource-based developed countries.

Argentina Was Not The Growth Champion of Latin America

According to the Kirchners' administration, Argentina was the growth champion in the Latin American region during the last decade.

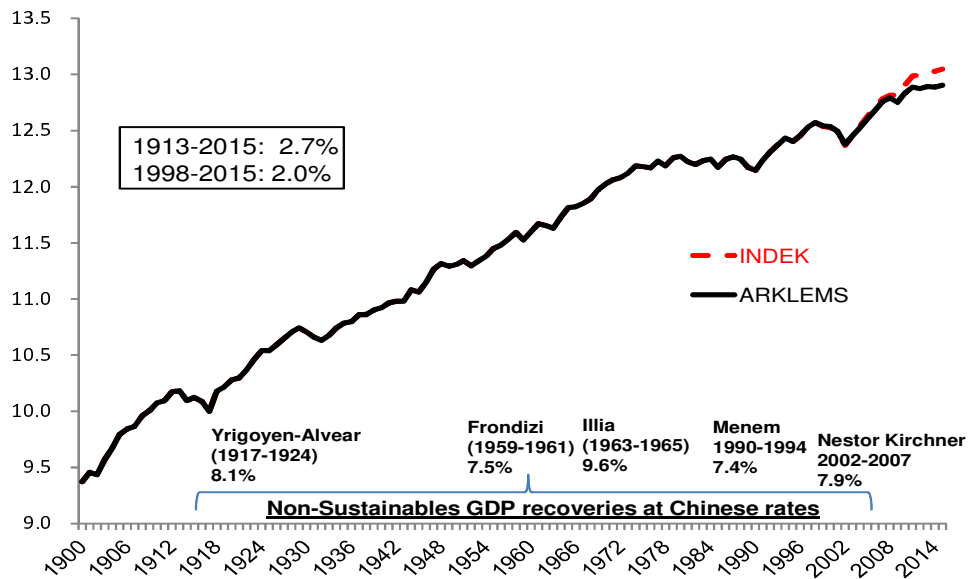
But, taking into account new INDEC and ARKLEMS series, Argentina had moderate GDP growth during the commodities boom (Chart 5). Although still higher than the average Latin America growth, the new estimates show that Argentina was far from being the growth champion of the region that the INDEK series claimed it to be.

The beginning of the commodities price boom in 2002 coincided with the end of the great economic depression in 1998-2002, which had affected Latin America. Notably, Argentina's GDP decline, during 1998-2002, was the deepest of the region, excluding Uruguay.

Several reasons underlie the large impact of external shocks on Argentina at the beginning of

12 The series is based on Tornquist index. See Coremberg *et al.* (2007).

Chart 4: Argentine GDP Growth, 1900-2015 (logs)



Source: INDEK, INDEC, ARKLEMS.

the 21st century: low resilience of the Argentine economy to external shocks due to fiscal deficits, a high public debt to GDP ratio, and a strong commitment to the Currency Board. But, as previously mentioned, tail winds from positive terms of trade, after 2002, allowed Argentina to achieve a remarkable resurrection. Long-run growth is defined between peaks of the GDP cycle. Panel C in Chart 5 shows that Argentina had the worst growth performance of the region in the 1998-2015 period, except for Venezuela.

Stylized Facts on Productivity

Argentina has experienced several structural changes during the last two decades in a context of high economic instability, which hampered the sustainability of long-run growth. The key variable that explains the sustainability of economic growth is productivity.

This section analyses Argentina's growth profile during the commodities price boom taking into account the new stylized facts. We estimate

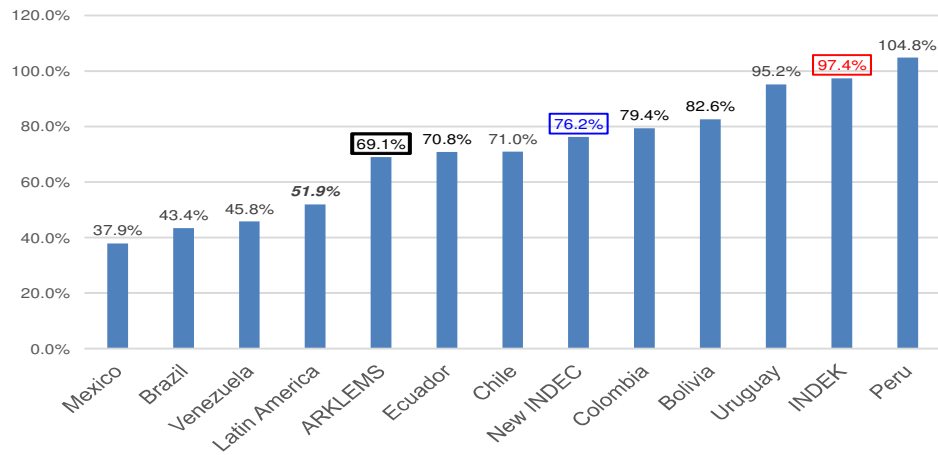
the source of growth taking advantage of ARKLEMS' database on capital and labour services. ARKLEMS follows KLEMS methodological standards developed by the OECD (2001, 2008) and EUKLEMS (2007). Capital input is measured by ICT and non-ICT capital services weighted by user costs. Labour input is composed of hours worked and labour "quality". Labour quality is measured by jobs composition weighted by relative wages by skills (gender, age, education and formal and informal labour workers).¹³ Total factor productivity (TFP) is computed as the difference between GDP growth and the contribution of capital and labour services. We compute TFP by taking into account ARKLEMS input series with the INDEK GDP series and the new INDEC GDP series.

As seen in Chart 6 and Table 3, the overestimation of GDP growth by INDEK generates a false TFP growth after 2007, the first year of political manipulation of official statistics.

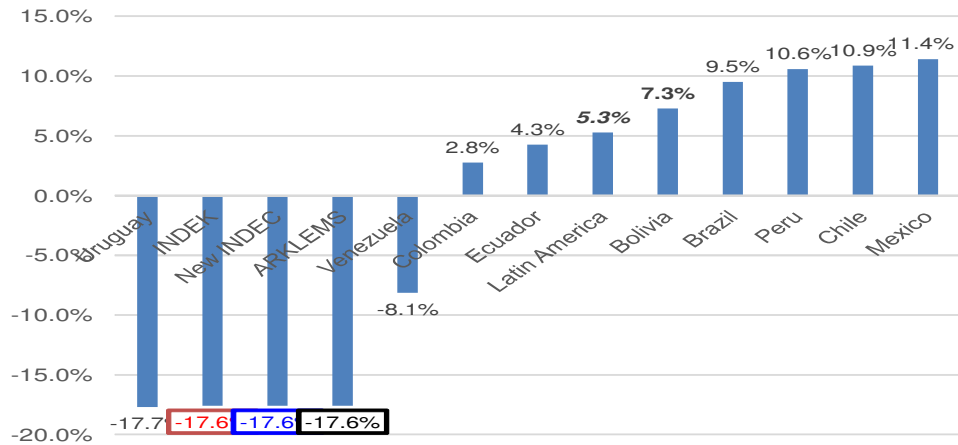
¹³ See Coremberg (2008) for more detail.

Chart 5: GDP Growth in Selected Latin American Countries

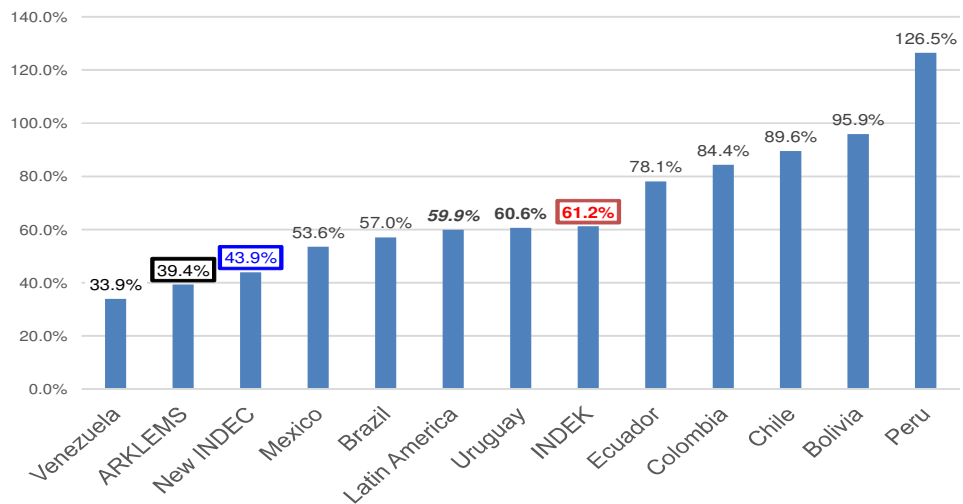
Panel A: 2002-2015



Panel B: 1998-2002

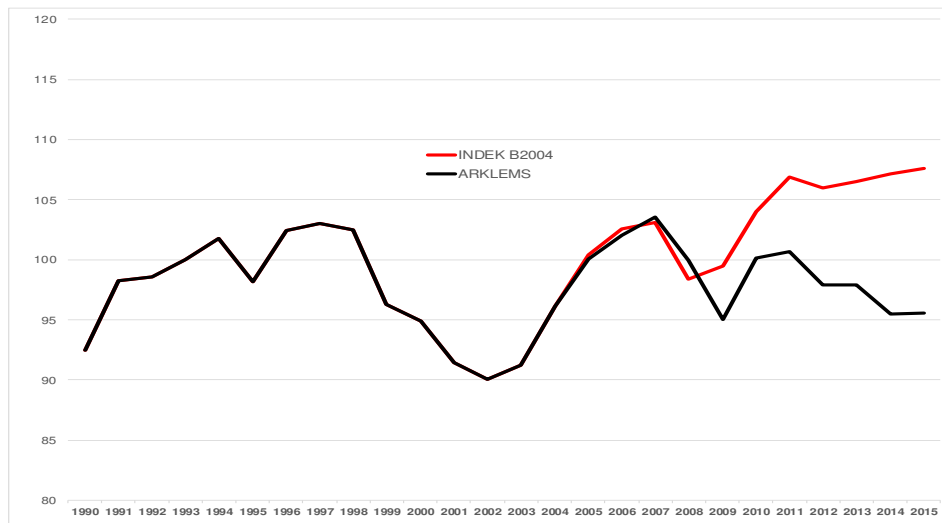


Panel C: 1998-2015



Sources: ARKLEMS and TED. The TED estimates come from ECLAC based on each country's official National Accounts except Argentina.

Chart 6: Total Factor Productivity in Argentina, 1990-2015 (base year=2004)



Source: ARKLEMS.

Table 3: Sources of Argentine GDP Growth, 1990-2015, (percentage point contribution)

	1990-1998	2002-2015	1990-2015	1998-2015
GDP NEW INDEC	5.6	4.5	3.2	2.2
Capital (K) Contribution (ARKLEMS)	2.5	2.6	2.0	1.8
Labour (L) Contribution (ARKLEMS)	1.7	1.5	1.2	0.9
TFP (ARKLEMS)	1.3	0.5	0.1	-0.4
TFPK (False)	0.0	1.0	0.5	0.7
GDP INDEC	5.6	5.4	3.7	2.9

Source: ARKLEMS.

The new GDP stylized facts change Argentina's growth profile. If the INDEC's estimate is accepted, Argentina showed an intensive growth profile based on important TFP gains of 1 per cent per year over the 2002-2015 period, as shown in Chart 7, Panel A.

But new GDP estimates, thanks to new INDEC data, confirm ARKLEMS' research, of an extensive growth profile based on factor accumulation. Almost all the GDP growth is explained by the contribution of capital and labour services with TFP growth of only 0.5 per cent. Thus GDP growth during the commodities price boom was moderate, and it did not

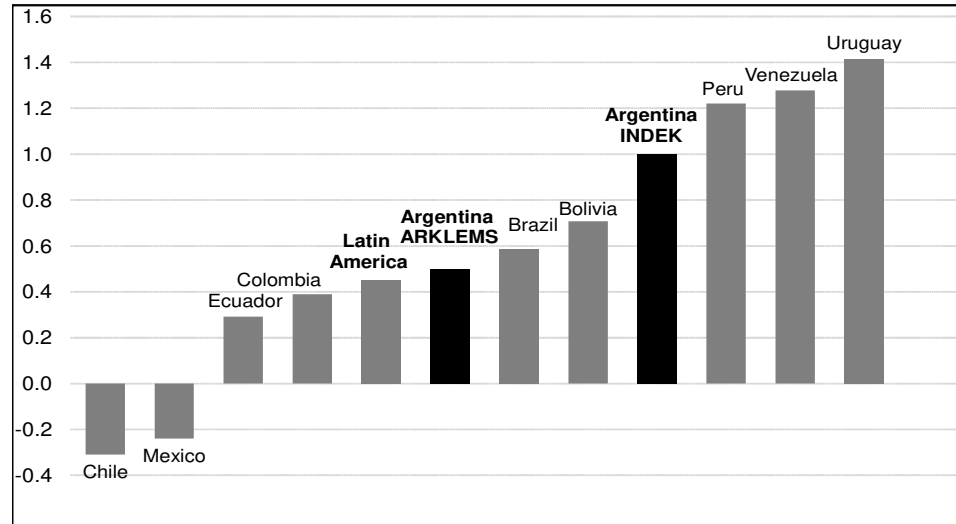
stem from strong TFP growth. First, most of the TFP gains during the recovery period were due to utilization effects, which are not sustainable in the long run. Short-run utilization effects took advantage of high unemployment and capacity under-utilization built up during the recession.¹⁴ Second, taking a long-run perspective, instead of false TFP gains due to GDP overestimation by INDEC, there were TFP losses (0.4 per cent per year) between the cyclical peaks of 1998 and 2015 (Chart 7, Panel B).

Argentina experienced moderate TFP growth, mostly due to recovery effects, during the recent commodities boom instead of being a

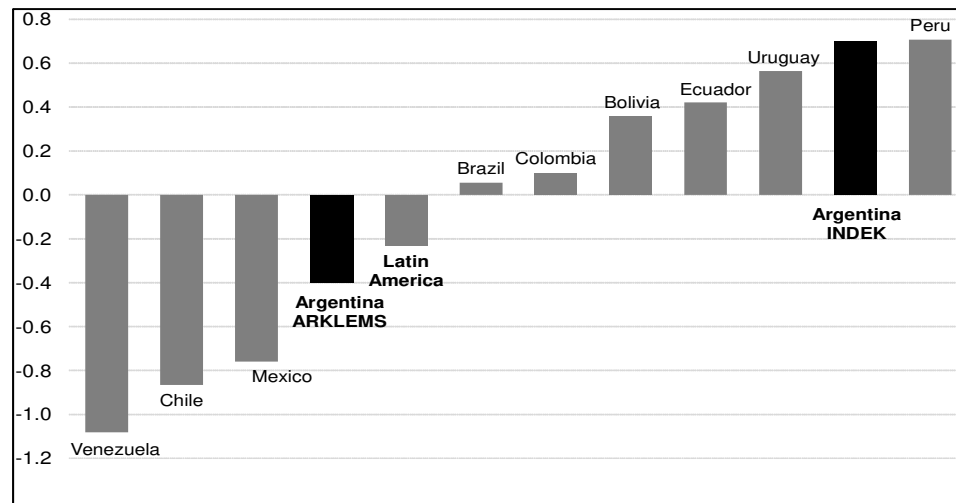
14 See Coremberg (2008) for more detail of Argentina's sources of growth for previous periods of political intervention at INDEC.

Chart 7: Total Factor Productivity (TFP) Growth in Selected Latin America Countries, (average annual rate of change)

Panel A: Recovery Period 2002-2015



Panel B: Long Run, 1998-2015



Source: INDEC, new INDEC, ARKLEMS, The Conference Board Total Economy Database.

productivity champion, as claimed by the Kirchner government.

Conclusion

The Argentine National Statistics Institute (INDEC) suffered political intervention from 2007 to 2015 during the Kirchner Administration. With a new government installed in Argentina in 2016, INDEC has published revised GDP estimates that confirm previous

ARKLEMS measurements and thus counter INDEC's GDP myths. These new estimates show that INDEC overstated GDP growth (30 per cent instead of 16 per cent) from 2007 to 2015, by discretionary manipulation.

Argentina showed a moderate recovery of GDP during the commodities price boom after 2002. Applying the NBER-Rostow and Hausmann *et al.* methodology, Argentina's GDP recovery at Chinese rates from 2002 to 2007 was

not sustainable. Argentina grew at the same rate during the commodities boom as the long-run trend of the last century. Argentina was the second worst GDP performer among ten Latin American countries in the long run, after Venezuela.

An analysis of the sources of growth also demonstrates that Argentina's growth was not sustainable during the recent commodities price boom. The GDP overestimation translated into false TFP gains. ARKLEMS series shows moderate GDP growth did not translate into strong TFP gains. Actually, Argentina had a negative TFP performance over the 1998-2015 period, instead of being the productivity champion of Latin America.

The credibility and reputation of official statistics is a critical issue not only for academic purposes but mainly for public policies that directly affect economic performance and the welfare of nations. According to the new stylized facts, Argentina could not escape from its development failure destiny based on decades of low productivity and economic growth.

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How Does the Productivity and Economic Growth Performance of China and India Compare in the Post-Reform Era, 1981-2011?

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ABSTRACT

Applying an aggregate production possibility frontier (APPF) framework for growth accounting à la Jorgenson *et al.* to economy-wide Chinese and Indian industry productivity accounts, constructed in the spirit of the KLEMS principle, we estimate and compare growth and productivity performance in China and India over their post-reform period from 1981 to 2011. We show that during this period China grew over 50 per cent-faster than India in value added (9.4 versus 6.1 per cent per annum) but about 25 per cent-slower than India in TFP (0.83 versus 1.13 per cent per annum). The two economies also experienced very different growth and productivity performances over sub-periods distinguished by special policy regimes and governing systems. While both countries appeared to enjoy their best performances in the 2002-2007 period following China's WTO entry, China faltered much more in terms of total factor productivity growth in the wake of the global financial crisis.

Benefiting from their market-oriented reforms, the world's two most populous countries, China and India, with of population of 1.39 and 1.34 billions respectively, have

changed, and are still changing, the landscape of the world economy at a high speed. According to the Total Economy Database (TED) constructed by The Conference Board (TCB) that

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uses alternative (non-official) GDP estimates for China following Maddison and Wu (2008), China grew by 7.5 per cent per annum over the period 1990–2015 whereas India grew by 6.4 per cent per annum.² The two economies also appeared to be most resilient to the global financial crisis and its long recessionary aftermath. Based on the same TED data (TCB, 2016), over the period 2008–2015 India performed even better than China by maintaining its previous 6.4-per cent annual growth rate, whereas China decelerated somewhat to 5.8 per cent per annum. Meanwhile, the rest of the world grew by 2.7 per cent per annum.

As a consequence of such rapid growth, by a 1990 G-K PPP yardstick following Maddison (2001), China and India overtook Japan in terms of GDP size in 1995 and 2006, respectively. While the world is paying serious attention to their fast pace of catching up with an enormous size effect on the world economy, their true productivity performances have been somewhat ignored. In this regard, the most important teaching of the TCB-TED data is that by the time of overtaking Japan, China achieved only 10.6 per cent of Japan's level of per capita GDP and 10.1 per cent of Japan's level of labour productivity. In the case of India, these ratios are similar, 11.8 and 14.2 correspondingly.³ In sharp contrast, when Japan surpassed Germany in 1967 it had already attained 82.2 per cent of Germany's level of per capita GDP and 75.5 per cent of Germany's level of labour productivity (TCB, 2016).

Even if considering that pre-war Japan had already reached the same level of development as that of the mid-1950s, China and India are still not yet in the same league with other East Asian counterparts such as South Korea and Taiwan in terms of labour productivity. Apparently, both China and India benefitted from a huge demographic dividend, but to a large extent they were hindered by their less satisfactory total factor productivity (TFP) growth. However, TFP studies focusing on the total economy have not reached a consensus about the productivity performance of the two economies (for the case of China, see Wu, 2011).

There is a tendency in literature to show unrealistically high TFP growth in the case of China compared to that of India. For example, Bosworth and Collins (2008) find that over the period 1978–2004, China's TFP growth was 4.6 per cent per annum vis-à-vis India's 1.6 per cent per annum. Jorgenson and Vu (2005) show that during the period 1989–1995 China's TFP growth was 6.3 per cent per annum compared to India's 2.1 per cent per annum, but during the period 1995–2003 the two economies converged to the same rate of TFP growth at 2.5 per cent per annum. Some studies questioned the reliability of these TFP estimates given the likelihood of upward bias in official growth estimates (Maddison and Wu 2008; Bardhan 2010; Wu 2014).

Some researchers show that institutional deficiencies might have affected productivity growth in both China and India. Hsieh and Klenow (2009) use micro-data on manufacturing

2 Maddison and Wu proposed a volume-movement approach to adjust for the upward-bias in Chinese official statistics (Maddison and Wu 2008; see Wu, 2014 and 2016a, for further development). To have a world-wide perspective, we use the Maddison-Wu estimates in the TCB-TED data to show more plausible growth rates for China. However, as explained in the data section, to obtain industry information and maintain a necessary coherence between industries and the national accounts, which is essential in the KLEMS-type industry-level data construction, in the present study we accept Chinese official output estimates but adjust them for conceptual, coverage and classification inconsistencies (Wu, 2016b).

3 However, by 2015 the two ratios had increased to 31.8 and 28.5 per cent of the Japanese level in the case of China and 18.2 and 23.2 per cent in the case of India, reflecting China's much faster catch-up with Japan in terms of output per capita and per worker compared to India (TCB, 2016).

establishments to measure the potential extent of misallocation in China and India using the United States economy as a benchmark. When capital and labour are hypothetically reallocated to equalize the marginal products across plants to the extent observed in the United States, they find that the manufacturing TFP would be 30-50 per cent higher in the case of China and 40-60 per cent in the case of India. This suggests there are institutional barriers to factor mobility in both countries.

The institutional effect calls for an industry level analysis of productivity performance. It is essential to have an industry perspective because government interventions are often made through industry-specific policies. Industries that are more prone to state controls may affect other industries through the input-output linkages of the economy. There is also a strong consensus among economic observers that China's growth has benefitted from a strong, export-oriented manufacturing sector, whereas India's growth has largely been attributed to the rapid expansion of ICT (information and telecommunication technology)-related services although the post-reform development of Indian manufacturing industries is by no means insignificant (Bardhan, 2010). This also requires industry-level TFP analysis.

Industry-level TFP studies require extensive data embedded in a coherent national accounts framework (e.g. Jorgenson, Gollop and Fraumeni, 1987; Jorgenson, Ho and Stiroh, 2005a and 2005b). Such research has long been obstructed by data problems. The situation began to improve in the early 2000s, thanks to the EU-KLEMS project aiming to establish industry productivity accounts coherently

linked to the national accounts through input-output tables.⁴

Building in this development, Chinese and Indian researchers have also made efforts to solve their industry-level data problems in the spirit of the KLEMS principles. Such KLEMS-type data have become available for China from Wu (Wu, 2016b) and for India from the Indian KLEMS team (Das *et al.*, 2016),⁵ hence facilitating the current study. Methodology-wise this study adopts the Jorgensonian aggregate production possibility frontier (APPF) framework incorporating the Domar aggregation scheme to account for the contributions of individual industries to the growth of aggregate inputs and output, as well as the reallocation effects of factors on TFP growth (Jorgenson, Ho and Stiroh, 2005a). This approach relaxes most of the restrictive assumptions adopted by the widely used aggregate production function approach in the growth accounting literature, especially that all industries are homogenous, satisfy the same value added function, and face the same input and output prices.

This article contains five sections. The first main section outlines the process of reforms in China and India emphasizing institutional deficiencies. The methodology of productivity measurement used is presented in Section 2. The datasets for China and India are briefly described in Section 3. The empirical results on growth and productivity for the two countries are reported and compared in Section 4 with an emphasis on the effects of China's entry into the World Trade Organization (WTO) and the global financial crisis (GFC) upon both of the economies. The fifth and final section briefly concludes and proposes the way forward for future research.

4 "KLEMS" is used as an acronym for Capital, Labour, Energy, Materials and Services that are used to produce goods or services. See O'Mahony and Timmer (2009) for an introduction of the EU-KLEMS database.

5 The data work in both countries is on-going and closely integrated with the World KLEMS initiative based in Harvard University.

Reforms Under Different Governance Systems and Implications for Productivity Growth

At the time of their market-oriented reforms, China and India were among the most protected and heavily regulated economies of the world. Strictly following the Marxist dogma that prohibited the market system and private ownership, China, under Mao's rule, adopted a Soviet-type central planning system with omnipresent state power till the end of the 1970s. During the same period, pursuing Gandhi's ideology in the Indian independence movement, India also practiced a similar central planning system with strong state controls over commerce and inward-looking import substitution policies (Kotwal *et al.*, 2011). However, despite the policies that discouraged the development of private enterprises and restricted the market allocation of resources, India did not outlaw private ownership and the market.

Officially, China started its agricultural reform in 1978 and industrial reform in 1984. However, if considering that China's agricultural reform through the 1980s was only a return to the pre-planning farming system, it could be compatible to that of India's private farming system by the late 1980s. At the turn of the 1990s when India began deregulating capital goods industries and trade, Deng Xiaoping, the paramount leader of the People's Republic of China at the time, called for bolder reforms to take China out of the shadow of the Tiananmen political turmoil of 1989. Thus, we could say that by this time both countries were more or less engaged in a full-scale reform despite maintaining their pre-reform political systems, with China firmly sticking to an authoritarian regime and India following a democratic system. Compared to India, China was more open to foreign trade and direct investment, but it had also used more administrative power to intervene in

resource allocation to promote growth, which negatively affected the development of a healthy legal framework and an efficient financial system (Xu, 2011). In contrast, India has inherited a better financial sector and a more functional market system that has nurtured a dynamic entrepreneur class (Eichengreen *et al.*, 2010).

After a comprehensive comparative assessment of the economic rise of China and India in the post-reform era, Bardhan (2010) concludes that reforms in China have been deeper. They have resulted in a transformation, particularly through labour-intensive rural industrialization, which is still largely absent in India. He explores the factors that inhibit labour-intensive industrialization in India and draws attention to the special institutional features of Chinese reforms in terms of decentralization and career incentives for officials which uniquely facilitated economic growth.

Indeed, in recent decades, India has benefitted from the growing outsourcing of business services and has generated considerable export revenues in the telecommunication sector. Yet, as Sachs (2015) comments, after two decades of impressive economic growth, India has still over a third of its population living in extreme poverty. There are virtually two Indias, one of educated managers and engineers who have been able to take advantage of opportunities made available through globalization, and the other of a huge mass of uneducated people who make a living in low-productivity jobs in the informal sector, the largest of which is still agriculture.

While Indian economists make a very positive assessment of the Chinese system, Chinese economists have attempted to understand its deeply-rooted institutional problems. Xu (2011) explains the "China puzzle" of a rapid growth without a healthy legal system. He attributes the growth-promoting role of local governments to a hybrid system in which a decentralized economic authoritarian regime is established coher-

ently with a highly centralized political regime. In an empirical study, Li and Zhou (2005) show that since all efforts made by local governments are indexed by the rate of local GDP growth and assessed by upper authorities as political performance, officials are highly motivated to engage in "growth tournament" with their peers in other localities.

Consequently, their restless search for new growth engines has resulted in increasing government interventions in resource allocation and business decisions (Huang 2012; Wu and Shea 2008). Wu (2016b) argues that the government's heavy involvement has (so far) successfully solved China's growth problem, but this has taken its toll on the economy's efficiency and productivity growth, hence raising a question of growth sustainability. Indeed, Wu, Shea and Shiu (2015) using a DEA approach, show that the government-engineered growth tends to promote investment in technology but at the expenses of efficiency. The majority of China observers also agree that such a Chinese model of growth is also responsible for widespread corruption.

Taking these institutional differences and areas with unfinished reforms as a background, in this article, we are interested mainly in examining and comparing the industry origin of the growth and productivity performances between the two giant economies over the same period that saw distinct policy regime shifts and macro-economic shocks.

Accounting for the Sources of Growth with Industry Origin⁶

The widely used aggregate production function approach to TFP analysis is subject to very stringent assumptions that "value-added functions exist and are identical across (underlying) industries up to a scalar multiple" and "the

aggregation of heterogeneous types of capital and labour must receive the same price in each industry" (Jorgenson, Ho and Stiroh, 2005a). This article adopts Jorgenson's aggregate production possibility frontier (APPF) framework instead, incorporating Domar weights to account for contributions of individual industries to the growth of aggregate inputs and output through input-output links (Domar, 1961). The empirical differences between the two approaches deliver interesting insights about the role of factor reallocations in promoting TFP growth.

The APPF approach in growth accounting relaxes the strong assumption that all industries are subject to the same value-added production function to account for the industry origin of aggregate growth (Jorgenson, 1966). The Domar-weighted aggregation was introduced into the APPF framework by Jorgenson, Gollop and Fraumeni (1987) to allow direct aggregation across industries to account for the role of industries in the changes of aggregate inputs. It has been used in Jorgenson and Stiroh (2000), Jorgenson (2001) and Jorgenson, Ho and Stiroh (2005a, 2005b) to quantify the role of information technology (IT)-producing and IT-using industries in the United States economy.

To illustrate this methodology, we begin with a production function where industry gross output is a function of capital, labour, intermediate inputs and technology indexed by time. We use individual industries as building blocks which allow us to explicitly trace the sources of aggregate productivity growth and input accumulation to the underlying industries. Focusing on an industry-level production function given by equation (1), each industry (j), purchases distinct intermediate inputs, capital and labour services to produce a set of products:

$$Y_j = f_j(K_j L_j X_j T) \quad (1)$$

6 This section is adopted from Wu (2016b).

where Y is output, K is an index of capital service flows, L is an index of labour service flows, X is an index of intermediate inputs, either purchased from domestic industries or imported, and T refers to time, so that change in technology can be captured. Note that all input variables and output are also indexed by time but this is suppressed for notational convenience.

Under the assumptions of competitive factor markets, full input utilization and constant returns to scale, the growth of output can be expressed as the cost-weighted growth of inputs and technological change, using the translog functional form:

$$\Delta \ln Y_j = \bar{v}_j^K \Delta \ln K_j + \bar{v}_j^L \Delta \ln L_j + \bar{v}_j^X \Delta \ln X_j + v_j^T \quad (2)$$

where $\bar{v}_j^K$, $\bar{v}_j^L$, and $\bar{v}_j^X$ are two-period averages of nominal weights of input $v_j^K = P_j^K K_j / (P_j^Y Y_j)$, $v_j^L = P_j^L L_j / (P_j^Y Y_j)$, and $v_j^X = P_j^X X_j / (P_j^Y Y_j)$, respectively. Note that under constant returns to scale $\bar{v}_j^K + \bar{v}_j^L + \bar{v}_j^X = 1$, which is based on industry production accounts in nominal terms. Each element in the right-hand side of equation (2) indicates the proportion of output growth accounted for respectively by the growth of capital services ($\bar{v}_j^K \Delta \ln K_j$), labour services ($\bar{v}_j^L \Delta \ln L_j$), intermediate materials ($\bar{v}_j^X \Delta \ln X_j$), and total factor productivity (v_j^T).

One of the advantages of equation (2) is that it can better account for each input services by different types. For example, it can account for labour services provided by different types of labour with specific demographic, educational and industrial attributes, as shown in pioneering studies by Griliches (1960), Denison (1962) and Jorgenson and Griliches (1967). It has relaxed

the usual strong assumption that treats the employed or hours worked as a homogenous measure of labour input. The growth of total labour input is thus defined as a Törnqvist quantity index of individual labour types as follows:

$$\Delta \ln L_j = \sum_h \bar{v}_{h,j} \Delta \ln H_{h,j} \quad (3a)$$

where $\Delta \ln H_{h,j}$ indicates the growth of hours worked by each labour type h (with specific gender, age and educational attainment) and its cost weights $\bar{v}_{h,j}$ given by two-period average shares of each type in the nominal value of labour compensation controlled by the labour income of industry production accounts.

The same user-cost approach is also applied to K and M to account for the contribution of different types of capital asset (Z_K) and intermediate input (X_m) in production with type-specific, two-period average cost weight defined as $\bar{v}_{k,j}$ and $\bar{v}_{m,j}$, respectively:

$$\Delta \ln K_j = \sum_K \bar{v}_{K,j} \Delta \ln Z_{K,j} \quad (3b)$$

and

$$\Delta \ln X_j = \sum_m \bar{v}_{m,j} \Delta \ln X_{m,j} \quad (3c)$$

It should be noted that the equations from (2) through the whole set of (3) also explicitly express the methodological framework for the China Industry Productivity (CIP) industry-level data construction that is linked to and controlled by the national production and income accounts.⁷

Using the value-added concept, equation (2) can be rewritten as:

$$\Delta \ln Y_j = \bar{v}_j^V \Delta \ln V_j + \bar{v}_j^X \Delta \ln X_j \quad (4)$$

where V_j is the real value-added in j and v_j^V is the nominal share of value-added in industry gross output. By rearranging equations (2) and

7 The China Industrial Productivity Database Program is sponsored by the Japanese Research Institute of Economy, Trade and Industry (RIETI) and the Institute of Economic Research at Hitotsubashi University. The application of equations 2 and 3 in CIP will be discussed when we discuss the data issues in the following section.

(4), we can obtain an expression for the sources of industry value-added growth (i.e. measured in terms of input contributions):

$$\Delta \ln V_j = \frac{\bar{v}_j^K}{\bar{v}_j^V} \Delta \ln K_j + \frac{\bar{v}_j^L}{\bar{v}_j^V} \Delta \ln L_j + \frac{1}{\bar{v}_j^V} v_j^T \quad (5)$$

Growth of aggregate value-added by the APPF approach is expressed as weighted industry value-added in a Törnqvist index:

$$\Delta \ln V = \sum_j w_j \Delta \ln V_j \quad (6)$$

where w_j is the share of industry value-added in aggregate value-added. By combining equations (5) and (6), we can have a new expression of aggregate value-added growth by weighted contribution of industry capital growth, industry labour growth and TFP growth:

$$\begin{aligned} \Delta \ln V &= \sum_j w_j \Delta \ln V_j \\ &= \sum_j \left(\bar{w}_j \frac{\bar{v}_j^K}{\bar{v}_j^V} \Delta \ln K_j + \bar{w}_j \frac{\bar{v}_j^L}{\bar{v}_j^V} \Delta \ln L_j + \bar{w}_j \frac{1}{\bar{v}_j^V} v_j^T \right) \end{aligned} \quad (7)$$

Through this new expression, we have introduced the well-known Domar weights in our aggregation (Domar, 1961), i.e. a ratio of each industry's share in total value-added (w_j) to the proportion of the industry's value-added in its gross output (v_j^V).

If we maintain the stringent assumption that capital and labour inputs have the same marginal productivity in all industries we can define aggregate TFP growth as:

$$\begin{aligned} v^T &\equiv \sum_j \bar{w}_j \Delta \ln V_j - \bar{v}^K \Delta \ln K \\ &\quad - \bar{v}^L \Delta \ln L \end{aligned} \quad (8)$$

However, this assumption is not likely to hold, in particular in China and India, as argued above. It is therefore interesting to look at the difference of the two measurement approaches. By subtracting equation (7) from equation (8) and rearranging, we can show how the aggregate TFP growth relates to the sources of TFP growth at the industry level and to the effect of factor mobility across industries (Jorgenson, Ho and Stiroh, 2005a):

$$\begin{aligned} v^T &= \left(\sum_j \bar{w}_j \frac{\bar{v}_j^K}{\bar{v}_j^V} v_j^T \right) \\ &\quad + \left(\sum_j \bar{w}_j \frac{\bar{v}_j^K}{\bar{v}_j^V} \Delta \ln K_j - \bar{v}^K \Delta \ln K \right) \\ &\quad + \left(\sum_j \bar{w}_j \frac{\bar{v}_j^L}{\bar{v}_j^V} \Delta \ln L_j - \bar{v}^L \Delta \ln L \right) \end{aligned} \quad (9)$$

in which the reallocation terms in the second and third brackets can be simplified as:

$$v^T = \sum_j \bar{w}_j \frac{\bar{v}_j^K}{\bar{v}_j^V} v_j^T + \rho^K + \rho^L \quad (9')$$

Equation (9) expresses the aggregate TFP growth in terms of three sources: Domar-weighted industry TFP growth, effects of reallocation of capital and reallocation of labour across industries.

This Domar weighting scheme (w_j / v_j^V), plays a key role in the direct aggregation across industries under the Jorgensonian growth accounting framework. A direct consequence of the Domar-aggregation is that the weights do not sum to unity, implying that aggregate productivity growth amounts to more than the weighted average of industry-level productivity growth (or less, if negative). This reflects the fact that productivity change in the production of intermediate inputs do not only have an "own" effect but in addition they lead to reduced or increased prices in downstream industries,

and that effect accumulates through vertical links. As elaborated by Hulten (1978), the Domar aggregation establishes a consistent link between the industry-level productivity growth and the aggregate productivity growth. Productivity gains of the aggregate economy may exceed the average productivity gains across industries because flows of intermediate inputs between industries contribute to aggregate productivity by allowing productivity gains in successive industries to augment one another. The same logic can explain productivity losses.

The next two terms reflect the impact on aggregate TFP growth of the reallocation of capital (ρ^K) and labour (ρ^L) across industries, respectively. Each reallocation term, is obtained by subtracting cost-weighted aggregate factor (capital or labour) input growth from the Domar-weighted input growth across industries. It should be noted that theoretically, when these terms are not negligible it indicates that industries do not face the same factor costs, which suggests a violation of the assumption of the widely used aggregate approach. However, one should not expect a significant reallocation effect in an economy where there is a well developed market system.

Data Issues

China and India KLEMS database

The data used in this article for both China and India are reconstructed based on official statistics. In the case of China, unlike in Maddison and Wu (2008) the official data are not challenged because there are no alternative data that can be used to reconstruct industry accounts

(Wu and Ito, 2015). The data reconstruction follows the KLEMS principles. This means that for output measures, the gross output of an industry equals the total costs of "KLEMS" and the gross output of an economy equals the sum of the costs of KLEMS of all industries (O'Mahony and Timmer, 2009). At the industry level, this is expressed in equation (2). For China, the KLEMS database is part of the ongoing China Industry Productivity (CIP) Database Project.⁸ For India, it is part of the ongoing India KLEMS Database Project, which is explained in Das *et al.* (2016).⁹

Note that due to various data constraints we do not have the same measures for all variables in the two countries. In particular, in the case of China, labour input is estimated based on hours worked to capture the difference in hours worked per worker, whereas in the case of India despite differences in hours worked across different employment status there is not yet estimation for hours worked for the workforce (Aggarwal and Erumban, 2013). In addition, in the China CIP/KLEMS data all volume indicators are measured in 1990 prices and in the Indian KLEMS data such indicators are measured in 2004 prices. These differences are likely major sources of potential biases in the estimates.

Industrial classification and concordance

The classification of industries follows the International Standard Industrial Classification (ISIC) principles although somewhat constrained by country-specific problems. The China CIP/KLEMS dataset adopts a classifica-

8 It is beyond the scope of this study to go through a long history of the data research. We thus refer interested readers for details to three working papers by Wu (2015) on capital input, Wu and Ito (2015) on output and prices, and Wu, Yue and Zhang (2015) on labour quantity and compensation matrices. A brief introduction to data is provided in Wu (2016b). To access the current version of the CIP/KLEMS database and Indian KLEMS database, please follow the link managed by the World KLEMS Initiative: <http://www.worldklems.net/data.htm>.

9 Interested readers should also consult Erumban and Das (2013) on capital input, and Aggarwal and Erumban (2013) on employment.

tion system in line with the 2002 CSIC (China Standard of Industrial Classification) which classifies the Chinese economy into 37 industries. The Indian KLEMS dataset originally adopts the 1998 NIC (National Industrial Classification) and reclassified the Indian economy into 27 industries in line with the EU KLEMS standard of industrial classification. In this study, to facilitate China/India productivity comparisons, the 37 Chinese industries are reclassified to match the 27 Indian industries. See Table A1 in appendix for the country-specific classification concordance between China and India.

Industry Grouping

To better distinguish industries by their positions in the production chain or distance from final demand in productivity analysis, we further categorize the 27 industries into ten groups (Table A1). In this grouping, we first allow agriculture (group 1) mining (2), utilities (7) and construction (8) to stand alone as they are. Then we divide the manufacturing sector into four groups, namely, and "light manufacturing (largely consumer goods)" (3), "intermediate materials" (4), "electricals and ICT (information-communication technology)" (5) and "machinery and motor vehicles (including all other transport equipment)" (6). Given data constraints, especially limited classification in the Indian data, unfortunately we cannot clearly distinguish investment goods from consumer goods, but noticeably, most investment goods are produced by groups 4 and 5. We finally categorize all services into two groups, that is, one market services group including trade and

hotels, transport and storage, post and telecommunication, business services and financial services, and another non-market services group including public administration, health and education social services.

Periodization

The dataset used in this study covers the period 1981-2011.¹⁰ To help better interpret and analyze the results against major events such as important policy regime shifts and external shocks, we divide the period into four sub-periods taking into accounts such events: 1981-1991, 1991-2002, 2002-2007, and 2007-2011.¹¹ The first sub-period is from 1981 to 1991. This was an early reform period for both countries. China had successfully conducted agricultural reform and introduced a planning-market double track reform to the industrial sector. India began to dissolve the long-lasting planning controls over capital goods industries and trade began to dissolve through a series of deregulation of a large number of industry groups. This sub-period ended in the aftermath of China's Tiananmen unrest (1989).

We set the next period to start in 1991 largely because in India this marks the beginning of the 1991-1992 comprehensive trade policy reforms to reduce tariffs and eliminate most non-tariff barriers while in China, Xiaoping's bolder call for deepening reforms in 1992 broke the stand-off of the country's ideological debate on the nature of market reforms. This sub-period ends in 2001 or just before China joined the World Trade Organization (WTO) at the end of that year. This sub-period also includes the Asian

10 Note that the annual Chinese data throughout the paper refer to a standard calendar year, whereas the annual Indian data refer to a fiscal year ended in March of the following year.

11 This periodization focuses on policy regime shifts rather than depending on empirically-tested structural breaks in the data. However, our sup-Wald test for unknown break points in the output data suggests that there is only one statistically significant break point in each case, that is, 2005 in the case of China and 2006 in the case of India.

Table 1: Sources of Gross Output Growth by Industry Group, 1981-2011: China Versus India (Gross output-weighted as percentage points of annual gross output growth)

	GO	L	K	X	TFP	GO	L	K	X	TFP
	China					India				
1. Agriculture	5.88	-0.03	2.73	2.74	0.44	2.87	0.31	1.43	0.65	0.49
2. Mining	7.53	0.45	3.82	5.46	-2.21	5.21	0.86	4.03	1.74	-1.42
3. Light manufacturing	11.27	0.31	2.15	7.77	1.04	6.72	0.27	0.99	5.33	0.14
4. Intermediate materials	11.48	0.24	2.25	8.43	0.56	7.83	0.19	1.21	6.04	0.39
5. Electricals and ICT	20.70	0.45	2.28	13.63	4.35	10.45	0.50	1.11	7.16	1.68
6. Mach. and motor vehicle*	15.23	0.15	1.56	10.06	3.45	8.85	0.44	1.22	6.42	0.77
7. Utilities	10.02	0.23	2.94	7.33	-0.49	7.30	0.57	1.38	4.11	1.23
8. Construction	10.86	1.28	1.20	8.24	0.14	6.73	1.89	0.83	5.56	-1.55
9. Market services	9.97	1.14	4.35	5.43	-0.95	8.07	1.30	2.92	2.92	0.93
10. Non-market services	8.20	1.93	4.53	4.47	-2.73	5.91	1.50	1.85	1.47	1.09
<i>Sum of 3-6: Manufacturing</i>	<i>13.36</i>	<i>0.29</i>	<i>2.07</i>	<i>9.27</i>	<i>1.73</i>	<i>7.63</i>	<i>0.25</i>	<i>1.12</i>	<i>5.88</i>	<i>0.40</i>
<i>Sum of 9-10: Services</i>	<i>9.38</i>	<i>1.39</i>	<i>4.77</i>	<i>5.10</i>	<i>-1.88</i>	<i>7.34</i>	<i>1.41</i>	<i>2.27</i>	<i>2.37</i>	<i>1.28</i>

Source: Authors' estimates using equation (2). The measures of L, K and X (the growth of X is E, M and S weighted) follow equations 3a, 3b and 3c. *Including other transport equipment.

Financial Crisis of 1997-1998 and its three years deflationary aftermath in China.

We set the next sub-period from 2002 to 2007 to capture the effect of China's WTO entry. This is an important period that saw China's unprecedented expansion in export-oriented manufacturing, taking its comparative advantage not only in labour-intensive production but also in economies of scale. Undoubtedly, the Chinese government, both central and local, played an imperative role in engineering such an expansion (Wu, 2016b). We expect this China WTO effect to have a significant bearing on its competitors like India. This sub-period is then followed by the last sub-period from 2007 to 2011 aiming to capture the Global Financial Crisis impact and its recessionary aftermath. It is of great interest to see how differently the two giant economies responded to the crisis in terms of both output growth and productivity performance.

Empirical Results

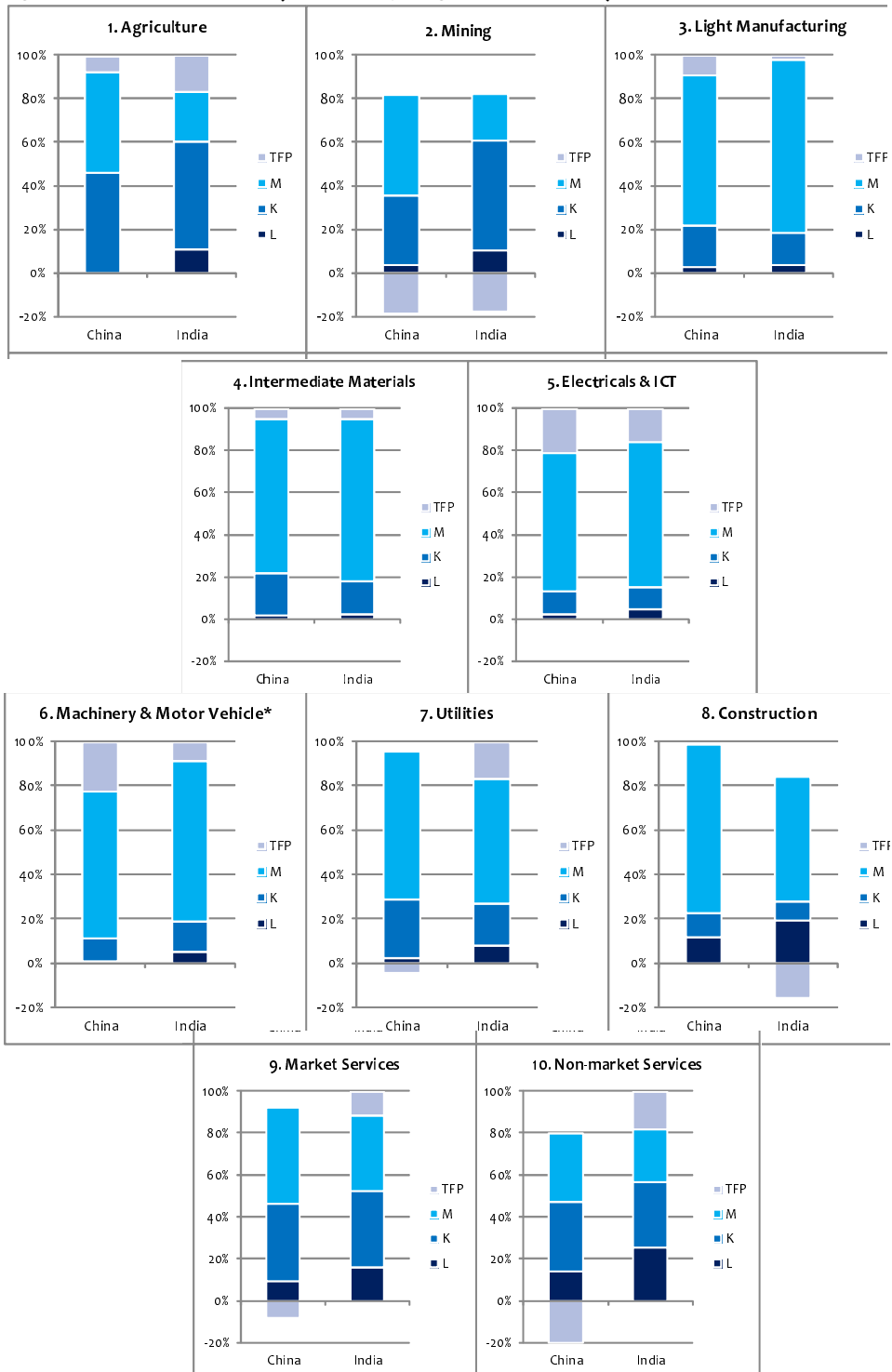
In our empirical exercise, we opt for the double deflation approach to deflate gross output

and intermediate inputs at the industry level. The input price change of an industry is a weighted average of the price changes of all inputs across industries used by that industry including input from the industry itself. The change of value added is hence derived based on equation (4). The measure of capital and labour inputs follows equations (3a) and (3b) although in the case of India we have to use numbers employed instead of hours worked for labour unit. In what follows, we report the empirical results by steps and compare the performances between the two countries against the macro-economic background that is captured by our periodization.

Sources of Gross Output Growth by Industry Group

We start with an examination of industry group-level sources of gross output growth as reported in Table 1 for the entire period in question for both China and India. The results are group-specific and methodologically based on equation (2). They provide industry group-level sketches on the contribution of each input

Chart 1: Input Contribution to Gross Output Growth by Industry Group, 1981-2011
Average: China Versus India (Gross output growth = 100%)



Note: *Including other transport equipment.
Source: Authors' estimates.

to gross output (GO) growth. Estimation as such is by no means accurate because it includes double counting. However, examining these building blocks is a necessary starting point because industries are building blocks of the national economy and the originators of aggregate productivity growth.

Table 1 presents (nominal) gross output-weighted input growth as percentage points of the real annual GO growth rate presented in the first column of the China and India panels respectively. To help better understand the relative contribution of each input Chart 1 depicts all the inputs as shares of a standardized gross output growth for all ten industry groups. A quick glance can tell that in general the differences between China and India for capital input are much more obvious than for labour input. Industry group comparisons however can reveal more distinctions between the two economies.

We can start from a performance comparison for the two primary groups, i.e. agriculture and mining. It may not be a big surprise to see that the Chinese agriculture grew twice faster than that of India, but to see that such growth relied little on labour contribution over the three decades (Table 1). In fact, China's labour input in agriculture declined by 0.03 per cent per annum. In the Indian agriculture sector on the contrary, labour input still grew by 0.31 per cent per annum. Both countries show similar and positive TFP growth, yet India appears to be slightly better. And the Chinese agriculture seemed to rely more on the growth of intermediate inputs.

In the case of mining, China grew more than 40 per cent faster but depended much more on the growth of intermediate inputs than India. According to the estimated TFP growth for this sector, both countries appear to be inefficient in mining, but worse in the case of China. Chart 1,

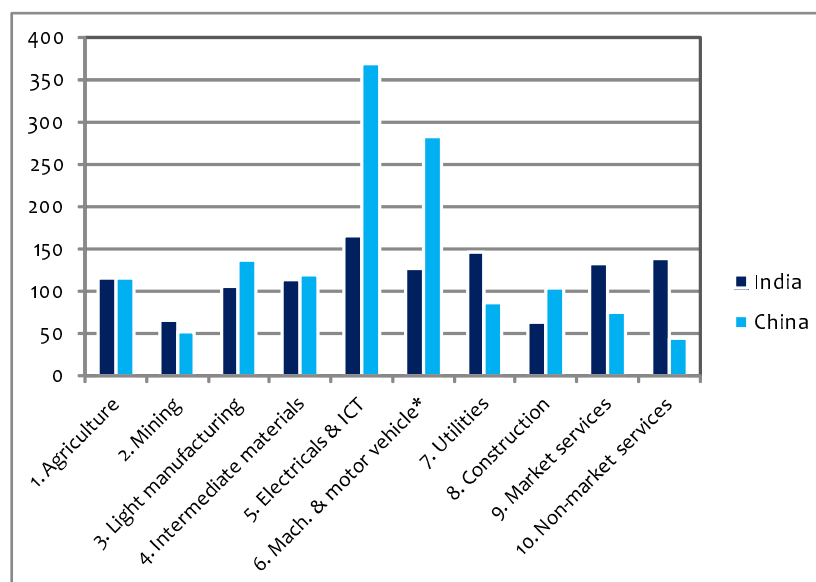
which is based on the numbers in Table 1, presents distinctive illustrations for these observations.

Next, we examine and compare the four manufacturing groups between the two economies, namely light manufacturing goods (group 3), intermediate materials (group 4), electrical and ICT products (group 5), and machinery and motor vehicles (group 6). Noticeably, electrical-ICT products and machinery-motor vehicles were the most rapidly growing groups in both economies in which consumer electronics and automobiles manufacturing played a very important role, but China grew twice as fast as India.¹² Although China and India are the world's most populous countries, China relied less on the growth of labour input in these manufacturing industries than India. India was less efficient not only because its greater dependence on the growth of input materials but also due to a slower TFP growth (see standardized shares in Chart 1). Based on the industry group TFP performance, it is also interesting to see that both economies seemed to have enjoyed comparative advantage in electrical and ICT manufacturing (group 5) as well as in machinery and motor vehicle manufacturing (group 6), albeit China is still evidently more productive than India. Of course, we have to wait for the more strict assessment later in a cross industry analysis as expressed in equation (9).

Since the strong growth in China and India had to be fueled by energy, how to produce energy more efficiently was an imperative challenge for both countries. It has been widely believed among Chinese observers that China is less efficient in energy production and usage than India and thus Chinese growth is much more energy-consuming than India's. We may be the first ones to provide supportive empirical evidence for China's disadvantage in energy pro-

12 In both China and India these industries substantially benefitted from deregulation of international trade and foreign direct investment (Liew and Wu, 2007; Das, 2016).

Chart 2: Total Factor Productivity by Industry Group: China Vis-A-Vis India 1981-2011(1981 = 100)



Source: See Table 1. *Including other transport equipment.

duction as shown by TFP growth referring to utilities with respect to India (Table 1 and Chart 1).

The Indian construction industry appears to be much more inefficient than its Chinese counterpart because it relied significantly more on the growth of input materials and experienced negative TFP growth, as shown in Table 1. Turning to services, both market and non-market, we show that China long suffered long from negative TFP growth. In the case of India, nonetheless, services appear to have been more labour-intensive, as measured by a labour-output ratio based on Table 1, less input materials-consuming, and to have experienced stronger TFP growth, especially for non-market services (Table 1 and Chart 1).

Chart 2 provides a TFP index for each industry group to show accumulated TFP growth over the entire period benchmarked on 1981 (=100). Obviously, industries above the benchmark line marked by 100 experienced TFP growth whereas industries below the line suffered from TFP decline. In general, productivity

performance was much more dispersed across industry groups in China than in India. Despite the existence of productivity super stars, such as the group of electrical and ICT products and the group of machinery and motor vehicles, more industry groups experienced productivity losses in China than in India. One may reasonably conjecture that non-market forces must play a greater role influencing resource allocation, favouring some industries, hindering others, in China than in India.

Industry Contribution to Aggregate Value-Added Growth

From the examination of sources of gross output growth across industry groups in China and India, we have seen that industry groups performed very differently within each country in terms of the growth of factors and TFP. The comparison between the two countries reveals a sharp contrast. In this sub-section we scrutinize the sources of value added growth in the two countries in the APPF framework taking into account that industries (groups) may have very

Table 2: Sources of Aggregate Value-Added Growth in China and India, 1981-2011
(Contributions are share-weighted growth rate in percentage points)

China

	1981-1991	1991-2001	2001-2007	2007-2011	1981-2011
<u>Industry contributions to value-added growth (ppts)</u>					
Value-added growth (%)	8.81	8.85	11.37	9.37	9.41
1. Agriculture	1.73	1.31	0.37	0.11	1.10
2. Mining	-0.04	0.17	-0.14	0.19	0.04
3. Light manufacturing	1.19	1.79	1.66	1.23	1.49
4. Intermediate materials	0.97	1.90	1.41	1.40	1.42
5. Electricals & ICT	0.82	0.87	1.02	0.75	0.87
6. Machinery & motor vehicles*	1.10	0.77	1.15	0.73	0.95
7. Utilities	0.33	0.01	0.62	0.43	0.30
8. Construction	0.52	0.49	0.56	0.50	0.52
9. Market services	1.61	1.25	3.56	3.17	2.09
10. Non-market services	0.58	0.29	1.17	0.85	0.64
Sum of 3-6: Manufacturing	4.07	5.32	5.23	4.11	4.73
Sum of 9-10: Services	2.18	1.53	4.73	4.03	2.72
<u>Factor contributions to value-added growth (ppts)</u>					
Value-added growth (%)	8.81	8.85	11.37	9.37	9.41
- Capital input:	5.83	7.01	9.45	10.83	7.61
- Stock	5.83	7.08	9.54	10.82	7.65
- Capital quality (composition)	-0.00	-0.07	-0.08	0.01	-0.04
- Labor input:	1.12	1.12	0.59	0.77	0.97
- Number (homogenous)	1.07	0.69	0.54	-0.60	0.61
- Labor quality (composition)	0.06	0.43	0.05	1.37	0.36
- Aggregate TFP	1.86	0.72	1.32	-2.22	0.83

India

	1981-1991	1991-2001	2001-2007	2007-2011	1981-2011
<u>Industry contributions to value-added growth (ppts)</u>					
Value-added growth due to (%)	4.87	5.83	7.75	7.16	6.07
1. Agriculture	0.78	0.89	0.51	0.64	0.75
2. Mining	0.20	0.08	0.08	0.08	0.12
3. Light manufacturing	0.38	0.38	0.34	0.65	0.41
4. Intermediate materials	0.59	0.36	0.81	0.74	0.58
5. Electricals & ICT	0.12	0.09	0.14	0.19	0.13
6. Machinery & motor vehicles*	0.13	0.20	0.40	0.35	0.24
7. Utilities	0.18	0.22	0.22	0.09	0.19
8. Construction	-0.00	0.13	0.81	0.33	0.25
9. Market services	1.24	2.32	3.58	2.88	2.28
10. Non-market services	1.25	1.16	0.84	1.22	1.13
Sum of 3-6: Manufacturing	1.23	1.03	1.70	1.92	1.35
Sum of 9-10: Services	2.48	3.48	4.42	4.10	3.42
<u>Factor contributions to value-added growth (ppts)</u>					
Value-added growth due to (%)	4.87	5.83	7.75	7.16	6.07
- Capital input:	2.75	3.03	4.34	4.79	3.43
- Stock	2.30	2.74	4.02	4.50	3.09
- Capital quality (composition)	0.45	0.29	0.32	0.29	0.35
- Labor input:	1.83	1.42	1.35	1.15	1.51
- Number (homogenous)	1.04	0.83	0.72	0.39	0.82
- Labor quality (composition)	0.79	0.60	0.63	0.75	0.69
- Aggregate TFP	0.28	1.38	2.05	1.22	1.13

Source: Authors' estimates using equation (7). *Including other transport equipment.

rizes the results. In what follows we first examine the contribution of each industry group to aggregate value-added growth through each sub-period to see the role of each group in driving the growth. We then discuss the results of growth accounting in this framework in the form of both aggregate value-added and labour productivity functions.

A manufacturing sector can be formed by aggregating industry group 3 to 6 and a services sector by aggregating industry groups 9 and 10. A distinctive picture of growth emerges from looking at the aggregate. On average one half of China's value-added growth over the period 1981-2011 was driven by manufacturing (50.3 per cent, measured as 4.73 ppts of the 9.41 per cent growth, Table 2) and, in contrast, more than a half of India's growth by services (56.2 per cent, measured as 3.41 ppts of the 6.07 per cent growth, Table 2). This holds true for all sub-periods. If concentrating only on the contribution of market services to the growth, it was 22.2 per cent in the case of China (measured as 2.09 ppts of the 9.41 per cent growth) and 37.6 per cent in the case of India (2.28 ppts of the 6.07 per cent growth). Interestingly, when India underwent more comprehensive reforms in the 1990s, the growth of market services already made up nearly 40 per cent of annual value-added growth (2.32 ppts out of 5.83 per cent growth in 1991-2001). Meanwhile, in China, this was only less than 15 per cent (1.25 ppts out of 8.85 per cent annual growth in 1991-2001).

However, we also notice that a rebalancing took place in both economies following China's WTO entry. In India, while the growth in market services continued and was more rapid (3.58 per cent per annum in 2001-2007 compared to 2.32 per cent in 1991-2001), the growth of intermediate materials and machinery manufacturing groups, accelerated by a speed that was more than double the previous rate. In China, while the growth of some manufacturing industries

decelerated, the growth of market services increased dramatically.

The contribution of agriculture to aggregate value-added growth declined inevitably in the two countries, but in China it was much faster than in India. When China experienced a sharp drop from about 20 per cent in 1981-1991 (1.73 ppts of aggregate value-added growth of 8.81 per cent) to almost one per cent in 2007-2011 (0.11 ppts of aggregate value-added growth of 9.37 per cent), India underwent a process in which the contribution declined from 16 per cent to less than 10 per cent. We also find that in both cases, the contribution of mining was trivial (0.4 per cent for China and 2.0 per cent for India taking annual growth over the entire period as 100) and the contribution of utilities and construction also appears to be small and similar between the two countries (3.2 per cent and 5.5 per cent for China and 3.1 per cent and 4.1 per cent for India, calculated based on Table 2).

Factor Contribution to Aggregate Value-added Growth

In Table 2, we show our estimates of factor contribution to the aggregate value-added growth including the contribution of TFP growth in the same APPF framework. On an average, the estimated TFP growth for the entire period 1981-2011 is 1.13 per cent per annum for India and 0.83 per cent per annum for China. That Indian TFP growth was over one-third faster than that of China comes as a rather big surprise. Both countries did not perform as well as the post-war East Asia forerunners such as Japan, South Korea and Taiwan (Felipe, 1999). Throughout the sub-periods, China's TFP growth was more volatile than that of India. It can be seen that from the 1980s, India's TFP was on an upward march, reflecting that domestic reforms in manufacturing and trade liberalization had gradually improved efficiency

Table 3: Decomposition of Aggregate Labour Productivity Growth in China and India, 1981-2011 (Contributions are weighted growth in per cent)

China

	1981-1991	1991-2001	2001-2007	2007-2011	1981-2011
<u>Growth Rates</u>					
Value-Added Growth (APPF)	8.81	8.85	11.37	9.37	9.41
-Value added per number employed	6.26	7.26	10.08	10.78	7.96
- Number employed (natural unit)*	2.55	1.59	1.28	-1.41	1.45
<u>Factor Contributions</u>					
Value-Added per employed person	6.26	7.26	10.08	10.78	7.96
- Capital deepening	4.35	6.11	8.71	11.63	6.78
- Labor quality	0.06	0.43	0.05	1.37	0.36
- TFP growth	1.86	0.72	1.32	-2.22	0.83

India

	1981-1991	1991-2001	2001-2007	2007-2011	1981-2011
<u>Growth Rates</u>					
Value-Added Growth (APPF)	4.87	5.83	7.75	7.16	6.07
-Value added per number employed	2.89	4.19	6.26	6.35	4.46
- Number employed (natural unit)*	1.97	1.64	1.48	0.80	1.61
<u>Factor Contributions</u>					
Value-Added per employed person	2.89	4.19	6.26	6.35	4.46
- Capital deepening	1.82	2.22	3.58	4.39	2.65
- Labor quality	0.79	0.60	0.63	0.75	0.69
- TFP growth	0.28	1.38	2.05	1.22	1.13

Source: Authors' estimates using labour productivity version of equation (7). *This can be compared to "numbers in homogenous unit" in Table 2.

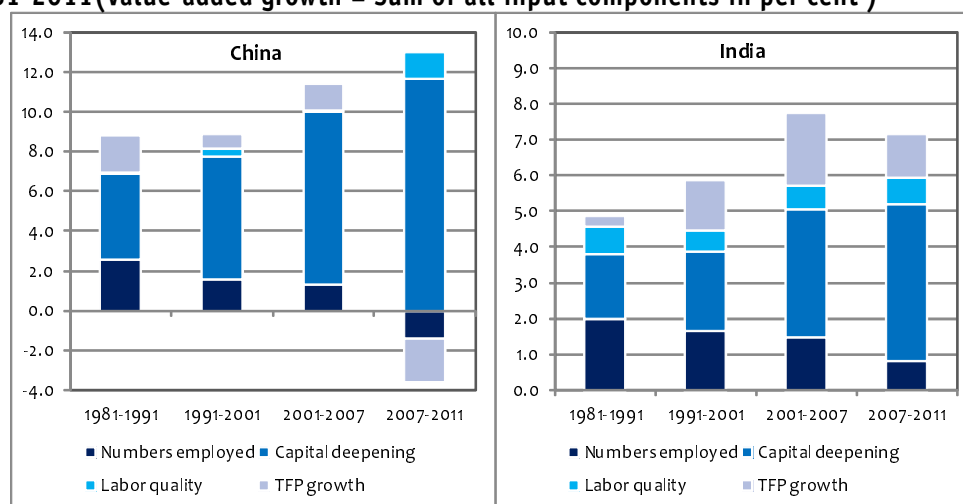
and even maintained positive following the Global Financial Crisis shock and its recessionary aftermath. In the case of China, we find that after strong TFP growth in the first decade of reforms (1.86 per cent per annum in 1981-1991), the gain in TFP was not that dramatic over the 1990s and the post-WTO period, and turned negative in the 2007-2011 sub-period.

Our estimates of the sources of value-added growth also put the two economies in sharp contrast. In China, on the average of the period 1981-2011, 80.9 per cent of the 9.41 per cent real growth per annum was attributable to physical capital input, 10.3 to labour input and merely 8.8 to TFP calculated. In India, the corresponding figures are 56.5 per cent, 24.9 per cent and 18.6 per cent with respect to the 6.07 per cent real growth per annum. This suggests

that China has been much more dependent on physical capital input than India.

As an usual and insightful analysis, in Table 3 and Chart 3 we also introduce growth accounting in the form of labour productivity, which to a large extent captures the effect of the so-call "demographic dividend" by separating the growth of numbers employed from the growth of output per employed person. As shown in Chart 3, it is clear that both economies have been increasingly driven by capital deepening. But the Indian economy looks healthier than the Chinese economy as suggested by their different TFP performances relative to their different capital-deepening processes. One explanation could be that India was relatively more insulated from the world economy than China, hence less volatile. Also, after three decades of rapid

Chart 3: Sources of Aggregate Value-Added Growth Over Sub-Periods in China and India, 1981-2011 (Value-added growth = Sum of all input components in per cent)



Source: Table 3.

growth, China is slowing down to rebalance its economy from export-driven to less-volatile domestic consumption driven (Das Krishna and Bhardwaj, 2016; Bloom *et al.*, 2010). Another explanation could be that China has long been relied on government-engineered growth and hence suffered increasingly from misallocation of resources (Wu, 2016b).

To examine and compare the TFP dynamics of the two economies over time, in Chart 4 we translate the annual aggregate TFP growth rates into a level index with 1981 as the base year. We also add a regression line to each country's index as its underlying productivity growth trend to benchmark its actual TFP movement. It is apparent that China's first TFP drive was associated with the early agricultural and industrial reforms in the early 1980s, but it ended at the time of the Tiananmen political crisis in 1989. Deng's call for bolder reforms in the early 1990s resulted in TFP growth but not as strong as that in the 1980s. The Chinese economy returned to its productivity trend following its WTO entry. This ended in the wake of the Global Financial Crisis.

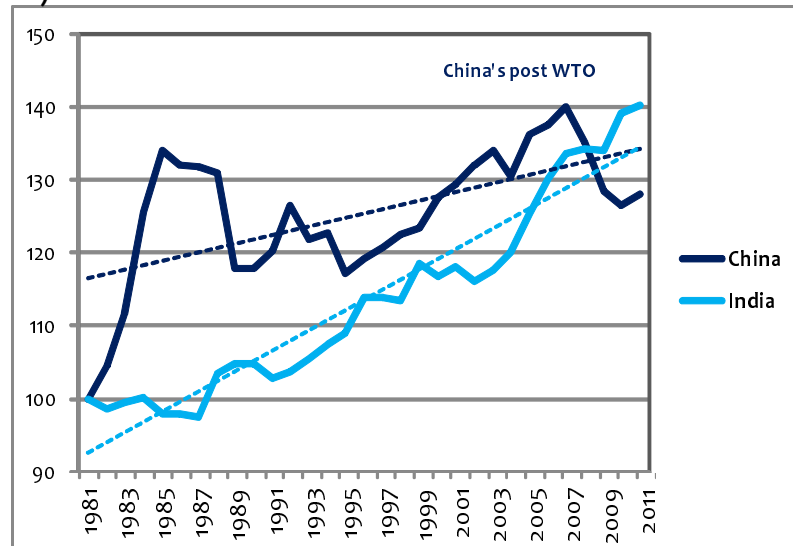
In contrast, India's TFP performance over time does not look as dramatic as that of China. However, it seems that Indian reforms indeed promoted a steady TFP improvement that remarkably converged with the Chinese productivity trend (Chart 4). Although we find that India's TFP also began to accelerate following China's WTO entry, we do not attempt to investigate the existence of a causal relationship in this study.

The post-GFC period saw a very different story to that of 2001-2007. While India seemed to have managed to continue its TFP growth, China, after a tremendous negative shock from the global financial crisis, appeared to be following a two year deteriorating productivity downturn until 2010. With the available data, it is perhaps too early to speculate on likely productivity developments in the two economies after 2011.

The Industry Origin of Aggregate TFP Growth and the Reallocation Effect

As expressed in equation (9), using the Domar aggregation approach the aggregate TFP

Chart 4: Index of Aggregate Total Factor Productivity in China and India, 1981-2011 (1981 = 100)



Source: Table 2.

growth rate can be decomposed into three additive components, that is, the change of the Domar-weighted aggregate TFP, the effect of capital reallocation across industries and the effect of labour reallocation across industries. The results are reported in Table 4, respectively for China and India.

When estimated with the Domar weights, we find that over the period 1981-2011, India's TFP growth (0.87 per cent per year) was still faster than China's TFP growth rate (0.61 per cent). We also find that contributions of the industry groups to the Domar-weighted annual TFP growth vary but to a much greater extent in the case of China compared to the case of India. For India, the major contributors to the TFP growth rate were services, in which market and non-market services made an equal contribution of 26.5 per cent each, or 53.1 per cent in total, to the aggregate TFP growth of 1.13 per cent per annum, including both Domar and reallocation effects (Table 4). Also for the same period, the contribution of the "manufacturing" group (made up of item 3 to 6) was 29.2 per cent. These findings appear to be fairly in line with their

contributions to the aggregate value-added growth (6.07 per cent per annum, Table 2), i.e. 56.2 and 22.4 per cent.

The case of China, nonetheless, seems to tell a very different story. The Chinese "manufacturing" and "services" groups contributed respectively 50.3 per cent and 29.0 per cent, respectively, to the aggregate value-added growth of 9.41 per cent per annum (Table 2), but their corresponding contributions to the aggregate TFP growth of 0.83 per cent per annum (Table 4) were 202.4 and -130.1 per cent, respectively. Such an unreasonable mismatch of growth and productivity performances is observed throughout all sub-periods with the worst case in the period 1991-2001. It may be reasonable to argue that entering WTO introduced an institutional correction to the Chinese economy. If these estimates are acceptable, we may need to consider accepting Wu (2016b)'s institutional hypothesis that the growth-motivated government uses a kind of "cross subsidization" to promote the growth of labour-intensive manufacturing to timely harvest China's demographic dividend while supporting

Table 4: Domar-Weighted TFP Growth and Reallocation Effects in China and India, 1981-2011 (Growth in per cent per annum and contribution in percentage points)

China

	1981-1991	1991-2001	2001-2007	2007-2011	1981-2011
Aggregate TFP growth	1.86	0.72	1.32	-2.22	0.83
1) Domar-weighted TFP growth	1.47	0.63	1.47	-2.90	0.61
1. Agriculture	0.89	0.46	-0.18	-0.68	0.33
2. Mining	-0.43	-0.00	-0.71	-0.36	-0.33
3. Light manufacturing	-0.17	0.92	0.67	0.13	0.40
4. Intermediate materials	-0.22	1.02	0.10	-0.40	0.23
5. Electricals & ICT	0.57	0.56	0.40	0.14	0.47
6. Machinery & motor vehicles*	0.84	0.58	0.56	-0.03	0.58
7. Utilities	0.07	-0.32	0.21	0.18	-0.01
8. Construction	0.07	-0.06	0.17	-0.17	0.02
9. Market services	0.19	-1.27	1.22	-0.32	-0.16
10. Non-market services	-0.34	-1.25	-0.98	-1.41	-0.92
Sum of 3-6: Manufacturing	1.02	3.07	1.74	-0.16	1.69
Sum of 9-10: Services	-0.16	-2.52	0.24	-1.73	-1.07
2) Reallocation of K (p^K)	-0.26	-0.36	-1.34	-0.15	-0.49
3) Reallocation of L (p^L)	0.65	0.44	1.19	0.83	0.71

India

	1981-1991	1991-2001	2001-2007	2007-2011	1981-2011
Aggregate TFP growth	0.28	1.38	2.05	1.22	1.13
1) Domar-weighted TFP growth	0.52	1.02	1.34	0.67	0.87
1. Agriculture	0.12	0.30	-0.00	0.27	0.18
2. Mining	-0.05	0.03	-0.16	-0.11	-0.05
3. Light manufacturing	0.01	-0.01	-0.00	0.43	0.06
4. Intermediate materials	0.18	-0.10	0.39	0.15	0.13
5. Electricals & ICT	0.06	0.04	0.09	0.10	0.06
6. Machinery & motor vehicles*	-0.03	0.07	0.20	0.18	0.08
7. Utilities	0.04	0.14	0.14	-0.04	0.08
8. Construction	-0.30	-0.26	-0.05	-0.47	-0.26
9. Market services	-0.01	0.42	1.01	-0.29	0.30
10. Non-market services	0.49	0.39	-0.27	0.43	0.30
Sum of 3-6: Manufacturing	0.23	-0.01	0.67	0.87	0.32
Sum of 9-10: Services	0.48	0.81	0.74	0.14	0.60
2) Reallocation of K (p^K)	-0.27	0.37	0.37	0.42	0.16
3) Reallocation of L (p^L)	0.03	-0.01	0.35	0.13	0.09

Source: Authors' estimates following equation (9). *Including other transport equipment.

strategic industries that are capital-intensive and may not be in line with China's comparative advantage. The government-favored or selected industries enjoy the benefit of various underpaid costs (Huang and Tao, 2010), which in turn as a negative externality takes the toll on the costs of other industries.

The considerable factor reallocation effects on TFP growth in both economies, as presented

in the last two rows of Table 4, suggest that industries indeed face different factor costs. This implies that the traditional aggregate production function approach is inappropriate, as discussed in Jorgenson *et al.* (2005a and 2005b). In theory, along with market-oriented reforms such reallocation is expected to be TFP promoting. This is largely reflected by the case of India that over the period 1981-2011 the reallocation

of capital and labour contributed to the 1.13 per cent aggregate TFP growth by 0.16 and 0.09 percentage points, respectively. In the case of China, nevertheless, the reallocation of capital resulted in a big loss of -0.49 ppts. However, China's net reallocation effect was still positive (0.22 ppts out of the 0.83 per cent aggregate TFP growth), thanks to a significant gain of 0.71 ppts from labour reallocation that could be attributable to substantial improvements of China's labour market. This may also lend strong support to our conjecture that institutional defects including government interferences are mainly responsible for the productivity loss due to the misallocation of capital in China. In our view, institutional effects on both growth and productivity performances between the two countries remain a very challenging and exciting topic of research.

Concluding Remarks

In this study we apply the same aggregate production possibility frontier (APPF) framework for growth accounting à la Jorgenson *et al.* (2005a and 2005b) to an economy-wide Chinese and Indian industry-level dataset, separately constructed in the spirit of the KLEMS principle using official statistics, to estimate growth and productivity performance in China and India over the post-reform period from 1981 to 2011. This is the first attempt made to compare the two countries in a consistent and rigorous empirical assessment for growth and productivity performance.

We show that over the three decades China grew over 50 per cent faster than India in value added (9.4 per cent versus 6.1 per cent per annum) but about 25 per cent slower than India in TFP (0.83 versus 1.13 per cent per annum). The two economies also experienced very different growth and productivity performances over various sub-periods distinguished by special policy regimes and governing systems. While

they both appeared to enjoy their best performances following China's WTO entry, China suffered much more in productivity growth in particular in the wake of the Global Financial Crisis.

We find that manufacturing and services indeed played distinctly different roles in the two economies. In terms of the GDP growth, they accounted for 50.3 per cent and 29.0 per cent respectively in China, whereas in India their contributions nearly reversed to 22.4 and 56.2 per cent, respectively. In terms of the TFP growth, in India the contributions of the two sectors largely mirrored their role in the GDP growth, but this is not the case of China where a seemingly implausible high contribution by manufacturing (about 200 per cent) co-existed with a huge loss by services (about -130 per cent). We argue that such an imbalance in China may be to a large extent explained by the negative effect of capital reallocation on TFP growth that reflects serious institutional barriers to factor mobility and government intervention induced misallocation of resources.

However, we would like to make it clear that our empirical findings and implications drawn from them are confined to the data used. Both the Chinese CIP/KLEMS dataset and India KLEMS dataset are still evolving over time with new source data and more methodological sophistication towards an accurate measurement of variables. Specifically, we are working together to develop more comparable datasets for the two economies in terms of classification, prices and hour-based quantitative measure of employment. Such data improvements may allow productivity comparisons in terms of levels as well as growth rates. Lastly, among various contrasts between the two economies that could motivate interesting comparative studies, comparisons in institutional effects on productivity performance should be prioritized.

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Appendix Table 1: Concordance Table for China and India Industry Data and Grouping

CHINA CIP/KLEMS	INDIA KLEMS	Grouping
1 Agriculture	1 Agriculture	1. Agriculture
2 Coal mining	2 Mining and quarrying	2. Mining
3 Oil and gas extraction		
4 Metal mining		
5 Non-metallic minerals mining		
6 Food and kindred products	3 Food products, beverages and tobacco	3. Light manufacturing
7 Tobacco products	4 Textiles, textile products, Leather and footwear	
8 Textile mill products		
9 Apparel and other textile products	5 Wood and products of wood	
10 Leather and leather products	6 Paper products, printing & publishing	
11 Saw mill products, furniture, fixtures		
12 Paper products, printing & publishing		
13 Petroleum and coal products	7 Petroleum & products; nuclear fuel	4. Intermediate materials
14 Chemicals and allied products	8 Chemicals and chemical products	
15 Rubber and plastics products	9 Rubber and plastic products	
16 Stone, clay, and glass products	10 Other non-metallic mineral products	
17 Primary & fabricated metal industries	11 Basic and fabricated metal products	
18 Metal products (excl. rolling products)		
19 Industrial machinery and equipment	12 Machinery, nec.	6. Machinery & motor vehicles.
20 Electric equipment	13 Electrical and optical equipment	5. Electricals & ICT
21 Electronic and telecommunication eq.		
22 Instruments and office equipment		
23 Motor vehicles & other transport eq.	14 Transport equipment	6. Machinery & motor vehicles.
24 Miscellaneous manufacturing	15 Manufacturing, nec; recycling	3. Light manufacturing
25 Utilities	16 Utilities	7. Utilities
26 Construction	17 Construction	8. Construction
27 Wholesale and retail trades	18 Trade	9. Market services
28 Hotels and restaurants	19 Hotels and restaurants	
29 Transport, storage & post	20 Transport and storage	
30 Information & computer services	21 Post and telecommunications	
31 Financial Intermediation	22 Financial services	
32 Real estate activities	27 Other services	10. Non-market services
33 Technical, science & business Services	23 Business service	9. Market services
34 Public administration and defense	24 Public administration and defense	10. Non-market services
35 Education	25 Education	
36 Health and social security	26 Health and social work	
37 Other services	27 Other services	

Can Intangible Investments Ease Declining Rates of Return on Capital in Japan?

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ABSTRACT

Japan's economic growth has slowed since the collapse of the bubble economy in the 1990s due to low capital accumulation. We focus on the low rate of return on capital, which led to this slow capital accumulation, finding that it was caused by an increase in the capital-output ratio and low capital share. Not only has the rate of return on capital declined, but its variance across industries has increased, as has the number of industries with negative rates of return. We estimate a profit function in which the profit rate is explained not only by the real wage but also by intangibles. The estimation results show that investment in human resources increases the profit rate and that intangibles contribute to this increase through productivity improvement, especially in the IT industry. Our study implies that governments should implement a comprehensive innovation policy that stimulates investments not only in R&D, but also in IT and human resources.

Many advanced countries have suffered slow growth rates since the start of the global financial crisis. In his 2015 IMF lecture, Professor Lawrence Summers warned that the United States and advanced countries in Europe might

follow the Japanese economy and suffer from a long-term stagnation similar to what Japan has suffered since the collapse of the bubble economy in the 1990s (Summers (2015a, 2015b)). He and his followers have emphasized that the

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Table 1: Sources of Economic Growth in Japan, the United States, Korea, and Republic of China, Taiwan (average annual % rate of change)

	Japan			United States		
	1980-90	1990-2000	2000-2010	1980-90	1990-2000	2000-2010
GDP	4.4	0.9	0.7	3.1	3.3	1.5
Labour input	1.1	0.0	0.0	1.0	0.9	-0.3
Capital input	1.9	1.0	0.3	1.2	1.3	1.0
TFP	1.5	-0.1	0.5	0.9	1.1	0.6
	Korea			Republic of China, Taiwan		
	1980-90	1990-2000	2000-2010	1980-90	1990-2000	2000-2010
GDP	9.1	6.1	4.2	7.9	6.5	3.4
Labour input	1.6	0.6	-0.1	1.1	0.6	0.5
Capital input	4.4	3.9	2.1	3.8	3.9	1.5
TFP	3.1	1.6	2.1	2.9	1.9	1.4

Source: JIP database, APO productivity databook

slow growth rate in advanced countries is caused by a decline in capital formation and real interest rates.²

This slow capital accumulation has led to stagnation in Japan. The gap in economic growth between Japan, the United States, and East Asian countries in the 2000s is not due to the gap in the contributions of labour input but to the gap in contributions of capital input, as shown in Table 1.

Before Summers pointed out the issues concerning the falling real interest rates and corporate profit rates, Japanese economists had discussed that it was the inefficiency of capital that had led to the low real interest and profit rates. Ando, Christelis, and Miyagawa (2003) and Hayashi (2006) argued that corporate savings in Japan were misallocated. As Japanese managers usually pay fixed dividends, the remaining corporate savings are excessively allocated to fixed capital formation, which induced low corporate profits. Based on these views, Saito (2007) argued that over-investment crowds out consumption and generates welfare loss. Fukao *et al.* (2016) confirmed that the over-investment in the 1980s and 1990s led to a high

capital-output ratio and a low rate of return on capital. Miyagawa (2004, 2005) suggested that the low corporate profit rate in the 1990s was caused by a high labour share and low TFP growth.

Since the global financial crisis, Japan's real capital stock has fallen despite its historically low interest rate and expansionary monetary policy. Murase and Ando (2014) demonstrated the possibility of a steady state whereby economic agents hold money instead of tangible capital under weak governance, allowing for a low capital accumulation under a zero interest rate. Benigno and Fornaro (2015) also show an equilibrium representing a secular stagnation by combining a standard short-run Keynesian model with an endogenous growth model. In this equilibrium, underemployment and low potential growth coexist under zero interest rates and pessimistic expectations of future growth.

These studies imply that the capital-output ratio, factor shares, and productivity growth play crucial roles in the decline of real rates of interest and corporate profit rates, which leads to low capital accumulation. We examine long-

² Solow (2014) also discussed the secular stagnation induced by low capital accumulation.

Table 2: Real Gross Rate of Return on Capital in Japan

	1980-1989	1990-1999	2000-2012
Marginal rate of return on capital (%)	13.6	12.9	10.4
Average rate of return on capital (%)	18.0	15.8	14.4

Source: Authors' calculations based on JIP2015 database.

term movements in the rate of return on capital using the Japan Industrial Productivity (JIP) database³ and determine whether wage rates and innovative factors which improve productivity affect the rate of return on capital by estimating a profit function.⁴

Movements in the marginal rate of return on capital are broken down into the capital-output ratio and capital share. We find that the capital-output ratio follows an upward trend, as Fukao *et al.* (2016) found, and is particularly high in non-IT industries. On the other hand, the capital share in non-IT industries has followed a downward trend over the past 30 years. In addition, the relative variance across industries asset types of the average rate of return on capital was very large in 2012, and the number of industries showing a negative rate of return has increased.

We estimate a profit function based on a simple production function that uses industry-level data and examine the factors affecting the rate of return on capital. The estimation results show, first, that an increase in wage rates has a negative impact on the rate of return on capital, as we expected. Second, greater investment in intangibles leads to higher rates of return on capital through productivity growth. Third, we find complementary effects among intangibles, especially in the IT industry. These results suggest

that governments should implement a comprehensive innovation policy that stimulates investments in not only R&D but in IT and human resources as well.

In the first section, we examine movements in the rate of return on capital, the capital-output ratio, and capital share using the JIP Database. In the second section, we estimate a profit function to examine the determinants of the profit rate. In the third and final section, we summarize our results and discuss their policy implications.

Why Has The Rate Of Return On Capital Declined?

We show two types of real gross rate of return on capital in the market sector in Table 2. The first measure is the marginal rate of return on capital (marginal product of capital = MPK). Assuming a Cobb-Douglas function ($Y_t = A_t K_t^\alpha L_t^{1-\alpha}$), where Y is value added, L is labour input, K is capital input, and A is a technological factor, we obtain the following MPK:

$$MPK = \frac{\delta Y}{\delta K} = \alpha \times \frac{Y}{K} \quad (1)$$

where α represents capital share. Then, we measure the marginal rate of return on capital

3 The Japan Industrial Productivity (JIP) Database is a KLEMS-type database that provides data on outputs, intermediate inputs, labour, and capital from 1970 to 2012. It contains 108 industries, categorized following the two-digit industry classification of the Japan Standard Industrial Classification (JSIC). The database is available on the website of the Research Institute of Industry, Trade, and Industry (RIETI). Fukao *et al.* (2007) show how the JIP database is constructed.

4 Many studies on investment behavior in Japan suggest that the profit rate (or the Tobin's Q indicating future profitability) is the most important determinant of capital formation (e.g. Tanaka and Miyagawa, 2011).

Table 3: Decomposition of Rate of Return on Capital in Japan

		1980-1989	1990-1999	2000-2012
Capital-output ratio	Market economy	2.53	2.67	3.12
	IT industries	1.72	1.91	2.11
	Non-IT industries	3.48	3.71	4.90
Capital share (%)	Market economy	34.3	34.1	32.2
	IT industries	31.4	33.6	32.9
	Non-IT industries	38.1	34.8	31.0

Source: Authors' calculations based on JIP2015 database.

by dividing the capital share by the capital-output (value added) ratio.⁵ We measure real value added by dividing nominal value added by the output deflator in the JIP database.⁶ We also measure capital share by dividing the sum of the operating surplus and consumption of fixed capital by the nominal value added in the JIP database.

The second measure is the average real rate of return on capital. We obtain this measure by dividing the sum of the operating surplus and consumption of fixed capital by the real capital stock in the JIP database.⁷

Table 2 shows that both rates of return on capital were lower in the 2000s than those in the 1980s and 1990s. The average rate of return declined drastically in the 1990s. On the other hand, we find a significant decrease in the marginal rate of return in the 2000s. Hence, the gap between the average and marginal rates of return slightly widened in the 2000s. This

increase implies that Japanese firms have concentrated on businesses that earn high profits by restructuring after the financial crisis in Japan, while the rate of return on new investment has declined.

Following Equation (1), we break down the marginal rate of return into the capital-output ratio and the capital share. We show these variables not only in the market sector but also in the IT-using and non-IT using sectors (Table 3). The IT-using industry is comprised of firms with a ratio of IT assets to total assets that exceeds the 2005 median value. IT assets consist of computers and peripheral equipment, communication equipment, and software.⁸

As Fukao *et al.* (2016) pointed out, the capital-output ratio in the market economy has been on an upward trend. The capital-output ratio in the non-IT sector has increased rapidly and seems to dominate the capital-output ratio movement in the market sector. The rising capital-output

5 All KLEMS-type databases like the JIP database assume that the marginal rate of return on capital in each asset can be captured as the capital service of this asset. This assumption implies that each type of capital is utilized efficiently. However, as Basu and Fernald (2001) and Miyagawa, Sakuragawa, and Takizawa (2006) showed, the capital utilization rate fluctuates in the short run. In addition, Jorgenson *et al.* (2007) and Fukao *et al.* (2012) showed that there can be a gap between the rate of return on capital at the aggregate level and the rate at the industry level due to a misallocation of capital input.

6 In the JIP database, real value added in some industries becomes negative when we measure it by subtracting real intermediate inputs from real output. Therefore, we obtain real value added by dividing nominal value added by an output deflator.

7 Operating surplus and consumption of fixed capital are deflated by the investment deflator by industry.

8 The sum of IT-using industries and non-IT using industries covers the total market economy. Hereafter, we call IT-using industries 'IT industries' and non-IT using industries 'non-IT industries'.

Table 4: Variances and Relative Standard Deviations in the Rate of Return on Capital in Japan

		1980	1990	2000	2012
Marginal rate of return	Variances	1785.6	1026.3	909.3	290.9
	Relative SD	1.5	1.2	1.4	1.5
Average rate of return	Variances	3256.9	1179.8	652.3	453.2
	Relative SD	2.0	1.3	1.4	1.7

Source: Authors' calculations based on JIP2015 database.

ratio in non-IT industries is caused by a steep decline in real value added, because this sector includes many stagnant industries.

Table 3 also shows movements in the capital share. The capital share in the market economy was greater than 30 per cent for the past 30 years. Since the 1990s it has been on a slight downward trend. Capital shares in the IT and non-IT sectors show movements different from that in the market sector. The capital share in the IT sector increased in the 1990s, while the capital share in the non-IT sectors has shown a downward trend. In Japan, the downward trend in the capital share in non-IT sectors has been more influential than has the movement in the IT sector.

The findings shown in Table 3 indicate variances in rates of return on capital among industries.⁹ Table 4 shows the variances and relative standard deviations (= standard deviation/mean) in the rates of return on capital. Variances in the rates of return have decreased as the rates of return have fallen. However, the relative standard deviations have not declined to the same extent. Since 1990 the relative standard deviation in the rate of return has increased despite the decrease in the rate of return. These findings suggest that specific factors at the industry level as well as aggregate factors may affect move-

ments in rates of return on capital. Below, we examine some of the factors affecting rates of return on capital using industry-level data.

Estimating the Profit Function

In this section, we empirically examine how the rates of return fluctuate. Taking the log in Equation (1), we obtain the following equation:

$$\ln r_t = \ln \alpha + \ln \left(\frac{Y_t}{K_t} \right) \quad (2)$$

where r is the rate of return on capital. Assuming a Cobb-Douglas function, Equation (2) leads to

$$\ln r_t = \ln \alpha + \ln A_t + (1 - \alpha) \ln \left(\frac{L_t}{K_t} \right) \quad (3)$$

When firms minimize their costs, (L/K) is negatively correlated with the relative factor price (w/r) . Arranging Equation (3) with respect to $\ln r$, we obtain

$$\ln r_t = \text{const} + \alpha w_t + b A_t \quad (4)$$

where w is the real wage. The real wage rate at the industry level is calculated as follows:

⁹ Nomura (2004) also found large variances in rates of return on capital across industries. As we use the JIP database, the rate of return on capital is measured on an activity basis. Firms combine some of the activities listed in the JIP database.

Real wage rate = (real value added * labour share)/total man-hours.¹⁰

We also assume that the technological factor is positively correlated with intangibles such as IT and R&D. Griliches and Mairesse (1990) and Hall (1993) assumed that R&D investment enhances technological progress. We extend this concept to the broader category of intangibles.¹¹ Our basic empirical equation is thus

$$\begin{aligned} \ln r_t = & \text{const} + \alpha_1 \ln w_{jt} \\ & + \alpha_2 \ln \left(\frac{K_{jt}^{IT}}{K_{jt}^T} \right) + \alpha_3 \ln \left(\frac{K_{jt}^{RD}}{K_{jt}^T} \right) \\ & + \alpha_4 \ln \left(\frac{K_{jt}^{HR}}{K_{jt}^T} \right) + \alpha_5 \ln Y_{jt} \\ & + u_j + n_t + \varepsilon_{jt} \end{aligned} \quad (5)$$

In this expression, K_{jt}^{IT} , K_{jt}^{RD} , K_{jt}^{HR} , and K_{jt}^T account for the capital stock in information technology, R&D, human resources (HR), and tangible assets, respectively.¹² Y is the value added by industry as a control variable. Subscripts j and t denote industry and time, while u_j and n_t denote industry and year fixed effects.¹³

Given the presumption that an increase in labour's share (decline in capital share) would

reduce the rate of return on capital, we predict the sign of the coefficient will be $\alpha_1 < 0$. Thus, $\alpha_2 > 0$, $\alpha_3 > 0$, $\alpha_4 > 0$ can also be predicted because an increase in intangible investments is expected to enhance the Hicks-neutral technology. Thus, intangibles have positive effects on the rate of return on tangible capital.

In addition to Equation (5), we also estimate the following equation to check for complementary effects between intangibles:

$$\begin{aligned} \ln r_t = & \text{const} + \alpha_1 \ln w_{jt} \\ & + \alpha_2 \ln \left(\frac{K_{jt}^{IT}}{K_{jt}^T} \right) + \alpha_3 \ln \left(\frac{K_{jt}^{RD}}{K_{jt}^T} \right) \\ & + \alpha_4 \ln \left(\frac{K_{jt}^{HR}}{K_{jt}^T} \right) + \alpha_5 \ln Y_{jt} \\ & + b_1 \ln \left(\frac{K_{jt}^{IT}}{K_{jt}^T} \right) \times \ln \left(\frac{K_{jt}^{RD}}{K_{jt}^T} \right) \\ & + b_2 \ln \left(\frac{K_{jt}^{IT}}{K_{jt}^T} \right) \times \ln \left(\frac{K_{jt}^{HR}}{K_{jt}^T} \right) \\ & + u_j + n_t + \varepsilon_{jt} \end{aligned} \quad (6)$$

When $b_1 > 0$, $b_2 > 0$ in Equation (6), we find positive complementary effects among intangibles on productivity growth.

10 According to the Monthly Labour Survey compiled by the Japanese Ministry of Health, Labour and Welfare, real wages have been declining since 2000. Contrary to this widely used statistic, the data series for real wages used in this study, obtained from the JIP database, shows an increasing trend over this period. The discrepancy between these data series is due partly to the inclusion of income from self-employment in the JIP database.

11 If we include intangibles in a production function, following Corrado *et al.* (2009), we have to adjust the value added accounting intangible investment. However, as the value added in the JIP2015 database does not fully consider the fact that intangibles are investment and have externality and network effects, we assume that intangibles affect Hicks-neutral technological progress.

12 Note that the "capital stock in information technology" used in the estimations do not account for investment in hardware associated with IT but only for investment in software.

13 To focus on the rate of return on tangible capital, we subtract the contribution of custom software from the rate of return on capital, which initially included the contribution of intangibles.

Table 5 Summary Statistics: Market Economy, 1985-2012

Variables	Definitions	Mean	Std. Dev	Min	Max	Obs
r_{marginal}	Marginal rate of return on capital	22.674	26.287	0.022	237.888	1,762
r_{average}	Average rate of return on capital	22.431	30.083	0.027	385.338	1,762
w	Wage	3.438	3.194	0.456	34.304	1,762
K_{IT}/K_T	IT capital stock over tangible capital stock	0.012	0.014	0.000	0.104	1,762
K_{RD}/K_T	R&D capital stock over tangible capital stock	0.046	0.091	0.000	0.829	1,762
K_{HR}/K_T	Human Resources capital stock over tangible capital stock	0.003	0.003	0.000	0.031	1,762
Y	Value added	3781351	5651996	47902.62	3.87E+07	1,762
$\ln r_{\text{marginal}}$	Log of marginal rate of return on capital	-1.899	0.954	-8.422	0.867	1,762
$\ln r_{\text{average}}$	Log of average rate of return on capital	-1.921	0.947	-8.208	1.349	1,762
$\ln w$	Log of wage	1.044	0.547	-0.785	3.535	1,762
$\ln K_{IT}/K_T$	Log of IT capital stock over tangible capital stock	-4.968	1.077	-9.099	-2.261	1,762
$\ln K_{RD}/K_T$	Log of R&D capital stock over tangible capital stock	-4.749	2.577	-16.357	-0.188	1,762
$\ln K_{HR}/K_T$	Log of Human Resources capital stock over tangible capital stock	-6.470	1.141	-10.102	-3.462	1,762
$\ln Y$	Log of value added	14.455	1.164	10.777	17.472	1,762

Notes: All variables are converted into values in constant prices for 2000.

Source: Authors' calculations based on the JIP2015 database.

As mentioned, our data are obtained from the JIP2015 database. Our analysis focuses on the market economy from 1985 to 2012, consisting of 92 industries. Appendix 1 provides a description of our dataset, and Appendix 2 shows the industrial classification. Table 5 presents summary statistics for the variables used in our analysis. We find that the percentage of R&D capital in tangible capital is about 5 per cent on average. The IT capital share is lower than that of R&D capital, and the HR capital share is the lowest (about 0.3 per cent on average and 3 per cent at maximum).

We use both the marginal and average rates of return for the rate of return on capital employed for our dependent variables. Panel A in Table 6 shows the results of the industry-level fixed-effect estimation for the market economy. We also conduct a GMM estimation to test for endogeneity among our explanatory variables, using the marginal rate of return on capital.¹⁴ First, the coefficient on wages is negative and significant in all estimations. Second, the coefficient on IT capital stock is positive and significant

in the estimations of Equation (6). Third, the coefficient on R&D capital stock is negative and significant in almost all equations, suggesting that R&D investments do have negative impacts on the rate of return on capital, which is highly counterintuitive. However, the coefficient on HR capital stock is positive and significant, suggesting that greater investment in HR leads to higher rates of return on capital. In addition, the coefficient in the cross term between IT and HR is positive and significant, implying that investment in HR has a positive impact on productivity improvement not only through its own effect but also via a complementary effect with IT.

Though the negative coefficient on R&D capital stock is puzzling, the coefficients on IT and HR capital stock are positive and significant, implying that these two intangible assets contribute to higher rates of return on tangible capital.

Panel B in Table 6 shows the fixed-effect and GMM estimation results for the market economy. We use the average rate of return on capital

14 The second lags of the dependent variable and the first difference of all the exogenous variables were used as instruments.

Table 6: Estimation Results Using the Marginal and Average Rate of Return on Capital In the Market Economy

Panel A: Dependent Variable: Marginal Rate of Return on Capital

Market economy									
Dependent variable: Marginal rate of return on capital									
	(1)		(2)		(3)		(4)		
	Coef.	Std. Err	Coef.	Std. Err	Coef.	Std. Err	Coef.	Std. Err	
ln w	-0.642	0.058 ***	-0.613	0.059 ***	-0.750	0.071 ***	-0.883	0.069 ***	
ln K_{IT}/K_T	0.031	0.026	0.476	0.095 ***	-0.066	0.036 *	0.555	0.128 ***	
ln K_{RD}/K_T	-0.068	0.020 ***	-0.116	0.046 **	-0.088	0.035 **	0.078	0.069	
ln K_{HR}/K_T	0.148	0.039 ***	0.433	0.071 ***	0.063	0.046	0.510	0.093 ***	
ln Y	1.413	0.049 ***	1.429	0.048 ***	1.585	0.059 ***	1.643	0.059 ***	
ln $K_{IT}/K_T \ln K_{HR}/K_T$			0.068	0.014 ***			0.075	0.018 ***	
ln $K_{IT}/K_T \ln K_{RD}/K_T$			-0.010	0.007			0.037	0.012 ***	
Constant	-20.962	0.741 ***	-19.433	0.801 ***	-23.745	0.901 ***	-21.234	1.027 ***	
	Fixed-effects model		Fixed-effects model		GMM		GMM		
Number of obs	1,762		1,762		1,732		1,732		
Number of groups	70		70		70		70		

Panel B: Dependent Variable: Average Rate of Return on Capital

Market economy									
Dependent variable: Average rate of return on capital									
	(1)		(2)		(3)		(4)		
	Coef.	Std. Err	Coef.	Std. Err	Coef.	Std. Err	Coef.	Std. Err	
ln w	-1.180	0.061 ***	-1.156	0.061 ***	-0.978	0.075 ***	-1.122	0.071 ***	
ln K_{IT}/K_T	0.075	0.027 ***	0.492	0.099 ***	0.021	0.038	0.905	0.124 ***	
ln K_{RD}/K_T	-0.059	0.020 ***	-0.076	0.047	-0.077	0.037 **	0.132	0.072 *	
ln K_{HR}/K_T	0.167	0.040 ***	0.413	0.073 ***	0.165	0.046 ***	0.656	0.091 ***	
ln Y	1.326	0.050 ***	1.342	0.050 ***	1.434	0.061 ***	1.528	0.060 ***	
ln $K_{IT}/K_T \ln K_{HR}/K_T$			0.060	0.014 ***			0.105	0.018 ***	
ln $K_{IT}/K_T \ln K_{RD}/K_T$			-0.004	0.007			0.046	0.012 ***	
Constant	-18.608	0.768 ***	-17.176	0.832 ***	-20.229	0.914 ***	-17.481	0.980 ***	
	Fixed-effects model		Fixed-effects model		GMM		GMM		
Number of obs	1,762		1,762		1,732		1,732		
Number of groups	70		70		70		70		

Source: Authors' calculations based on JIP2015 database.

as the dependent variable. First, we find negative coefficients of the real wage rate in all estimations, similar to the results shown in Panel A in Table 6. Second, contrary to those results, the coefficients on IT stock are positive in all estimations. Third, the coefficients on R&D stock show positive and significant impacts on the profit rate in the estimation in Column (4), although it shows the opposite effect in the other three estimations. Fourth, the results for HR are qualitatively the same as those shown in Panel A in Table 6.

Given these baseline results, we conduct an additional subsample analysis by dividing our

sample into IT industry and non-IT industry groups. Panel A in Table 7 shows the results for the IT industry using the marginal rate of return.¹⁵ IT stock has a positive and significant impact on the profit rate in all estimations. Contrary to the results shown in Panel A Table 6, R&D stock shows a positive and significant sign in Column (4). The cross term between IT and R&D also shows positive and significant complementary effects on productivity. The results for the other variables are almost the same as those shown in Panel A in Table 6. Overall, we find that intangibles play a crucial role in raising

15 We also estimate Equations (5) and (6), where the dependent variables are the average rate of return in the IT and non-IT industries. These estimation results are similar to those shown in Tables 8 and 9.

Table 7: Estimation Results Using the Marginal Rate of Return on Capital for IT and Non-IT Industries

Panel A: IT Industries

IT industries									
Dependent variable: Marginal rate of return on capital									
	(1)		(2)		(3)		(4)		
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	
ln w	-0.588	0.085 ***	-0.617	0.089 ***	-0.805	0.096 ***	-1.032	0.097 ***	
ln K_{IT}/K_T	0.138	0.043 ***	0.739	0.155 ***	0.124	0.047 ***	0.938	0.159 ***	
ln K_{RD}/K_T	-0.070	0.030 **	0.108	0.070	0.014	0.040	0.441	0.083 ***	
ln K_{HR}/K_T	0.091	0.055 *	0.296	0.103 ***	0.209	0.059 ***	0.444	0.105 ***	
ln Y	1.443	0.068 ***	1.479	0.069 ***	1.578	0.085 ***	1.730	0.086 ***	
ln K_{IT}/K_T ln K_{HR}/K_T			0.066	0.021 ***			0.061	0.023 ***	
ln K_{IT}/K_T ln K_{RD}/K_T			0.040	0.014 ***			0.103	0.016 ***	
Constant	-21.487	1.061 ***	-19.988	1.181 ***	-21.291	1.251 ***	-20.146	1.342 ***	
	Fixed-effects model		Fixed-effects model		GMM		GMM		
Number of obs	1,040		1,040		1,018		1,018		
Number of groups	41		41		41		41		

Panel B: Non-IT industries

Non-IT industries									
Dependent variable: Marginal rate of return on capital									
	(1)		(2)		(3)		(4)		
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	
ln w	-0.664	0.079 ***	-0.722	0.078 ***	-0.629	0.062 ***	-0.658	0.062 ***	
ln K_{IT}/K_T	-0.053	0.030 *	0.315	0.159 **	-0.061	0.029 **	-0.065	0.152	
ln K_{RD}/K_T	-0.041	0.025	-0.384	0.076 ***	0.007	0.033	-0.176	0.078 **	
ln K_{HR}/K_T	0.177	0.059 ***	0.617	0.128 ***	0.078	0.038 **	0.266	0.114 **	
ln Y	1.433	0.067 ***	1.511	0.068 ***	1.432	0.058 ***	1.458	0.058 ***	
ln K_{IT}/K_T ln K_{HR}/K_T			0.094	0.023 ***			0.026	0.019	
ln K_{IT}/K_T ln K_{RD}/K_T			-0.053	0.011 ***			-0.030	0.012 **	
Constant	-21.256	1.026 ***	-21.084	1.235 ***	-20.991	0.907 ***	-21.285	1.184 ***	
	Fixed-effects model		Fixed-effects model		GMM		GMM		
Number of obs	722		722		714		714		
Number of groups	29		29		29		29		

Source: Authors' calculations based on JIP2015 database.

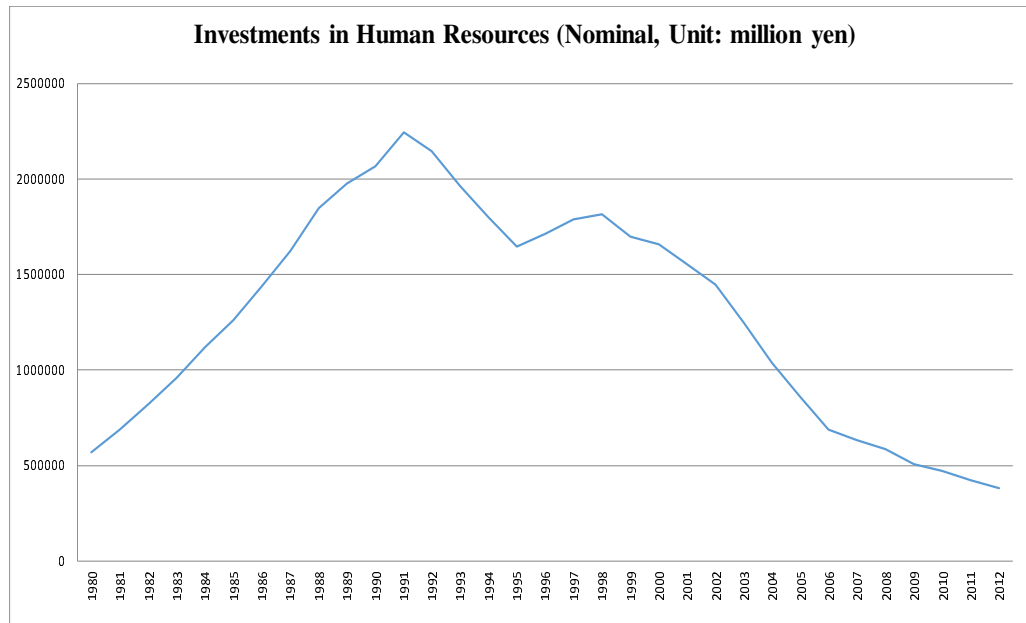
profit rates through productivity improvement in the IT industry.

Panel B in Table 7 shows the results for non-IT industries using the marginal rate of return. The coefficient on the IT investment ratio is not stable, suggesting that IT investment does not contribute to a higher rate of return on capital in non-IT industries. As in Panel A in Table 6, the coefficient on R&D is negative and significant in Columns (2) and (4). The cross terms between intangibles show mixed results: the cross term between IT and HR is positive and significant, as in the previous results, on the other hand, the cross term between IT and R&D is negative and significant.

The estimation results shown in Table 7 offer hints concerning the puzzling results shown in Table 6. In the IT industry, the IT capital stock has a positive and significant impact on profit rates. The coefficient on R&D stock has a positive sign, except in Column (1) in Panel A in Table 7. On the other hand, in non-IT industries, IT and R&D show no positive impact on profit rates. These estimation results for both industries suggest that the ambiguous estimation results for IT and R&D are caused by the contrast between the results for non-IT industries and those for the IT industry.

Non-IT industries include many traditional industries in decline. Firms in such industries

Chart 1: Investments in Human Resources in the Market Economy in Japan, 1980-2012



Source: Authors' calculations based on JIP2015 database.

have no incentive to invest in IT; thus, IT facilities do not contribute to the rate of return on capital. Moreover, R&D efficiency may decline in these industries, as Bloom *et al.* (2017) pointed out. Ikeuchi *et al.* (2013) have also shown that Japanese firms in traditional industries have moved their high-productivity factories overseas. We may not have captured the relationship between productivity and R&D due to this hollowing-out effect.

Importantly, the positive and significant sign of the IT industry implies that IT investments improve technology levels in this industry. In other words, IT investments are likely to raise the rate of return on tangible capital for industries with a larger accumulation of IT stock.

Almost all the estimation results indicate that the coefficients on HR capital stock (α_4) are positive and significant, suggesting that growth in

HR is crucial to increasing the rate of return on capital. However, Chart 1 shows that investments in HR at current prices have fallen steeply in Japan since 2000, which might have led to the low rate of return on capital.¹⁶

Finally, we find many positive and significant cross terms between intangibles, implying that complementary effects among intangibles raise the profit rate. Chun *et al.* (2015) examined the correlation between the dynamics of IT assets and R&D or other intangibles (including HR) and found that the dynamics of IT assets were not positively correlated with that of intangibles in Japan during the 2000s. The evidence in Chun *et al.* (2015) and our estimation results on the cross terms between intangibles indicate that the lack of complementary effects among intangibles in Japan has led to the declining profit rate.

16 Chun *et al.* (2015) showed their estimation method and data source for HR in detail. After the collapse of the bubble economy, Japanese firms shifted from regular employment to irregular employment practices. Opportunities for education and training are often fewer for irregular employees than for regular employees, which is one reason why HR investment has decreased since 1990. Investments in HR include off-the-job training costs, which corresponds to 'firm-specific human capital' in Corrado *et al.* (2009).

Conclusion and Policy Implications

The Japanese economy has suffered from long-term stagnation since the collapse of the bubble economy in the 1990s. Advanced economies such as the United States and Europe have been following in Japan's footsteps since the global financial crisis. One of the main symptoms of this long-term stagnation is the low growth rate induced by stagnant capital formation under low interest rates. We focus on movements in the real rate of return on capital in order to understand secular stagnation using the JIP database.

First, we divide the rate of return on capital into the capital-output ratio and capital share. We find that the capital-output ratio shows an upward trend. The ratios in non-IT industries are particularly high, indicating that these industries have accumulated inefficient capital stock. These findings are consistent with the argument in Fukao *et al.* (2016). On the other hand, the capital share has been maintained at over 30 per cent, but has shown a downward trend in non-IT industries over the past 30 years. The downward trend in the rate of return on capital has caused a number of industries to have negative profit rates. In addition, the greater relative standard deviation indicates that industry-level factors affect the dispersion of the rate of return on capital.

Based on these findings, we estimate a profit function based on a simple production function in which the profit rate is affected by factor prices and total factor productivity. We choose intangibles such as IT investment and R&D investment as determinants of productivity. While the level of IT and R&D investments are relatively high in Japan, the rate of return on capital, which could benefit from such high

investments, is low. To clarify the mechanism of this phenomenon, we empirically examine the effect of intangibles on the profit rate.

The estimation results show, first, that a higher real wage is associated with a lower rate of return, as expected. This might imply that a policy measure intended to increase wages does not necessarily stimulate capital formation. On the other hand, the positive sign of value added suggests that an increase in aggregate demand is likely to increase capital formation.

Second, in a puzzling result, IT has a positive and significant effect on the rate of return on tangible capital, especially in the IT industry. In non-IT industries, we find no positive or significant effects of IT on the rate of return on capital, implying that non-IT firms might not be fully utilizing the performance of IT facilities. Thus, we suggest that Japanese management should pay more attention to ways of incorporating IT technologies in their firms.

Third, in non-IT industries, R&D investment has a negative and significant impact on the rate of return on capital, possibly due to declining research efficiency and the relocation of high-productivity factories overseas.

Fourth, in a particularly important result, strongly positive HR-related effects on the rate of return on capital appear in the results for the market economy, despite the rapid decline in HR investments in Japan since 2000.¹⁷

Fifth, complementary effects contribute to the increase in profit rates in the IT industry. Due to the rapid decline in HR investments, however, these effects have little significance in Japan. This result suggests that governments should encourage not only expenditures in HR but also comprehensive investments in intangibles.

17 Fukao and Otaki (1993) provided a model in which conventional capital formation is associated with human capital accumulation. Otaki and Yaginuma (2014) emphasized that skill in human capital is crucial for firm growth.

The argument of Benigno and Fornaro (2015) that we cannot rely on an aggregate demand policy but need an aggressive innovation policy to end the current stagnation is supported by the policy implications of our estimation results. Indeed, an aggregate demand policy implemented through an increase in wages would fail to induce aggressive capital formation. We need a bold innovation policy that includes not only accumulation in HR but also organizational reforms that can vitalize the complementary effects between intangibles.

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Appendix Table 1: Data Definition

Variables	Definitions	Constructions
r_marginal	Marginal rate of return on capital	Capital share $\times$ (Value added / Net capital stock)
r_average	Average rate of return on capital	(Operating surplus + Consumption of fixed capital) / Net capital stock
w	Wage rate	Labor share $\times$ value added / Man-hours
IT	Capital formation in Information Technology (IT)	See Chun et al. (2015)
K _{IT}	IT capital stock	See Chun et al. (2015)
RD	Capital formation in R&D over R&D capital stock	See Chun et al. (2015)
K _{RD}	R&D capital stock	See Chun et al. (2015)
HR	Capital formation in Human Resources	See Chun et al. (2015)
K _{HR}	Human Resources capital stock	See Chun et al. (2015)

Notes: All variables are converted into values in constant prices for 2000. We obtain the data from the JIP2015 database.

Appendix Table 2: JIP Database Industrial Classification in the Market Economy

IT industries	Non-IT industries
9 Seafood products	1 Rice, wheat production
10 Flour and grain mill products	2 Miscellaneous crop farming
17 Furniture and fixtures	3 Livestock and sericulture farming
20 Printing, plate making for printing and bookbinding	4 Agricultural services
21 Leather and leather products	5 Forestry
22 Rubber products	6 Fisheries
23 Chemical fertilizers	7 Mining
24 Basic inorganic chemicals	8 Livestock products
25 Basic organic chemicals	11 Miscellaneous foods and related products
27 Chemical fibers	12 Prepared animal foods and organic fertilizers
28 Miscellaneous chemical products	13 Beverages
29 Pharmaceutical products	14 Tobacco
34 Pottery	15 Textile products
38 Smelting and refining of non-ferrous metals	16 Lumber and wood products
40 Fabricated constructional and architectural metal products	18 Pulp, paper, and coated and glazed paper
41 Miscellaneous fabricated metal products	19 Paper products
42 General industry machinery	26 Organic chemicals
43 Special industry machinery	30 Petroleum products
44 Miscellaneous machinery	31 Coal products
45 Office and service industry machines	32 Glass and its products
46 Electrical generating, transmission, distribution and industrial apparatus	33 Cement and its products
47 Household electric appliances	35 Miscellaneous ceramic, stone and clay products
48 Electronic data processing machines, digital and analog computer equipment and accessories	36 Pig iron and crude steel
49 Communication equipment	37 Miscellaneous iron and steel
50 Electronic equipment and electric measuring instruments	39 Non-ferrous metal products
52 Electronic parts	51 Semiconductor devices and integrated circuits
53 Miscellaneous electrical machinery equipment	54 Motor vehicles
56 Other transportation equipment	55 Motor vehicle parts and accessories
57 Precision machinery & equipment	58 Plastic products
59 Miscellaneous manufacturing industries	60 Construction
63 Gas, heat supply	61 Civil engineering
67 Wholesale	62 Electricity
68 Retail	64 Waterworks
69 Finance	65 Water supply for industrial use
70 Insurance	66 Waste disposal
78 Telegraph and telephone	71 Real estate
79 Mail	73 Railway
81 Research (private)	74 Road transportation
85 Advertising	75 Water transportation
86 Rental of office equipment and goods	76 Air transportation
88 Other services for businesses	77 Other transportation and packing
90 Broadcasting	87 Automobile maintenance services
91 Information services and internet-based services	89 Entertainment
92 Publishing	94 Eating and drinking places
93 Video picture, sound information, character information production and distribution	95 Accommodation
96 Laundry, beauty and bath services	97 Other services for individuals

Net Investment and Stocks of Human Capital in the United States, 1975-2013

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ABSTRACT

This article continues the research initiated in Christian (2010, 2014) on measurement of human capital stocks and investment in the United States. It develops estimates of a series of human capital stock and net investment from 1975 to 2013, using the lifetime earnings approach of Jorgenson and Fraumeni (1989, 1992). The series decomposes net investment into investment from births, investment in education net of aging of persons enrolled in school, depreciation from aging of persons not enrolled in school, depreciation from deaths, and a residual term that includes net migration and measurement error. The study also discusses the cost-based approach of measurement in human capital of Kendrick (1976) and compares investment in education between the cost and income approaches. The stock of human capital rose at an annual rate of 1.0 per cent between 1977 and 2013, with population growth as the primary driver of human capital growth. Per capita human capital remained much the same over this period, with the effect of greater levels of education being offset by the effect of an aging population.

Accounting for human capital continues to be one of the liveliest topics in national accounts. The stock of human capital measures the long-term productive capacity of a population or workforce. Activities that add to this stock, such as education, are identified as investment in human capital, and are valued at the extent to which they increase the human capital stock. Boarini *et al.* (2012) identify several reasons for persistent interest in human capital, including as an avenue to a more complete understanding of

productivity and economic growth, as a broader measure of capital for assessing the sustainability of economic development, as an alternative approach to measuring the output and productivity of the education sector, and as an indicator of overall economic well-being.²

This study continues the research of Christian (2010, 2014) and develops estimates of a series of human capital from 1975 to 2013 using the income-based approach of Jorgenson and Fraumeni (1989, 1992). The estimates include

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2 Liu and Fraumeni (2014) review conceptual and practical aspects of human capital and its prospective employment in national accounts.

human capital embodied in persons of all ages, including children, persons of working age, and persons of retirement age, whether currently in the labour force or not. The primary data set used in producing the estimates is the March demographic and October school enrollment supplements of the Current Population Survey. The stock of human capital rose at an annual rate of 1.0 per cent between 1977 and 2013, with the effect of greater levels of education, which increases the stream of earnings produced over the remaining lifetime of the existing population, being offset by the effect of an aging population, which reduces this stream of earnings. Per capita human capital remained much the same over this period, with the effect of greater levels of education being offset by the effect of an aging population. While net investment in education rose annually by 1.0 per cent per year, net investment in human capital as a whole declined between 1977 and 2013, with depreciation from aging increasing substantially over this period. The series presented includes both a market component based on lifetime market earnings (which is what is used to measure the above growth rates), as well as a non-market component based on lifetime non-market production. It also breaks out "active" human capital, which is comprised of persons of working age and older, separately from "nascent" human capital, which is comprised of children younger than working age.

The study also discusses the cost method of human capital, most commonly associated with Kendrick (1976). It compares income-based and cost-based estimates of investment in education, with the former typically being about three times greater than the latter. Interestingly, when GDP is measured using income-based measures of investment in education as an alternative to the cost-based consumption measures in the official GDP estimates, the extent of the decline

in GDP in the Great Recession is mitigated by a modest degree.

The two sections that immediately follow briefly discuss alternative approaches to human capital measurement and review recent efforts in measurement of human capital. The main results of the study are in the section entitled "Updated and Extended Income-Based Measures of Human Capital for the United States". This section presents new measures of human capital in the United States from 1975 to 2013 using a method based on the income-based approach of Jorgenson and Fraumeni (1989, 1992). The last three sections discuss cost-based approaches to human capital, illustrate the implications of human capital investment measures for education with respect to the Great Recession, and present possibilities for future research.

Methods for Measuring Human Capital

Human capital can be measured in several different ways. The most commonly applied method is the lifetime income approach of Jorgenson and Fraumeni (1989, 1992). The lifetime income approach measures the stock of human capital using an estimate of the lifetime earnings in present discounted value of all persons in a population. Net investment in human capital is measured as the impact of events that either increase (births, education, immigration) or reduce (deaths, aging, emigration) the total lifetime income of a population. The Jorgenson-Fraumeni model requires data on population, average earnings, and school enrollment rates by age, sex, and education, as well as data on survival rates by age and sex. It also requires specifying a real per capita income growth rate, which makes it possible to project average earnings into the future, and a discount rate, which makes it possible to combine current and projected future earnings into a single measure of lifetime

income in present discounted value. While the original Jorgenson-Fraumeni paper measured both a market and non-market component to human capital, most applications of human capital focus only on the market component.

An alternative to the lifetime income approach is the cost approach (Kendrick, 1976). This approach measures investment in human capital by the cost of producing it. Kendrick includes in human capital investment the costs of rearing children to working age, education and training, health and safety (although only in part, attributing the other part to maintenance), and job search, hiring, migration, and other costs associated with labour mobility. From accumulated investment over time, appropriately depreciated, a stock of human capital can be measured. Recent applications of the cost approach, such as Kokkinen (2011) and Gu and Wong (2015), have focused on the cost of education. A cost-based measure of human capital, based on per capita accumulated educational expenditure, is a component of the Index of Economic Well-Being produced by the Center for the Study of Living Standards (CSLS) (Osberg and Sharpe, 2011).

A third approach is the indicators approach, which measures human capital using an indicator or group of indicators, such as average years of schooling or literacy rate (OECD, 1998). A fourth approach is the indirect approach, which is employed by the World Bank (2011). This approach measures intangible capital, which is equal to the difference between a country's future consumption stream in present discounted value and the value of its physical capital and natural capital. Intangible capital includes human capital and social/institutional capital.

Recent Research in Human Capital

The OECD Human Capital Project

One of the most ambitious recent projects in human capital is the Human Capital Project of the Organization for Economic Co-operation and Development (OECD) (Liu, 2014). It measures the stock of human capital over time between 1997 and 2007 in 16 countries, including the United States, with the years covered differing from country to country by data availability. The approach used is the lifetime income approach of Jorgenson and Fraumeni (1989, 1992), which will be henceforth described simply as Jorgenson-Fraumeni. While the original Jorgenson-Fraumeni papers (and this study) measure a version of the human capital stock that includes all persons, including children, the OECD project focuses specifically on human capital embodied in persons of working age, defined as persons ages 15 to 64. This is referred to by Li *et al.* (2010) as "active" human capital.

Country-specific Studies in Human Capital

Recent studies that measure human capital for individual countries have overwhelmingly employed the lifetime income approach. These include studies for Argentina (Coremberg, 2010); Australia (Wei, 2004, 2008); Canada (Gu and Wong, 2010, 2015); China (Li *et al.*, 2010); India (Gundimenda *et al.*, 2006); Mexico (Coremberg, 2015); the Netherlands (Rensman, 2013); New Zealand (Le, Gibson, and Oxley, 2006); Norway (Liu and Grecker, 2009); Sweden (Ahlroth, Bjorklund, and Forslund, 1997); the United Kingdom (Jones and Chiripanhura, 2010); and the United States (Christian, 2010, 2014).

Some individual country studies employ the cost method, such as Kokkinen's (2011) study for Finland and Gu and Wong's (2015) study for

Canada. Both of these studies focused on investment in education. Gu and Wong (2015) measured investment in education in Canada using both the lifetime-income and the cost method for comparison, and compared real growth in educational investment over the 1975-2005 period between the two approaches.

In 2013, the United Nations Economic Commission for Europe (UNECE) established a Task Force on Measuring Human Capital with the purpose of creating guidelines and best practices for countries to establish satellite accounts for human capital. This task force produced a guide that was published in December 2016 (United Nations Economic Commission for Europe, 2016).

Updated and Extended Income-Based Measures of Human Capital for the United States

Using data from the Current Population Survey, I have updated and extended the human capital series in Christian (2010, 2014) to cover the 39 year period between 1975 and 2013. The extended series includes both market and non-market components, and both nominal and real measures. This series makes it possible to identify longer-term trends in human capital that cover multiple generations. It also overlaps with the original lifetime-income-based human capital measures of Jorgenson and Fraumeni.

Method

The lifetime income approach of measuring human capital, developed by Jorgenson and Fraumeni, measures the stock of human capital as equal to the total lifetime income in present discounted value of a population. The approach begins by measuring average lifetime income by year, age, sex, and level of education, which is done by starting at the oldest (or topcoded) age in the population for which human capital is

measured and working backwards. In the results presented in this article, age is topcoded at 80. Lifetime income at age 80 and older is equal to:

$$i_{y,s,80+,e} = [1-(1+\rho)^{-1}(1+g)sr_{y,s,81+}]^{-1}y_{y,s,80+,e}$$

where

$i_{y,s,a,e}$ = lifetime income in year y of persons of sex s , age a , and years of education e

$y_{y,s,a,e}$ = yearly income in year y of persons of sex s , age a , and years of education e

$sr_{y,s,a}$ = survival rate in year y of persons of sex s from age $a-1$ to age a

ρ = discount rate

g = income growth rate

The above equation is the sum of an infinite series equal to expected lifetime income in present discounted value of a person who has an annual probability of survival of $sr_{y,s,a}$, who conditional on survival receives an income that starts at $y_{y,s,80+,e}$ and grows at a rate of g each year, and who discounts future earnings at an annual rate of ρ . This is different from the original Jorgenson-Fraumeni papers, which set lifetime income to zero for people at the maximum measured age, but it is an appropriate and inclusive adaptation given that people at age 80 or older do earn income.

At all other ages, lifetime income is equal to:

$$i_{y,s,a,e} = y_{y,s,a,e} + (1+\rho)^{-1}(1+g)sr_{y,s,a+1} \times \left[senr_{y,s,a,e} i_{y,s,a+1,e+1} + (1-senr_{y,s,a,e}) i_{y,s,a+1,e} \right]$$

where

$senr_{y,s,a,e}$ = school enrollment rate in year y of persons of sex s , age a , and years of education e .

This is the sum of yearly income and the present discounted value of expected lifetime income one year later. The second term on the

right-hand-side of the above equation is equal to current lifetime income of people one year older, adjusted for discounting, income growth, probability of survival, and probability of increasing educational attainment. This approach projects income in the future by age, sex, and level of education using income in the present, multiplied by an income growth rate. It also projects school enrollment in the future using school enrollment in the present. In the model used in this article, the probability of school enrollment is assumed to be zero for persons younger than 5 or older than 34. In addition, yearly income is assumed to be zero for persons younger than 15. This was the case in the original Jorgenson-Fraumeni papers as well, except that (consistent with Census definitions at the time) persons were able to earn income at age 14.

The approach described above is used to compute lifetime market income and lifetime non-market income. Yearly market income is set to average pre-tax wage, salary, and self-employment earnings by age, sex, and education. This is different from the original Jorgenson-Fraumeni approach, which used post-tax compensation; however, given that human capital is ultimately a measure of the productive capacity of a population, pre-tax earnings, which measure the value of labour to producers of goods and services, is the more appropriate measure. An even more appropriate measure of yearly income may be pre-tax compensation, which would include the value of benefits and employer contributions to social security. These aspects of compensation are difficult to capture using the data set used in this study, the Current Population Survey. However, one could approximate the extent to which human capital is undermeasured by the use of

earnings alone by using the overall, economy-wide ratio of wages, salaries, and self-employment income to total labour compensation.³

Yearly non-market income is set to the amount of time spent in household production multiplied by the average post-tax wage by age, sex, and education, where the tax rate used is the marginal tax rate. The post-tax wage is used because household production is produced by persons whose opportunity cost is equal to the value to them of additional time spent in market work. Time spent in household production is time not spent at work, in school, or in personal maintenance, which implicitly defines household production as all activities other than work, school, or personal maintenance. Time spent in school is assumed to equal 1300 hours per year for persons enrolled in school, while time spent in personal maintenance is assumed to equal 10 hours per day for all persons.

The stock of human capital (hc_y) is equal to the sum of lifetime income across all persons. This can be expressed simply as:

$$hc_y = \sum_s \sum_a \sum_e (pcount_{y,s,a,e} \times i_{y,s,a,e})$$

where

$pcount_{y,s,a,e}$ = population in year y of persons of sex s , age a , and years of education e .

This can be measured for market income only, for non-market income only, or for the two combined. When measuring the stock of human capital in real terms, the quantity is the population $pcount_{y,s,a,e}$ and the weight is lifetime income $i_{y,s,a,e}$. Under this approach, the volume of human capital changes with the size and distribution of the population by age, sex, and education, using lifetime income as the marginal rate of substitution across age, sex, and educa-

3 When this ratio is measured using the National Income and Product Accounts (NIPAs) of the U.S. Bureau of Economic Analysis, it increases steadily from 1.15 in 1975 to 1.21 in 1992, and remains around 1.2 since then. This is computed using Table 2.1 of the NIPAs, as the ratio of the sum of compensation and proprietor's income to the sum of wages and salaries and proprietor's income.

tion. In the results in this article, the volume of the stock of human capital is measured using a chained Fisher index, which is converted to constant 2013 dollars by multiplying by the stock's nominal value in 2013.

Changes in nominal human capital can be broken down into net investment and revaluation as follows:

$$hc_{y+1} - hc_y = \sum_s \sum_a \sum_e [(pcount_{y+1,s,a,e} - pcount_{y,s,a,e}) \times i_{y,s,a,e}] + \sum_s \sum_a \sum_e [pcount_{y+1,s,a,e} \times (i_{y+1,s,a,e} - i_{y,s,a,e})]$$

The first term on the right-hand side of the equality above is net investment: the impact of changes in the size and distribution of the population on the stock of human capital. The second term is revaluation: the change in the nominal human capital stock from switching from the old year's to the new year's measures of lifetime income.

Net investment can further be broken down into different components. In this article, net investment in human capital is broken down into five components:

- a) Investment from births;
- b) Investment from education net of the aging of persons enrolled in school;
- c) Depreciation from aging of persons not enrolled in school;
- d) Depreciation from deaths; and
- e) Residual net investment from migration and measurement error.

This is different in several aspects from the original Jorgenson-Fraumeni papers' approach. One substantial difference is that investment in education is measured net of aging, rather than as gross investment as in Jorgenson and Fraumeni (1992). Investment in education is measured net of aging while in school because it is a more robust measure than a gross measure of investment in education. When investment in education is measured on a gross basis, the resulting measures are often extremely large.

This is because gross investment in education is, for most persons of school age, measured as the difference between the lifetime earnings of people who are completing school on schedule and the lifetime earnings of people who are a year behind schedule. This is typically a very large difference, because students who have fallen behind have a considerably higher likelihood of dropping out of school completely. Measuring investment in education on a gross basis assumes that this difference is the return to a single year of education for everyone — the difference between lifetime trajectories with substantially different likelihoods of diploma or degree completion.

This is not necessarily an appropriate assumption, however. An alternative assumption is that people who actually attended school would, had they missed a year for exogenous reasons, just pick up where they left off a year later. Under this assumption, gross investment in education becomes much smaller (Christian, 2010). The above discussion is for a model where aging takes place before education, i.e. people enrolled in school move up one year in age and then move up one year in education. In the original Jorgenson-Fraumeni papers, education takes place before aging, which mitigates the size of gross investment, since the approach compares the lifetime incomes of people on schedule in their education with those of people one year ahead of schedule rather than one year behind it. However, the approach still compares the lifetime incomes of people on different educational trajectories and yields very large results.

Measuring investment in education net of aging does not require making quite such a strong counterfactual assumption, because it measures investment in education for enrolled persons as the total change in lifetime income from having an additional year of education and from being a year older. This is not the difference between staying on track or falling behind

(or moving unusually ahead) in one's education; rather, for school-aged people, it is the difference of moving one year further along a typical course of education. As a result, it does not require making an assumption about what would happen if a person who was on the typical course of education were to exogenously deviate from it. This yields a more robust measure with a smaller magnitude.

Residual net investment is another measure used in this article but not in the original Jorgenson and Fraumeni accounts. It is net investment that cannot be attributed to births, deaths, education, or aging. It likely has two components. The first is migration: people enter and leave a country, changing both the size and distribution of the country's population by age, sex, and education. The second, however, is measurement error. The data on births, deaths, education, and population are not constrained to perfectly match each other, and any additive frictions will also be reflected in the residual net investment measure.

Investment and depreciation are measured in real terms using chained Fisher volume indices, which are converted to constant 2013 dollars by multiplying by nominal values in 2013. Real net investment is computed by subtracting the real human capital stock from the following year's real human capital stock, and residual net investment is computed by starting with real net investment, subtracting investment from births and education, and adding depreciation from deaths and aging.

Data

The primary data sets used to produce the human capital measures are, as in Christian (2010, 2014), the October and March supplements of the Current Population Survey (CPS). The October supplements from 1975 to 2014 are employed to estimate population and school enrollment in the United States by age, sex, and

individual year of education. The March supplements from 1976 to 2014 are employed to estimate average number of hours worked and average hourly earnings by age, sex, and individual year of education.

Until 1991, the CPS measured educational attainment using individual years of education, with no education as the lowest measured level of education and 18 years of education as the highest. Beginning in 1992, the CPS switched its measure of educational attainment to one that emphasized degrees and credentials earned: high school diploma, some college-no degree, some college-associate's degree, bachelor's degree, master's degree, etc. In 1998, the CPS added additional questions that made it relatively easy to measure reasonably well educational attainment by individual year. From 1992 to 1997, however, it was necessary to impute the distribution by individual years of education of population, hours worked, and wages from the information about credentials earned only.

One implication of using the October CPS to compute school enrollment rates in the Jorgenson-Fraumeni models is that it is assumed that all students who are enrolled in October will complete a year of education by the end of the school year. This will lead to some overestimation of investment in education, since some students will drop out between October and the following June.

Federal and state marginal income tax rates for people in the March sample are computed using the Internet version of TAXSIM (v9), hosted at the web site of the National Bureau of Economic Research (Feenberg and Coutts, 1993). TAXSIM computes state marginal tax rates only as far back as 1977; they were imputed for 1975 and 1976 using the federal marginal tax rate and the coefficients from a regression of state marginal tax rates on federal marginal tax rates in 1977.

Table 1: Market Human Capital Stock and Net Investments in the United States, 1977 and 2013 (trillions of dollars)

	1977		2013	1977-2013
	Nominal	Real (2013\$)	Nominal	Annual pct. change, real
Human capital stock	\$41.1	\$169.2	\$239.4	1.0
Net investment in human capital	\$0.4	\$1.8	\$1.2	-1.1
Investment from births	\$0.7	\$2.9	\$3.5	0.5
Investment from education, net of aging	\$0.6	\$3.0	\$4.2	1.0
Depreciation from aging, non-enrolled	\$0.8	\$3.5	\$6.2	1.6
Depreciation from deaths	\$0.1	\$0.4	\$0.5	0.3
Residual net investment	\$0.0	\$-0.2	\$0.2	

Source: Author's calculations.

The population and school enrollment aggregates by year, age, sex, and educational attainment computed using the October CPS are adjusted before analysis to match reported aggregates. Population aggregates are adjusted to match January population estimates by the Bureau of the Census; estimates from January are chosen to correspond to annual measures of births and deaths based on the calendar year. The population estimates include all persons in the United States, including persons serving overseas in the Armed Forces; it is useful to note that this is different from the civilian non-institutional population (including children) universe of the CPS. School enrollments are adjusted to match elementary, secondary, and college enrollment results reported in the *Digest of Education Statistics* published by the U.S. Department of Education. The adjustments are made using a simple multiplicative factor applied to all age/sex/education groups.

Death rates by age and sex are measured using life tables from the Centers for Disease Control (CDC) and adjusted to match counts of deaths from the CDC. Births are also measured using counts from the CDC. The real per capita income growth rate is assumed to be 2 per cent

per year, and the discount rate is assumed to be 4 per cent.

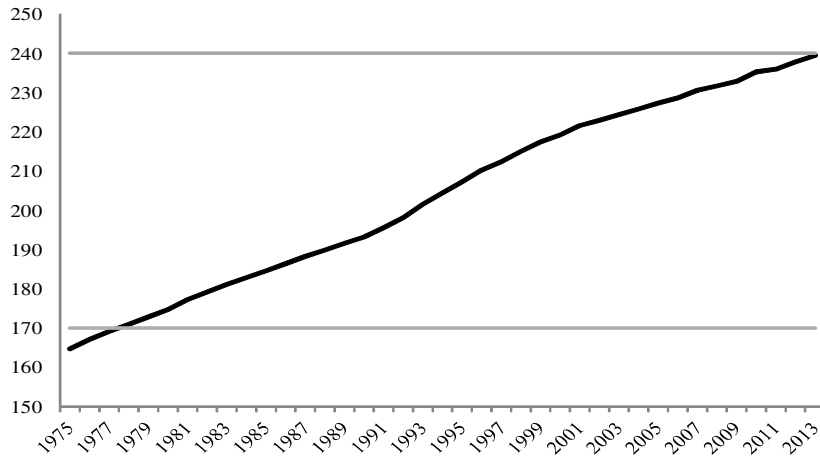
Income-based human capital measures, 1975-2013

Table 1 presents a summary of the market component of human capital using the income approach in the United States between 1977 and 2013. While the estimated series of human capital extends backward to 1975, the years 1977 and 2013 were chosen for comparison because both were at similar points in the business cycle — at an early point in recovery from a substantially large recession. The market component of human capital is presented because it is the aspect of human capital that is the focus of recent applications.

The market component of the human capital stock is about one-third of the combined market and non-market human capital stock. The proportion of the total human capital stock that is in the market component has declined steadily over the time period covered, from a peak of 33 per cent in 1977 to a low of 29 per cent in 2013.⁴ As can be seen in Table 1, the market component of the human capital stock has increased at an average annual rate of 1.0 per cent between 1977

4 While the market-to-non-market ratio of the stock of human capital has declined overall, the change has been in two different directions for men and for women. Between 1977 and 2013, the proportion of the human capital stock that is in the market component declined from 41 per cent to 34 per cent among men, but increased from 20 per cent to 24 per cent among women.

Chart 1: Market Component of Stock of Human Capital in the United States, 1975-2013
(trillions of constant 2013 dollars)



Source: Author's calculations.

and 2013. Net investment in human capital declined between 1977 and 2013 at an annual rate of 1.1 per cent, although, given the year-to-year volatility of the total net investment estimate (see Chart 3 below), this likely overstates the long-run downward trend. An alternative approach to measuring long-run change, which regresses log net investment on a time trend and is more robust to year-to-year volatility, measures a long-run annual rate of decline in real net human capital investment of 0.5 per cent per year.

Chart 1 presents the real stock of the market component of human capital for each year between 1975 and 2013, using a chained Fisher volume index. For the most part, the trend is of a steady rise over this period, with an acceleration during the 1990s and a slowdown in the twenty-first century.

The real stock of human capital can be straightforwardly decomposed across the size and distribution of the population by age, sex, and education if a Paasche or Laspeyres volume index is used to measure it in real terms. Since the real human capital stock is only trivially different across chained Fisher, Paasche, and Laspeyres indices, the switch to a Paasche for a

decomposition of changes from year to year is a reasonable choice. Let $pcount_{y,s(y'),a(y''),e(y''')}$ be equal to the population by sex, age, and education given:

- total population at time y ;
- distribution of population across sex at time y' ;
- distribution of population within sex and across age at time y'' ;
- distribution of population within sex and age and across education at time y''' .

Growth in human capital using a Paasche volume index can be decomposed as follows:

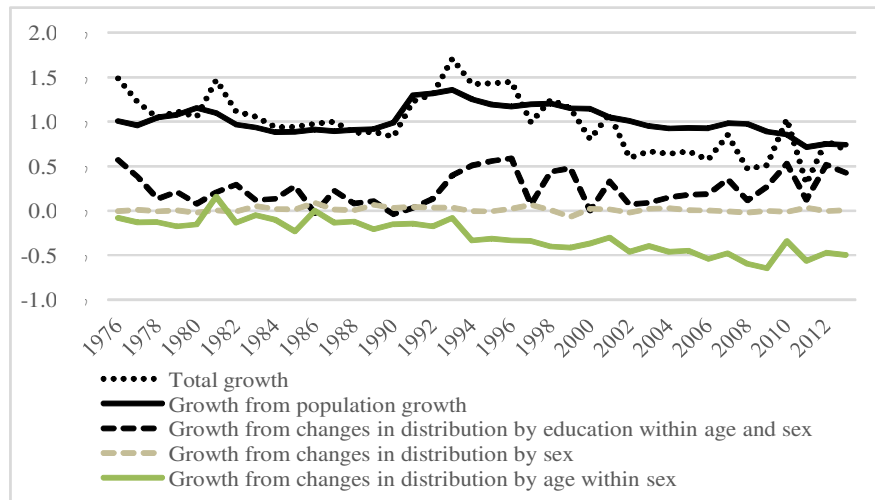
$$\begin{aligned} \text{Total growth} &= \sum_s \sum_a \sum_e [(pcount_{y+1,s,a,e} - pcount_{y,s,a,e}) \times i_{y+1,s,a,e}] / \sum_s \sum_a \sum_e (pcount_{y,s,a,e} \times i_{y+1,s,a,e}) \end{aligned}$$

$$\begin{aligned} \text{Growth from population growth} &= \sum_s \sum_a \sum_e [(pcount_{y+1,s(y),a(y),e(y)} - pcount_{y,s,a,e}) \times i_{y+1,s,a,e}] / \sum_s \sum_a \sum_e (pcount_{y,s,a,e} \times i_{y+1,s,a,e}) \end{aligned}$$

Growth from changes in the distribution of population by sex

$$\begin{aligned} &= \sum_s \sum_a \sum_e [(pcount_{y+1,s(y+1),a(y),e(y)} - pcount_{y+1,s(y),a(y),e(y)}) \times i_{y+1,s,a,e}] / \sum_s \sum_a \sum_e (pcount_{y,s,a,e} \times i_{y+1,s,a,e}) \end{aligned}$$

Chart 2: Annual Changes in the Real Market Human Capital Stock in the United States, 1976-2013, (per cent)



Source: Author's calculations.

Growth from changes in the distribution of population by age within sex

$$= \sum_s \sum_a \sum_e [(pcount_{y+1,s(y+1),a(y+1),e(y)} - pcount_{y+1,s(y+1),a(y),e(y)}) \times i_{y+1,s,a,e}] / \sum_s \sum_a \sum_e (pcount_{y,s,a,e} \times i_{y+1,s,a,e})$$

Growth from changes in the distribution of population by level of education within age and sex

$$= \sum_s \sum_a \sum_e [(pcount_{y+1,s,a,e} - pcount_{y+1,s(y+1),a(y+1),e(y)}) \times i_{y+1,s,a,e}] / \sum_s \sum_a \sum_e (pcount_{y,s,a,e} \times i_{y+1,s,a,e})$$

This decomposition does rely on a specific order in which population, sex, age, and education are approached. However, the order employed is a logical one. Population, unlike sex, age, and education, is a measure of size rather than distribution, and so it makes sense to approach it first. Sex is unlikely to be relevant at all given that its distribution does not change much over time, and so its placement is not especially relevant. Since education is substantially determined by age among persons of high school age or younger, it makes sense to decompose by age before education.

Chart 2 presents a graphical decomposition of yearly changes in human capital by population,

age, sex, and education over the 1975-2013 period using the Paasche volume index decomposition described above. A more detailed accounting of changes in the stock of human capital between 1977 and 2013 is presented in Table 2. This table breaks down changes in aging and in education across three age groups: pre-working-age (14 and younger), working-age (ages 15 to 64), and post-working-age (65 and older). Given the relatively long period of time, results in Table 2 are presented using both 1977 and 2013 lifetime incomes as fixed weights.

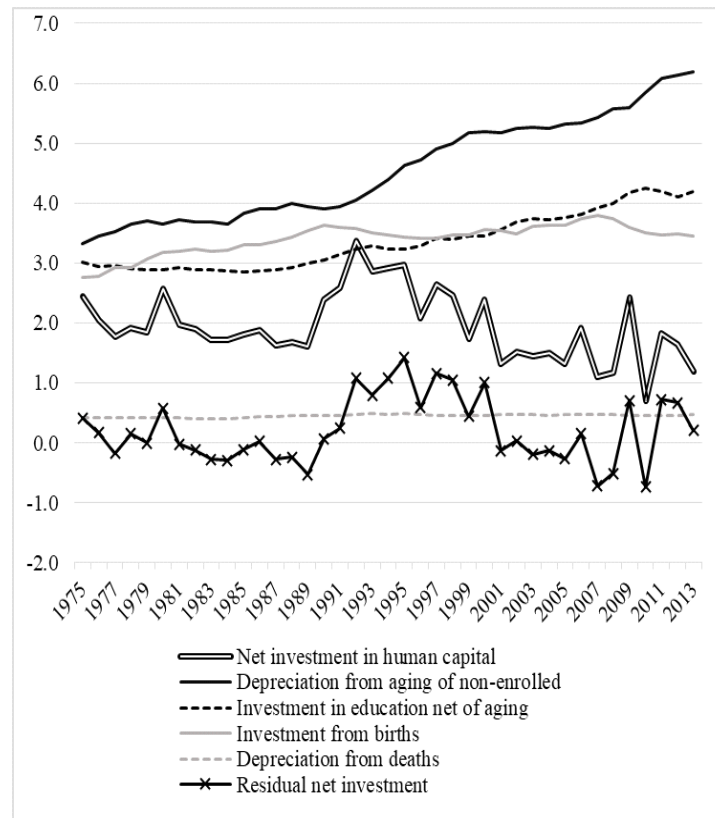
Between 1977 and 2013, the dominant driver of change in the stock of human capital was population growth. The second most important driver of change in human capital was an increase in the education level of working-age persons, which has a positive effect on human capital growth given that people with more education have higher lifetime incomes. The third most important driver was an increase in the average age of working-age persons, which has a negative effect on human capital growth given that older people have fewer working years remaining and lower lifetime incomes. The

Table 2: Decomposition of Total Growth in the Real Market Human Capital Stock in the United States, 1977-2013 (per cent change)

	1977 weights	2013 weights
Total cumulative growth	39.8	42.0
Population growth	44.0	44.0
Distribution by sex	0.9	0.5
Distribution by age within sex	-16.5	-18.2
Between age groups (0-14,15-64,65+)	-6.5	-7.3
Between children and adults (0-14,15+)	-2.0	-3.2
Between adults (15-64,65+)	-4.5	-4.2
Within age groups	-9.9	-10.9
Within children (0-14)	-0.2	-0.3
Within working-age adults (15-64)	-9.7	-10.5
Within post-working-age adults (65+)	0.0	-0.1
Distribution by level of education within age and sex	11.2	15.7
Within children (0-14)	-0.7	-0.8
Within working-age adults (15-64)	11.5	15.8
Within post-working-age adults (65+)	0.4	0.7

Source: Author's calculations.

Chart 3: Investment in Market Component of Human Capital in the United States, 1975-2013 (trillions of constant 2013 dollars)



Source: Author's calculations.

Table 3: Human Capital Stock and Investment in Education, Market and non-Market in the United States, Comparison with Jorgenson-Fraumeni, billions of current dollars.

Year	Human capital stock IG: 2% D: 4%		Human capital stock IG: 1.32% D: 4.58%		Investment in education IG: 1.32% D: 4.58%	
	Jorgenson-Fraumeni (1989)	New Series	Jorgenson-Fraumeni (1992)	New Series	Jorgenson-Fraumeni (1992)	New Series
1975	95,046	111,020	114,568	86,505	1,792.7	2,230.6
1976	103,214	119,993	121,760	93,508	1,825.5	2,505.8
1977	110,042	122,484	133,148	95,597	1,883.6	2,248.8
1978	122,024	130,473	146,260	102,049	1,991.9	2,455.2
1979	136,288	146,002	159,836	114,389	2,113.1	2,456.4
1980	142,516	157,640	171,254	123,551	2,346.6	2,579.2
1981	154,260	170,425	186,814	133,582	2,515.9	2,701.0
1982	166,990	187,872	198,951	147,107	2,834.9	3,108.5
1983	179,555	204,263	210,240	159,709	2,975.4	3,521.3
1984	193,829	215,685	225,320	168,665	3,171.2	3,829.2
1985	N/A	226,050	242,713	177,158	3,359.3	4,248.0
1986	N/A	241,262	268,567	188,764	3,779.0	4,663.8

Source: Jorgenson and Fraumeni (1989,1992); author's calculations.

Note: Results adjusted to match modeling in Jorgenson-Fraumeni as described in the text. In the column labels, IG is the income growth rate, while D is the discount rate.

impacts of education and aging have for the most part offset each other over this time period.

Chart 3 graphically presents the time series of investment in human capital from 1975 to 2013, breaking down net investment into five components: investment from births, depreciation from deaths, investment from education net of aging of persons enrolled in school, depreciation from aging of persons not enrolled in school, and residual net investment, which includes both migration and measurement error. The most apparent result is the growth of depreciation from aging since the early 1990s. The volatility of the residual component — which, in turn, creates volatility in the complete net investment measure — is likely to be a result of measurement error from measures on births, deaths, and education during the course of a year not perfectly lining up with measures of popula-

tion by age, sex, and education at the beginning of the year.

Comparison to Jorgenson-Fraumeni

The new human capital series presented here extends far enough back that it can be compared to the original results of Jorgenson and Fraumeni. However, the series is different in several aspects. In order to make the results in the new series more comparable to those in the original Jorgenson-Fraumeni series, the following adjustments were made to the new series:

- Measures combine both market and non-market components of human capital;
- Investment in education is measured as gross investment, rather than net of aging of people enrolled in school;
- Market lifetime income is measured using post-tax earnings rather than pre-tax earn-

ings, where the tax rate employed is an average tax rate;

- Earnings and value of non-market time are set to zero after age 75;
- The highest level of education is set to 17 years rather than 18 years;
- Results are adjusted using a constant multiplier to reflect total compensation rather than just wages, salaries, and self-employment income;
- The income growth rate is set to 1.32 per cent and discounting is set to 4.58 per cent for comparisons with results in Jorgenson and Fraumeni (1992).

The results of the comparison are presented in Table 3. The human capital stock results from this study roughly match measures of the human capital stock in Jorgenson and Fraumeni (1989). In contrast, this study estimates a substantially lower human capital stock than Jorgenson and Fraumeni (1992), but roughly match measures of gross investment in education.⁵

Active Human Capital

Many studies of human capital, including the OECD project, focus on the human capital of people of working age only, described in Li *et al.* (2010) as "active" human capital. The logic behind measuring active human capital is that a measure of human capital should only include people who are available to work. Jones and Chiripanhura (2010) note that this mirrors the idea of measuring physical capital in a way that only includes physical capital that is currently able to be deployed in production.

Table 4 splits human capital measures between "active" human capital, which includes persons

ages 15 and older, and "nascent" human capital, which includes persons ages 14 and younger.

The proportion of the human capital stock that is active has increased over time, from 70 per cent in 1977 to 73 per cent in 2013. People who are above "working age", which is often defined as people age 65 and older, are included in the measure of active human capital because the accounts presented here do take into account labour force participation by older people.

Separating investment in human capital between active and nascent human capital involves adding a new component to investment. When people turn 15 years old, they leave the nascent stock and enter the active stock. As a result, all human capital embodied in them is transferred from the nascent stock to the active stock. This transfer needs to be added as a component to net investment in both active and nascent human capital, as investment in the former and as depreciation of equal magnitude in the latter.

Over the 1975-2013 period, net investment in human capital excluding the nascent-to-active transfer is always positive in the nascent stock and is always negative in the active stock. Investment in education net of aging is always between 60 per cent to 67 per cent active and 33 per cent to 40 per cent nascent over this same period. This means that, net of aging of persons enrolled in school, investment in late secondary and post-secondary education is of greater magnitude when measured using lifetime earnings than investment in elementary and early secondary education.

Even if one regards the active human capital stock as the important stock measure, it is none-

5 Fraumeni *et al.* (2015) compare results from 1982 in Jorgenson and Fraumeni (1989) to results from 2009 in Christian (2014) and find substantive differences in several aspects of human capital. These include: the relative magnitudes of human investment, time in household production and leisure, and gross private domestic product; of gross private national human capital formation, gross private national capital formation, and full private national consumer outlays; and of gross private national saving and human capital saving. In contrast, a comparison of results from 1982 and 2009 in the account presented here finds that the relative magnitudes of these aspects have remained relatively similar over time.

Table 4: Active and Nascent Market Human Capital in the United States, 1977 and 2013 (trillions of current dollars)

	1977		2013	
	Active	Nascent	Active	Nascent
Human capital stock	28.6	12.5	175.7	63.7
Net investment in human capital	0.6	-0.2	1.3	-0.2
Investment from births	0.0	0.7	0.0	3.5
Investment from education, net of aging	0.4	0.2	2.8	1.4
Depreciation from aging, non-enrolled	0.8	0.0	6.1	0.1
Depreciation from deaths	0.1	0.0	0.4	0.0
Residual net investment	0.0	0.1	-0.1	0.3
Transfer, nascent to active stock, age 15	1.2	-1.2	5.1	-5.1
Net investment (excluding transfer)	-0.5	1.0	-3.8	5.0

Source: Author's calculations.

theless useful to account for net investment in both the active and nascent stocks. This is because net investment in the nascent stock ultimately accumulates to the active stock as cohorts within the nascent stock reach age 15. The advantage of accounting for investments in the nascent stock is that it will better reflect the timing of the investment.

Lifetime Income

The lifetime-income approach to measuring the human capital stock uses lifetime earnings as the rate of substitution between age, sex, and education. Chart 4 illustrates lifetime earnings, measured using cross-sections from 1977 and 2013, for men and women at different ages and different levels of education.

In both charts, lifetime earnings appear to decline roughly linearly between the ages of 25 and 65 for both men and women at a given level of education. The lifetime return to education is substantially higher in 2013 than in 1977, and, while men have higher measured lifetime earnings in both years, the difference between the

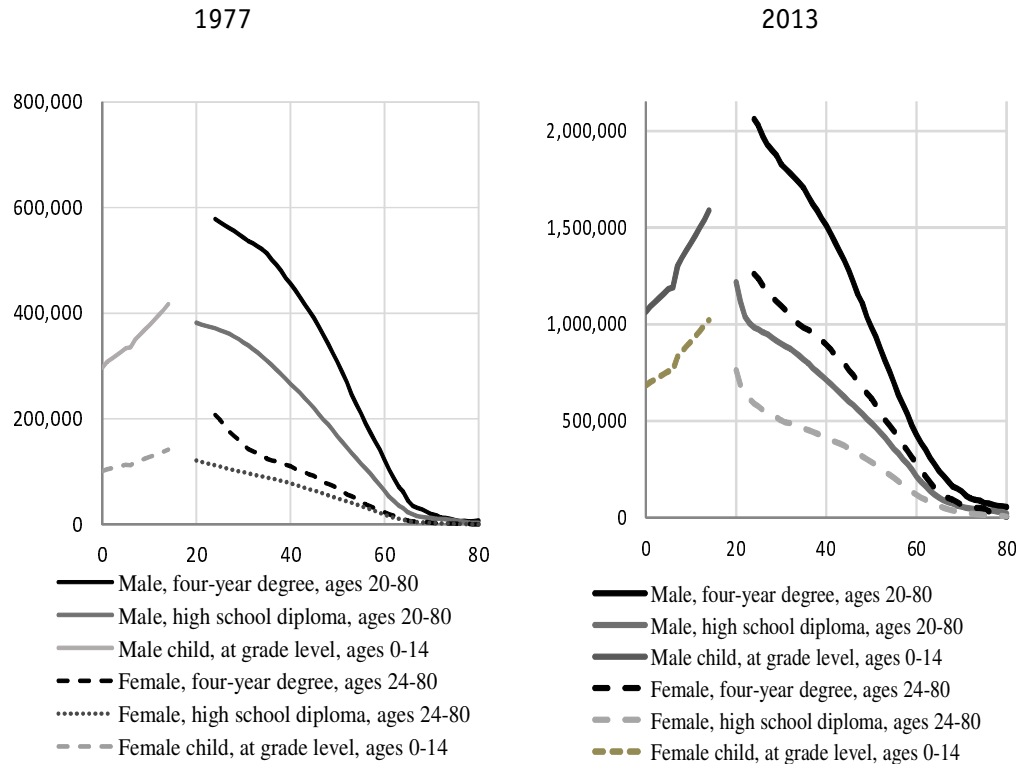
sexes is considerably smaller in 2013. The combination of these two factors reverse the order of lifetime earnings between men with high school diplomas and women with four-year degrees; while measured lifetime earnings were greater among the former using the 1977 cross-section, they are greater among the latter in the 2013 cross-section.

Per Capita Human Capital

The per capita human capital stock captures the composition of the human capital stock by age, sex, and education, using lifetime earnings as the rate of substitution between these characteristics. Per capita human capital is one focus of cross-country comparisons in the OECD human capital project.

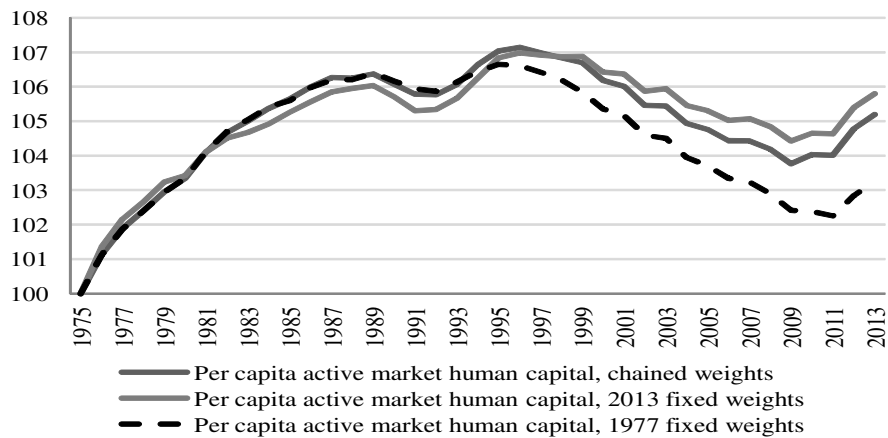
Measures of per capita human capital are most intuitive when measured using the active human capital stock per working-age person, with working age defined as ages 15 to 64. This provides a picture of the composition of the working-age population. People age 65 and older are not included in this measure, since many are

Chart 4: Lifetime Earnings by Sex, Age, and Education in the United States, 1977 and 2013, (current dollars)



Source: Author's calculations.

Chart 5: Per Capita Active Market Human Capital in the United States (1975 = 100)

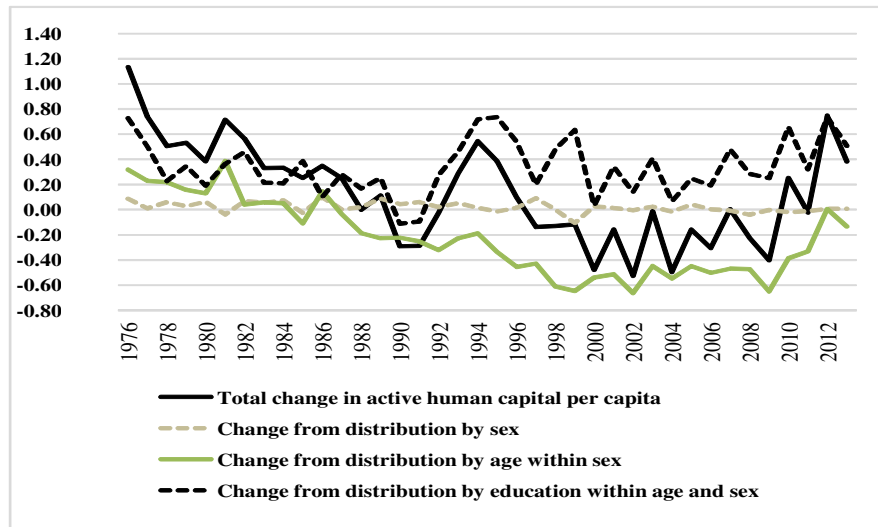


Source: Author's calculations.

retired and purposefully do not work; including them in a measure that attempts to capture the characteristics of the working-age population would be distortionary. Since the definition of working age for the per capita measures do not

include people 65 and older, lifetime earnings are computed for this particular application under the assumption that earnings are zero at age 65 and older.

Chart 6: Annual Changes in Real Per Capita Active Market Human Capital in the United States, 1976-2013 (per cent)



Source: Author's calculations.

Chart 5 presents per capita active market human capital, measured as a chained Fisher quantity index set to 100 in 1975, and alternatively as unchained, fixed-weight Paasche and Laspeyres quantity indices. Chart 6 presents year-to-year changes in per capita active human capital, decomposed into parts explained by changes in the distribution of the population by sex, by age within sex, and by level of education within age and sex, with the decomposition facilitated by using a Paasche quantity index.

The trend in per capita human capital from 1975 to 2013 depends on whether increases in the level of education of working-age people have a positive impact large enough to mitigate the negative impact from increases in the age of working-age people. Liu (2014) finds a similar pattern of aging and education having opposite effects on per capita human capital over time between the mid-1990s and the late 2000s in several countries (including the United States) in the OECD human capital project. For the most part, per capita human capital rises quickly in the late 1970s and 1980s, levels out in the

1990s, declines in the 2000s, and rises again in the early 2010s. Note that changes in per capita human capital over the 1975-2013 period differ depending on whether lifetime incomes from the late 1970s or the early 2010s are used to value it. This is likely because the return to education is considerably higher in the 2010s than in the 1970s (see, for example, the differences between college and high school lifetime earnings in Chart 4 above), since increases in the level of education are the primary positive factor contributing to changes in per capita human capital over this period.

The Stock of Human Capital Relative to GDP and to Fixed Assets

Table 5 on the next page compares the market human capital stock to other aggregates, in particular gross domestic product and the stock of fixed assets. Both total and active human capital declined relative to both aggregates between 1977 and 2013 reflecting the slower growth of the former.

Table 5: Ratio of Market Human Capital to GDP and Fixed Assets in the United States, 1977 and 2013

	Human capital to GDP	Active human capital to GDP	Human capital to fixed assets	Active human capital to fixed assets
1977	19.71	13.72	7.17	4.99
2013	14.34	10.52	4.91	3.60

Source: Author's calculations. GDP and fixed assets measures from the National Income and Product Accounts (NIPA) tables of the Bureau of Economic Analysis of the U.S. Department of Commerce.

Measuring Human Capital Using Cost

Kendrick's Cost Accounting for Human Capital

An alternative approach to accounting for human capital uses the cost of producing human capital rather than the income produced from activities that create human capital. Abraham (2010) notes that the cost and income methods are analogous, respectively, to the income and production sides of national accounts. The most widely cited example of accounting for human capital using cost is Kendrick (1976), which will henceforth be described simply as Kendrick. Kendrick defined human investment as the costs of rearing children to working age, education and training, health and safety, and labour mobility.

Kendrick's cost-based measures of the stock of human capital are substantially lower than the income-based measures of Jorgenson and Fraumeni. Jorgenson and Fraumeni (1989) directly compare them, and find that their income-based measures are typically about fifteen times greater than Kendrick's cost based measures. It is useful to note that the income-based measures in Jorgenson and Fraumeni (1989) combine a market and non-market component, including not only market earnings but also household production. However, inclusion of the non-market component of human capital is not nearly enough to account for this discrepancy.

A recent application of Kendrick's approach is Kokkinen (2011), which measured human capital investment and stock in Finland. Rather than focusing on all aspects of human capital defined by Kendrick, Kokkinen focused on human capital from formal education alone. His approach to human capital investment included only expenditures on education (specifically, in the context of Finland, government expenditures), and did not include foregone earnings. Kokkinen defines the human capital stock as only including the educational capital of persons of working age and outside of school. Under this approach, investments in education for students still enrolled in school are accumulated in an inventory, separate from the human capital stock. At the time of graduation, that accumulated educational investment is moved out of the inventory and into the human capital stock. The human capital stock, when understood this way, is an analogue in the cost method to income-based measures of active human capital. The inventory of human investment accumulated by persons still in school is an analogue to nascent human capital.

Measuring Human Capital Investment Using the Cost Method

Measuring human capital investment using the cost method requires identifying activities as human capital investment and measuring the costs of those activities. For some aspects of some activities, this can be as easy as re-classifying already existing aggregates in national

Table 6: Income- and Cost-based Measures of Investment in Formal Education in the United States, 1977 and 2013 (billions of current dollars)

Year	Cost-based education investment				Income-based education investment	Ratio of income and cost measures
	Personal consumption expenditure	Government consumption expenditure	Value of time spent at school	Total cost of education		
1977	17.7	95.4	73.2	186.3	629.5	3.38
2013	259.7	752.1	412.6	1,424.4	4,193.8	2.94

Source: Author's calculations.

accounts from consumption to investment. For example, to measure investment in formal education, one could re-classify personal consumption expenditures for education (NIPAs Table 2.4.5) and government consumption expenditures for education (NIPAs Table 3.17) as investment. This approach excludes the rental value of capital related to education, as well as the amount of time spent in school or study by students. For other activities, measuring investment requires more effort. To continue with the previous example, suppose one would like to include the value of student time in investment in formal education. This would, at the very least, require measuring the amount of time spent by students in school, computing an appropriate wage rate at which to value that time, and then multiplying the two.

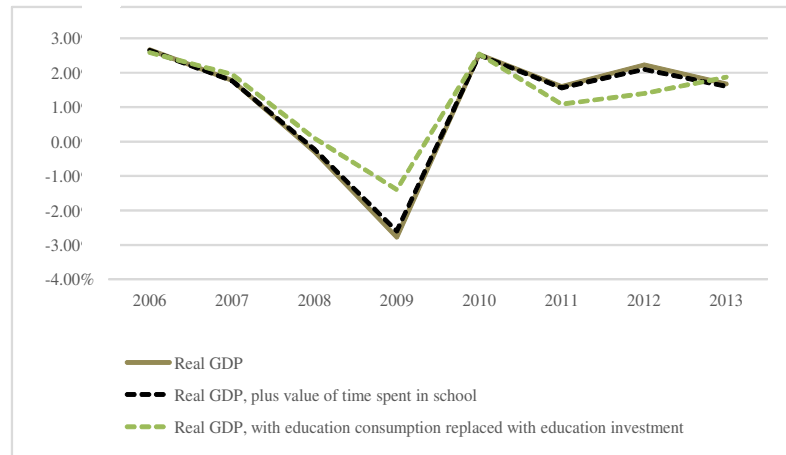
Another example would be if one wanted to exclude the research and public service function of higher education (as distinct from the instructional and student services function) from human capital investment. This would require either starting from more disaggregated data than that in the NIPAs or consulting an alternative data set such as the Integrated Postsecondary Education Data System (IPEDS) to estimate the proportion of aggregated expenditures that would need to be removed.

Ideally, measures of human capital investment that use the cost approach would cover the same activities as measures that use the income approach. Investment in education is an aspect of human capital investment in which cost

approaches and income approaches substantially agree. Both value the act of schooling at the time of schooling, but in different ways—the cost approach by the cost of producing education, and the income approach by the lifetime return to education. Table 6 provides a comparison of human capital investment from formal education using these two approaches. A similar comparison for Canada is in Gu and Wong (2015).

In Table 6, the income measure of investment in education is the market component of investment in human capital from education, as presented in Table 1. The cost measure of investment in education is comprised of personal and government consumption expenditure for education from the NIPAs, plus the value of student time. To compute the value of student time, enrollment by age, sex, and education is multiplied by 1300 hours per full-time equivalent enrolled person, where part-time enrolled persons are treated as one-third of a full-time enrolled person. This yields total hours in school or study by age, sex, and education. The hourly opportunity cost of student time is measured as earnings per hour by age, sex, and education from the March Current Population Survey, multiplied by one minus the combined federal and state marginal tax rate computed by TAXSIM. This is the same post-tax wage rate used in the computation of non-market human capital earlier in this article. It is assumed to be zero for children ages 14 and younger. The total value of student time by age, sex, and education is computed as the product of total hours in

Chart 7: Annual Change in Real GDP Using Different Accounting for Education in the United States, 2005-2013, (per cent)



Source: Author's calculations.

school or study multiplied by the hourly opportunity cost of student time by age, sex, and education. This is summed across age, sex, and education to compute total value of student time.

The income-based measure of investment in formal education in Table 6 is substantially larger than the cost-based measure, suggesting a substantial average surplus from education. Abraham (2010) discusses the frequently-noted differences between income- and cost-based measures of investment in education in detail. She notes that "[i]n contrast to the market accounts, where money spent on purchases for final demand must flow into someone's pocket as income, there is no conceptual identity between returns and costs for investment in education." Abraham suggests that one appealing way to include this difference in accounts is as profit to the household sector, although she also notes that the size of the difference may suggest measurement problems, such as possible overstatement of the returns to formal education in income-based measures.

Human Capital Investment and the Great Recession

According to the investment series presented in Chart 3, real market human capital investment in education peaks in 2010, which was also a peak year for the unemployment rate in the Great Recession. The increase in investment in education is driven by an increase in enrollment in higher education, which is historically countercyclical (Dellas and Sakellaris, 2003; Christian, 2007).

Given that alternative approaches to measuring investment in education tend to yield larger estimates than those in the NIPAs, it is possible that measures of overall output that use these alternative approaches will be less cyclical. Chart 7 shows year-to-year changes in GDP using two alternative approaches.

The first alternative approach simply adds the value of time spent in school or study to GDP. This is an implication of the cost approach to measuring investment in human capital, which otherwise typically re-classifies educational expenditure from consumption to investment within GDP. The value of time is measured as in Table 6 above. It is measured in real terms as a chained Fisher volume index of full-time equiv-

alent enrollments, using the opportunity cost of enrollment as a weight, then reflat to constant (2009) dollars. This is added to real GDP. The impact on year-to-year change of adding the value of student time on GDP is small. The total two-year drop in GDP from 2007 to 2009, which is -3.1 per cent in official real GDP, is mitigated only to -2.8 per cent when student time is included. This result is not surprising, since the value of time spent in school or study is less than 3 per cent the size of GDP through the 2010s.

The second alternative approach considered uses the income approach to measuring investment in education. This approach subtracts the component of official GDP that is attributable to education and adds in the market component of investment in education net of aging measured as described above. This is also a Fisher index of enrollments, but in this case weighted by lifetime incomes, and is the same as the series presented in Table 1 and in Chart 3, except reflat to 2009 rather than to 2013 dollars. The subtracted-out component of official GDP attributable to education is real personal consumption expenditures for education, plus an estimate of real government consumption expenditures for education.⁶

Using the income approach to measure investment in education has a more substantial effect on year-to-year changes in GDP. This should be less surprising, given that it changes GDP substantially, as well; the proportion of GDP that is attributable to education becomes much larger, increasing from 6 per cent of GDP to 23 per cent of GDP in 2009. It also has the effect of mitigating the Great Recession, reducing the total two-year drop in GDP between 2007 and 2009 from -3.1 per cent to -1.3 per cent.

Conclusions and Possibilities for Continued Research

This article has presented estimates of the stock of human capital using expected lifetime earnings between 1975 and 2013 in the United States. According to the income-based approach of Jorgenson and Fraumeni, the market component of the stock of human capital increased at an average rate of 1.0 per cent per year between 1977 and 2013. The dominant force in the increase in human capital over this time period has been population growth. Growth in the human capital stock per capita did not change substantively over the time period, due to the effects of greater levels of education and an aging population mostly offsetting each other. Measures of investment in education that use the income method are, historically, about three times greater than measures that use a method based on cost.

A natural extension of this work is to estimate a series of updated cost-based estimates of human capital stock and investment. This would provide another perspective on the recent history of human capital in the United States. Extending both a cost-based and income-based series further backward to before 1975 using historical data will yield a longer-term picture of the evolution of human capital in the United States.

The difference between measures of human capital investment and human capital stock between the cost and income approach, such as those presented for investment in education in Table 6, is an important area of investigation for further research into human capital. Abraham (2010) notes a wide range of possible reasons for measured differences in cost- and income-based measures of investment in education, with particular focus on potential distortions in the market for education and on assumptions of the

6 Real personal consumption expenditure on education is estimated from NIPAs Tables 2.4.3 and 2.4.5. Real government consumption expenditure on education is estimated from NIPAs Tables 3.15.3, 3.15.5, and 3.17.

income-based model about productivity and expected lifetime earnings streams.

Another extension of this work is to use the data set to produce results that are closely consistent with international efforts in human capital measurement. The results in this study use methods that were chosen to best fit data sets used in the United States, in particular the Current Population Survey. A good test of the robustness of human capital estimates would be to use the same data to estimate human capital using an approach that most closely matches those of the OECD human capital project (Liu, 2014).

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ICT Services and Their Prices: What Do They Tell Us About Productivity and Technology?

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ABSTRACT

This article reassesses the link between ICT prices, technology, and productivity. To understand how the ICT sector could come to the rescue of a whole economy, a multi-sector model developed by Oulton (2012) is extended to include ICT services and used to calibrate the steady-state contribution of the ICT sector to growth in aggregate U.S. labour productivity. The extended model also has implications for the relationship between prices for ICT services and prices for the ICT assets used to supply them, namely, that, ICT service prices may diverge from ICT asset prices and reflect productivity gains from ICT asset management by the sector. All told, because ICT technologies increasingly diffuse through the economy via purchased services (e.g. cloud services, data analytic services), they are not fully accounted for in the standard narrative of ICT's contribution to economic growth. When this omission is corrected and the price indexes for ICT assets developed in Byrne and Corrado (2017a) are used to indicate the relative productivity of the ICT sector, its contribution to potential labour productivity growth is estimated to be substantially larger than generally thought — 1.4 percentage points per year.

The importance of computers, computer microprocessors, and productivity-enhancing computer software in contributing to the acceleration of productivity growth in the United States in the second half of the 1990s is well established.² But the internet and mobile telephony — two of the 20th century's greatest inventions — have been largely absent in the

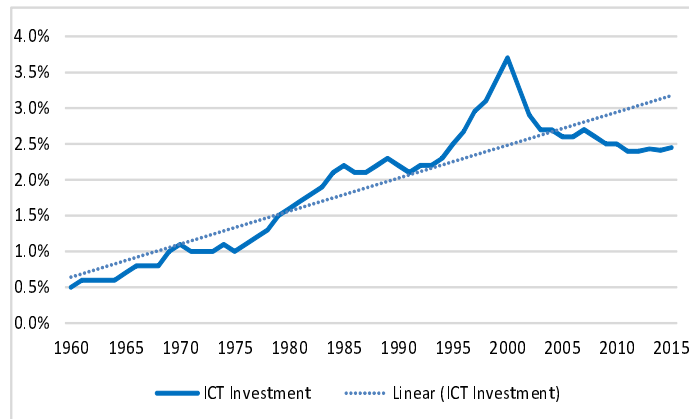
macroeconomic work on U.S productivity performance until recently. Our research on communications technology and communication equipment price measurement (Byrne and Corrado, 2015a,b) and its implications for interpreting U.S. productivity (Corrado, 2011; Corrado and Jager, 2014) puts these innovations front and center and offers a story in which communi-

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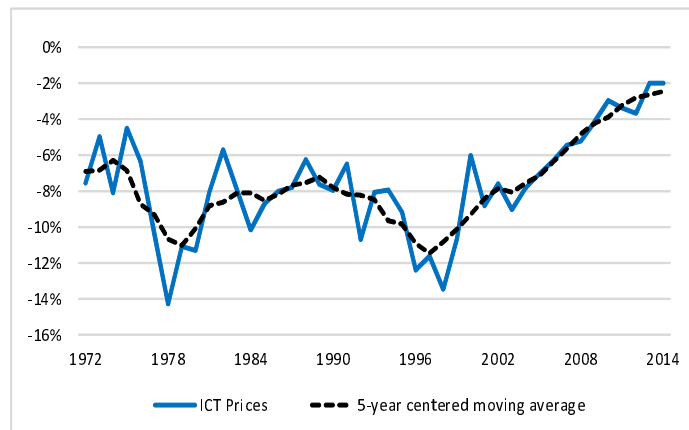
2 See, for example, Jorgenson and Stiroh (2000); Oliner and Sichel (2000) and Brynjolfsson and Hitt (2003).

Chart 1: ICT Equipment and Software Investment and Prices in the United States

Panel A: Nominal ICT Equipment and Software Investment, 1960-2015, per cent of GDP



Panel B: ICT Real Price Change, 1972-2014, annual rate



Note: Panel A reports private investment only. Nominal ICT investment and ICT price change are measured relative to nominal GDP and the GDP deflator, respectively, and exclude software R&D.
Source: Authors' elaboration of data from U.S. BEA.

cation and communication networks (as much as computing performance) drove productivity developments in the 1990s and early 2000s.

Communication technology has continued to advance since the early 2000s, and rising connection speeds have made possible the cloud and mobile platforms that are transforming how organizations use computing resources and exploit data. But measured productivity growth has slowed dramatically. The deterioration in

U.S. labour productivity growth is due in part to historically slow growth in real investment in information and communication technology (ICT) equipment and software, which no longer provides an extra boost to overall output per hour.³ Indeed, not only has nominal ICT equipment and software (E&S) investment relative to GDP moved sideways since 2010 (Chart 1, Panel A), relative ICT price change has posted *extremely* small declines of late, after having

3 Output per hour for the total U.S. economy grew an estimated 0.5 per cent per year from 2010 to 2015 — the slowest 5-year rate of change in the post WWII era based on The Conference Board's Total Economy Database™ whose output per hour series for the U.S. total economy begins in 1950.

gradually lost force since 2004 (Chart 1, Panel B).

Why is ICT investment so weak? And if digital innovations are so transformative, why are they not having a discernible impact on recent ICT prices (and labour productivity)? Google's Hal Varian offers a view from Silicon Valley, namely, that U.S. productivity is mis-measured (Aeppel, 2015). Another possibility is that the ICT sector is innovating and prospering but is too small to come to the rescue of an economy facing stiff supply-side headwinds that limit its productivity growth (Gordon, 2014a,b). As noted elsewhere (e.g. Brynjolfsson and Saunders, 2010) and by our calculations, the value added share of the U.S. ICT-producing sector (including ICT services production) has remained stable at about 6 per cent of nominal GDP since 2000, showing that it has remained relatively small for an extended period of time.

This article makes, we believe, three contributions that help address this conundrum: First, a multisector growth model developed by Oulton (2012) is extended to include purchased ICT services (e.g. cloud or data analytic services). The amended model shows how ICT can be a driver of growth when ICT investment remains weak and suggests the balanced growth contribution of ICT to U.S. labour productivity growth is very large — 1.4 percentage points per year. About 25 per cent of this total ICT sector contribution owes to the diffusion of ICT technology via purchases of cloud and related ICT services.⁴

Second, the model highlights the channels through which a transition to cloud computing can affect productivity growth and sets out the determinants of ICT services price change dur-

ing that transition and in balanced growth. The extended model implies, and we further posit via a user cost (Jorgenson, 1963) approach, that price change for marketed ICT services is proportional to price change for the productive assets used to produce them, but that efficiency gains from rising ICT capital utilization may drive an additional wedge between growth rates for ICT services prices and ICT asset prices.

Third, the article puts official ICT product prices under a microscope and reviews the consistency of 14 new ICT research price indexes with the model's implications. The new ICT product price indexes are based on our own earlier work (Byrne and Corrado, 2015a,b) and new work reported in a companion paper to this article (Byrne and Corrado, 2017b) that draws in part on the historical ICT price measurement literature (e.g. Berndt and Rappaport, 2001, 2003). The new price indexes are for cellular and data networking equipment, enterprise software products, high-end computers/servers, PCs, and computer storage systems. Along with high-speed broadband infrastructure, these ICT products have spurred the growth of cloud computing, datacenter design services, and data analytics over the last decade.

The companion paper documents how the new ICT product prices are folded into new estimates of national accounts-style investment price indexes that are then used in this article. The new ICT asset prices suggest that long-term trends in official ICT prices suffer from substantial mismeasurement and that the relative productivity of the ICT sector remains strong and continues to provide an extra kick to labour productivity growth — unlike the implication of Panel B in Chart 1.⁵

4 Note that this article bears most directly on interpreting trends in ICT investment and ICT services use via the take-up of cloud and related technologies by the producing sectors of the economy. Byrne and Corrado (2017a) assess the impact of the take-up of digital technologies by the household sector of the economy.

5 As discussed in Byrne, Fernald, and Reinsdorf (2016), ICT price mismeasurement has been with us for some time, and mismeasurement can only explain a small portion of the recent slowdown in output per hour growth. (Also see Syverson 2016).

We proceed as follows: Section 1 introduces the model, presents its solution, and discusses its implications for ICT services price change. Section 2 first shows how we measure the ICT versus the non-ICT producing sector and reviews selected indicators of ICT technical change, including ICT R&D. The section then describes how the new ICT era involves technologies delivered as services that raise the utilization of ICT capital, and illustrates the take up of these technologies via purchases of ICT services by the non-ICT-producing sector. Section 3 introduces the new ICT research product price indexes and reports and analyzes their implications for assessing ICT services price change and the relative productivity advantage of the ICT sector. This section then uses the implied productivity differential along with Section 2's information on income shares of ICT assets and ICT services to calibrate the model of Section 1. Because the results imply *very weak* productivity in the non-ICT-producing sector, we discuss and then conclude with several hypotheses why this situation is both plausible and likely temporary.

Framework

ICT plays a central role in modern economies, and quantitative assessments of longer-term economic growth prospects depend heavily on estimates of the contribution of ICT to productivity change for the years ahead. Oulton (2012) proposed an approach to making long-term growth projections based on a two-sector model of an open economy where one sector is an ICT-producing/supplying sector and the other sector is a general business sector excluding ICT producers. His approach is in the spirit of the growth accounting framework for making economic projections (Jorgenson, Ho, and Stiroh, 2004; Jorgenson and Vu, 2010; The Conference Board, 2015; Byrne, Oliner, and Sichel, 2013), in which one of the key drivers of economic growth

is growth of total factor productivity (TFP) in the ICT-producing sector *relative* to the rest of the economy.

Economic growth arises from faster relative growth of TFP in the ICT-producing sector because such growth manifests itself as faster relative ICT price declines, which then enables faster growth of income and consumption. Oulton's model makes these features of a Jorgenson-style growth projection explicit, along with its corollary that economies with little or no domestic ICT production derive benefits from faster TFP growth in ICT investment goods production in other countries in the form of improving terms of trade.

To account for the growth of cloud computing, datacenter design services and data analytics, we expand the Oulton model to include intermediate uses of ICT services. The expression for the steady state contribution of ICT to the growth of output per hour in the expanded model is unaffected by assuming a closed economy, as in the original Oulton model. Proceeding with a closed economy assumption for simplicity, the expanded model is set out below.

Expanded two-sector model

Total final demand (Y) consists of investment (I) and consumption (C) produced in two sectors of the economy. The two producing sectors are (1) an ICT sector (denoted by the subscript T) and (2) a general business sector excluding ICT producers (denoted by the subscript N). Each sector produces investment and consumer goods and services for final use. Thus we have

$$Y = C + I = Y_T + Y_N; \quad (1)$$

$$Y_T = C_T + I_T;$$

$$Y_N = C_N + I_N$$

and

$$PY = P_T Y_T + P_N Y_N; \quad (2)$$

$$\bar{w}_T = \frac{P_T Y_T}{PY}.$$

where P is the price level, P_T and P_N are sector prices, and $\bar{w}_T$ represents the relative size of the ICT sector in final demand in nominal terms.

With regard to intermediates, the ICT sector is assumed to supply services for its own intermediate use, as well as for intermediate use by other producers. The general business sector is assumed to produce intermediates for its own use only; these intermediates are omitted from its production function to keep the exposition simple.⁶ With sector N producing for final demand only, and each sector's output (production net of own use) denoted by Q_T and Q_N , respectively, sectoral production may be written in terms of the following outputs and inputs:

$$Q_T \equiv Y_T + S_T^N = A_T F^T(K_N^T, K_T^T, S_T^T, L^T)$$

$$Q_N \equiv Y_N = A_N F^N(K_N^N, K_T^N, S_T^N, L^N) \quad (3)$$

where K_i^j denotes sector j 's capital input from its stock of investment goods of type i ($i = T, N$) and S_T^j sector j 's intermediate use of ICT services. $L^j = hH^j$ is sector j 's labour input, H^j is hours worked in the sector, and h is a labour composition index applicable to the economy as a whole.

The value of each sector's factor payments is given by

$$P_i Q_i = R_N K_N^i + R_T K_T^i + WH^i + P_T S_T^i,$$

$$i = T, N \quad (4)$$

with relevant factor shares given by

$$\bar{v}_{K_T} = \frac{R_T (K_T^T + K_T^N)}{PY};$$

$$\bar{v}_L = \frac{W(H^N + H^T)}{PY}; \quad (5)$$

$$\bar{\zeta}_T^N = \frac{P_T S_T^N}{PY}.$$

In equation (4), R_N and R_T are the nominal rental prices of capital and W is the hourly wage, and in (5), $\bar{v}_L$ and $\bar{v}_{K_T}$ are the shares of labour and ICT capital in total income, respectively, and $\bar{\zeta}_T^N$ is ICT business services purchased by sector N relative to total income in the economy.

The model assumes there is faster technical progress in the ICT sector. Denoting the rate of growth in the Hicksian shifter (A_i) in the sectoral production functions (3) as μ_i , this assumption is expressed as $\mu_T > \mu_N$. A major simplifying assumption is then employed to solve the model, namely, that the sectoral production functions exhibit constant returns and differ only by their A_i terms. This implies factor shares and input quantities are the same in both sectors, in which case log differentiation of the factor payments equations (4) yields the result shown by Oulton that relative ICT price change equals (the negative of) relative TFP growth of the ICT-producing sector. Defining the relative ICT price as $p = P_T/P_N$, this result is expressed as a steady-state rate of change in relative prices $\dot{p}$ given by

$$\dot{p} = \mu_N - \mu_T < 0. \quad (6)$$

As may be seen, relative ICT price change is negative, reflecting the extent to which the relative growth of productivity in the ICT sector exceeds the growth of productivity elsewhere in an economy.

The expanded model's solution for the contribution of ICT to the growth in output per hour (OPH) is given by

⁶ The complications of chain weighting also are ignored.

$$\underbrace{\frac{\bar{v}_{K_T} + \bar{\zeta}_T^N}{\bar{v}_L}(-\dot{p})}_{\text{Investment (use) and productivity (diffusion) effects}} + \underbrace{\bar{w}_T(-\dot{p})}_{\text{Production effect}} \quad (7)$$

Investment (use) and productivity (diffusion) effects Production effect

For details of this solution, see Appendix A1.⁷ Equation (7) differs from the solution to the original Oulton model due to the presence of the term $\bar{\zeta}_T^N$ capturing the ICT services-using intensity of the economy. The solution nonetheless aligns with the usual growth accounting approach in which the contribution of ICT capital to growth in output per hour is identified as flowing through two channels: ICT use and ICT production. It is typical to consider the ICT use effect as operating through services provided by producers' own investment in ICT capital, i.e. via services generated by ICT assets that producers own themselves. In the expanded model, the channel also operates via non-ICT producers' purchases of ICT capital services, e.g. purchases of cloud services, that provide workers access to ICT technologies in essentially the same way.⁸

In steady-state growth, output and output per hour in the N sector grow less rapidly than output and output per hour in the T sector, the sector producing ICT goods and services. In fact, this growth differential is $-\dot{p}$, a result that follows from equality of the marginal product of factors used in the two sectors, which in turn follows from the assumption of perfect competition. The model thus implies that, to the extent μ_T really is greater than μ_N , real ICT services

prices fall (as they are on par with real ICT asset prices), and real ICT services output growth is faster than growth of real output of the general production sector, evidence for which shall be shown in section 3 below.

ICT services prices versus ICT asset prices

The ICT sector's output price is a single price P_T by assumption in a two-sector model. The strictness of this assumption may be readily relaxed, however, yielding the usual multiple sector framework with many relative prices and an aggregate production possibilities frontier that generates multiple types of C and I for final use (e.g. Jorgenson, 1966; Jorgenson, Ho, and Stiroh, 2005). In what follows, the user cost expression is used to set out the conditions under which a multiple sector framework generates essentially the same implication for ICT services prices as did the simple two-sector model.

Consider the determinants of prices for two types of ICT services in a multiple sector setting. The first is where ICT services production is highly ICT-capital intensive, as in the production of "public" cloud services by the ICT sector for sale to the non-ICT-producing sector (e.g. Amazon selling to GM). The second is where ICT services are for designing "private" cloud services facilities within firms in the non-ICT producing sector. In both cases, ICT services facilitate more efficient sharing of datacenter resources across users.

7 Appendix A1 can be found at http://www.csls.ca/ipm/33/Byrne_Corrado%20Appendix.pdf.

8 The contribution to productivity growth is particularly powerful when ICT services are domestically produced — i.e. the effect shown in equation (7) also includes the industry's contribution to TFP growth via the standard Domar-Hulten channel whereby innovation in upstream industries has impacts on aggregate TFP growth via using industries (Domar, 1961; Hulten, 1978). When purchased ICT services are imported, the technology diffusion channel (i.e. their capital deepening-like effect) is still there, but its positive impact is partially offset by the negative effect of ICT services imports on $\bar{w}_T$. Appendix A1 sets out the formula for the Domar-Hulten contribution of the ICT sector to TFP growth in the ICT-services amended model.

$P^{S_T} S_T^N$ is the value of ICT services, where P^{S_T} is a quality-adjusted price specific to each type of service. P^{I_T} will denote the quality-adjusted price of ICT assets relevant to each case (i.e. it is an investment price index). These prices are expressed as real prices P^{S_T} , P^{I_T} , relative to, say, the PCE or GDP deflator. A steady state-required real rate of return on assets ρ is defined consistently (i.e. the price change element is in the same relative terms).

Case 1

Cloud providers deliver infrastructure, platforms, and software as a service. In this case, ICT services prices are per period charges for resources managed by the cloud provider. Assume that these services are priced as capital services provided to a capital owner and equal to a rental price times the capital stock and a factor of proportionality:

$$P^{S_T} S_T^N = [(\rho + \delta_T) P^{I_T} K_T^I] \lambda \quad (8)$$

The expression in brackets is the standard expression for capital services and λ is a factor of proportionality representing the efficiency of ICT service provision relative to in-house ICT. As previously indicated, ρ is the real net return to capital investment; and δ_T is the depreciation

rate of ICT capital.⁹ The term ρ is constant in steady state growth by definition, and δ_T is constant by assumption. Thus, if the real price of cloud services P^{S_T} is falling rapidly in constant quality terms, equation (8) suggests that the driver of that change is either falling real prices of ICT investment goods P^{I_T} or rising efficiency (falling λ).

Under what conditions might λ fall? One possibility is increasing returns, e.g. if ICT assets were more or less a large fixed cost that substantially inflated average costs relative to marginal costs (a huge server farm, say). Increased utilization of the relevant assets leads to declines in average costs, and if such declines are passed on to customers, declines in P^{S_T} exceed those for P^{I_T} until steady state growth is achieved.¹⁰ In other words, from (8) we then have

$$\dot{P}^{S_T} \approx \dot{P}^{I_T} + \dot{\lambda}_T \quad (9)$$

where, note, $\dot{P}^{S_T}$, $\dot{P}^{I_T}$, and $\dot{\lambda}_T$ are all < 0 . $\dot{\lambda}_T$ reflects the drop in underutilization, which augments declines in cloud services prices relative to declines in prices of ICT assets according to equation (9).¹¹ Cloud services prices that fall less than ICT asset prices suggest providers are retaining the efficiency gains for themselves.

9 Appendix A1 (found at http://www.csls.ca/ipm/33/Byrne_Corrado%20Appendix.pdf) sets out the four real rental prices in the two-sector model in a no-tax world where the terms in the nominal interest rate and the relevant relative asset price change are summarized by ρ .

10 Note that equation (8) did not suggest or specify that ρ exhausted observed capital income, which is to say the nominal interest rate in ρ is an ex ante rate. As shown by Berndt and Fuss (1986), the marginal product of capital varies directly with capital utilization and is absorbed in capital income and attributed to capital rental prices only when ex post calculated rates of return are used.

11 To see this, let $\dot{\lambda}_T$ vary with capital utilization, e.g. as in $\dot{\lambda}_T = 1 - d$ where d is a measure of the underutilization of ICT assets (and can be calculated so as to exhaust capital income). Equation (9) then suggests that improvements in the utilization of ICT capital assets in the public cloud services-producing industry introduce a wedge $\dot{\lambda}_T$ between changes in observed prices for cloud services and prices for ICT assets. Such wedges presumably surface for only periods of time, as changes in utilization usually are a temporary phenomenon.

Case 2

System design services are purchased to improve the flow of ICT services produced within firms, and the services price is a fee proportional to the services-induced volume improvement in own-produced ICT services.¹² System design services may then be modeled as an increase in the efficiency of installed ICT asset stocks, an approach relevant to the spread and adoption of cloud technology, i.e. as in designing and installing a “private” cloud with significant server consolidation.

Note first that the real rental price of ICT capital services r_T^N and ICT capital owned within the non-ICT producing sector K_T^N are the subjects of analysis, and that

$$r_T^N K_T^N = \left[(\rho + \delta_T) p^{I_T} K_T^N \right]$$

is the real income attributed to non-ICT producers’ deployment of ICT capital. Consider next that producers will pay for system design services up to the point where fees do not exceed the present discounted value of per period benefits provided. Let α denote the proportional fee and $-\dot{\lambda}_N$ the proportional improvement in r_T^N that is provided.¹³ Ignoring discounting, the *effective* decline in real ICT asset prices faced by non-ICT producers using system design services $\dot{p}^{eI_T}$ is given by

$$\dot{p}^{eI_T} = \dot{p}^{I_T} + \dot{\lambda}_N (1 - \alpha) \quad (10)$$

and industry revenues are expressed as

$$p^{S_T} S_T^N = \alpha r_T^N K_T^N (-\dot{\lambda}_N) \quad (11)$$

Equation (10) suggests that ICT capital packs an extra punch to non-ICT producers’ productivity, as the effective growth in real services will exceed real growth in stocks due to increases in utilization of the stocks. Equation (11) suggests that ICT services will grow relative to ICT capital income when substantial improvements are being made by providers (and the improvements they make are long-lived).

All told, the $\dot{\lambda}$ ’s represent efficiencies enjoyed by companies that move from a traditional IT datacenter to a cloud computing platform; for new firms, efficiencies represent lower capital required to start a business. Combined, these efficiencies have the potential to be large because cloud computing refers not only to shifts in workload location (from on-premises environments to the public cloud) but also to increased take-up of cloud technologies within firms that result in much denser workload-to-ICT capital ratios.

Quality change or productive externality?

From a macroeconomic point of view, increased demand for cloud computing leads to decreased demand for computing hardware (for a given volume of ICT services) and increased demand for the software developers and software products that enable machine virtualization and application containerization.¹⁴ Over time, the associated extra kick in *effective* ICT price declines implied by equation (10) would lead to greater computerization/digitization of an economy, which would then translate into a restoration of the share of computer hardware in the mix of ICT investment in the longer run. With regard to communication equipment,

12 Note that in the very different case of ICT installation services, the price is simply a margin, i.e. an add-on to the purchase price of ICT assets that has no independent impact on the effectiveness of the investment beyond what is built into a quality-adjusted investment price index.

13 Where, as in footnote 10, there is an implicit term d capturing underutilization.

14 These technologies are discussed in the next main section.

although high-speed broadband is a fundamental enabler of cloud services, we have not identified first order impacts of virtualization and its associated efficiencies on the demand for communication equipment beyond the fundamental need to support datacenter IP traffic.

Before we go further, let us underscore that the server, storage, software product and computing services prices developed and used in section 3 of this article do *not* treat the application workload of IT capital, or the capability of software products or systems design services to enable cloud computing, as quality change. The macroeconomic impact of the adoption of cloud technology is via its contribution to productivity growth, as in network externalities (or spillovers to ICT capital in general). Cost savings due to virtualization, whether they accrue to cloud providers or to non-ICT producers, thus are viewed as productive externalities.¹⁵ While this position is parallel to treating the productivity enhancing impacts of internet platform business models as a (network) externality, virtualization as a computing technology is similar to multiplexing in communication where more and more signals are transmitted over physical networks (or spectrum), and where, to the extent possible, increases in capacity are built into quality-adjusted price indexes such as those developed for communications equipment in Byrne and Corrado (2015a,b). The adjustment of prices of servers, storage, systems software, and systems design services to consistently account for efficiencies due to virtualization and related cloud technologies is a similar challenge, but one well beyond the scope of this article.

ICT Sector Trends

Columns 1 and 2 of Table 1 define the empirical counterpart to sector T of the previous section. Column (1) are the detailed industries that we strive to measure, and column (4) indicates how close we come to achieving that using BEA's annual Input-Output and Final Uses data.

Using data for the T sector so defined, this section contains three subsections which do the following: (a) examine indicators of ICT technologies, including ICT R&D, that suggest that the pace of change in the newer ICT technologies remains very fast; (b) assess the relative growth of ICT services (which also bears on the diffusion of ICT technologies) and relative pattern of ICT investment by major component; and (c) quantify the model's parameters for the relative size of the ICT sector and the diffusion of its technology in the economy, namely, $\bar{w}_T$, $\bar{v}_{K_T}$, and ζ_T^N . Relative ICT asset price change is presented in section 3, and quantitative implications of the model of section 1 are drawn there.

Technology and R&D

Internet and wireless technologies

Faster relative growth of TFP in ICT production is usually attributed to the relatively rapid pace of advances in computing and semiconductor technology, especially in the speed of microprocessors (MPUs) used in computers (Jorgenson, 2001) — and, according to many accounts, such advances slowed in the first half of the 2000s (Hilbert and Lopez, 2011; Pillai, 2011, 2013). By contrast, advances in communications technology, i.e. internet and wireless technologies, continued at a similar pace (Byrne and Corrado, 2015a,b).

15 This is not to suggest that these effects cannot be isolated and quantified, as they have been in work that adds a separate channel to decompositions such as equation (7) to account for ICT to contributions to productivity growth beyond the direct capital contributions captured in growth accounting. For example, Corrado (2011) and Corrado and Jäger (2014) showed that network externalities were a noteworthy contributor to productivity growth in the United States and eight major European countries during the internet and wireless network expansion in the first half of the 2000s. Beyond broadband, however, spillovers to ICT have not been found in macro or industry-level data (Stiroh, 2002), despite a large micro-based literature suggesting externalities to IT use by individual firms. See Corrado and van Ark (2016) for further discussion.

Table 1: ICT-Producing Industries

NAICS 2007 code	Description	Primary Use	BEA industry data code
(1)	(2)	(3)	(4)
Manufacturing			
3341, 3344	Computers and semiconductors	Final and Intermediate	334 (pt)
3342, 3343, 334511	Communication equipment	Final	334 (pt)
3346	Magnetic and optical recording media	Final	334 (pt)
Services			
5112	Software publishing	Final	511 (pt)
515	Broadcasting	Final	513 (pt)
517 (pt)	Telecommunications, excluding wireline telephony (but including internet access)	Final and Intermediate	513 (pt)
5182	Data processing, hosting, and related	Intermediate	514 (pt)
51913	Internet publishing and broadcasting and web search portals	Intermediate	514 (pt)
541511	Custom computer programming	Final	5415
541512 (pt)	Computer systems design (integrators)	Final	5415
541512 (pt)	Computer systems design (consultants)	Intermediate	5415
541513,9	Other computer related services	Intermediate	5415

Note: (pt) after an industry codes denotes that not all of the industry consists of the component listed in column (2).

Source: Authors' elaboration of NAICS and data from BEA supply-use tables.

Internet and wireless technologies are not single identifiable inventions, but rather a suite of communications technologies, protocols, and standards for networking computers and mobile devices.¹⁶ Advances in these technologies have been very rapid in the past 25 years and continue at blistering rates to this day. Without continued increases in internet technology and capacity from 2010 to 2015, the world could not have achieved the reported 29 per cent per year increase in IP traffic and nearly 78 per cent per year increase in wireless *data* traffic that it did during this period (Chart 2, Panel A).¹⁷

All told, the internet markets of the G-20 were projected to reach \$4.2 trillion in 2016 — nearly double their size in 2010. Three out of four datacenter workloads are expected to be processed in the cloud by 2018, and Internet of

Things (IoT) devices attached to the internet — most of them wirelessly — are expected to increase more than 25 fold, from nearly 1 billion units in 2010 to 26 billion units by 2020 (IoT devices *exclude* PCs, tablets and smartphones).¹⁸ These estimates plus a continuation of the demand for mobility and hotspots cannot be realized without continued, rapid increases in communications capacity, especially wireless capacity. Panel B of Chart 2 shows that by one measure (the rate at which wireless-related telecommunications patents are granted in the United States), the current pace of change in communications technology is more rapid than it was in the late 1990s.

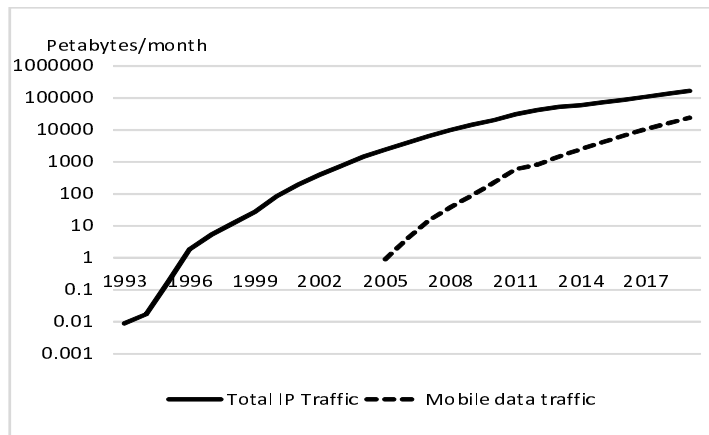
16 This paraphrases Greenstein (2000: 391), who was describing internet technology.

17 The calculations are based on the historical data and 2015 estimate reported in issues of Cisco's Visual Networking Index and Global Mobile Data Forecast Update.

18 The sources for these forecasts are Boston Consulting Group (2012), Gartner (2013), and Cisco's Global Cloud Index (Cisco, 2013).

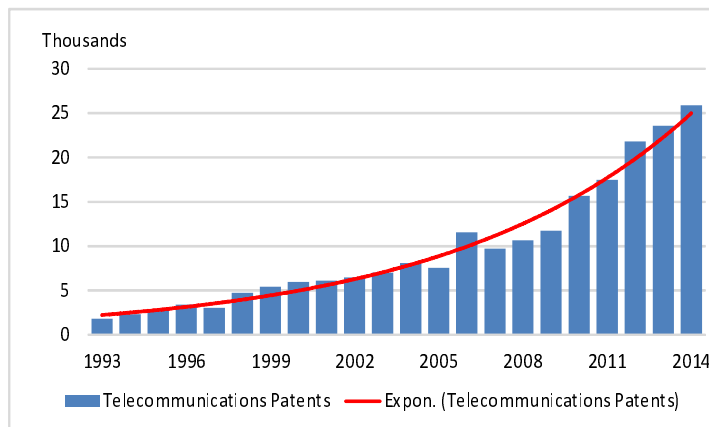
Chart 2: Global IP Traffic and U.S. Telecommunications Patents

Panel A: Global IP Traffic, 1993-2019 (incl. forecast)



Source: Cisco's Visual Networking Index 2014-2019 (May 2015) and earlier editions.

Panel B: U.S. Wireless-related Telecommunications Patents, 1993-2014



Source: U.S. Patent and Trademark office, Part 1, Patent Counts by Class by Year (sum of classes 370, 375, 379, and 455). Available at <http://www.uspto.gov/web/offices/ac/ido/oeip/taf/cbcbby.htm>. Accessed October, 2015.

Cloud technologies

Cloud service providers supply ICT resources over the internet.¹⁹ Services range from simple data storage to full provision of software for “business intelligence” applications. Access is as ubiquitous as wireless and wireline networks. The feasibility and affordability of cloud services is the capstone of an ongoing series of networking innovations that have raised access

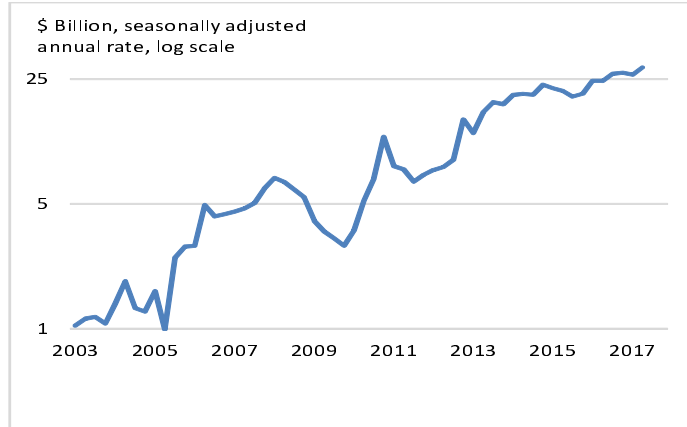
speeds, lowered storage costs, and perhaps most importantly, enabled seamless and invisible sharing of computing resources across users.

Cloud computing involves three major technologies that raise the utilization of computer resources and speed software development: virtualization, grid computing and containerization. “Virtualization” provides each user with a distinct virtual machine with its own operating

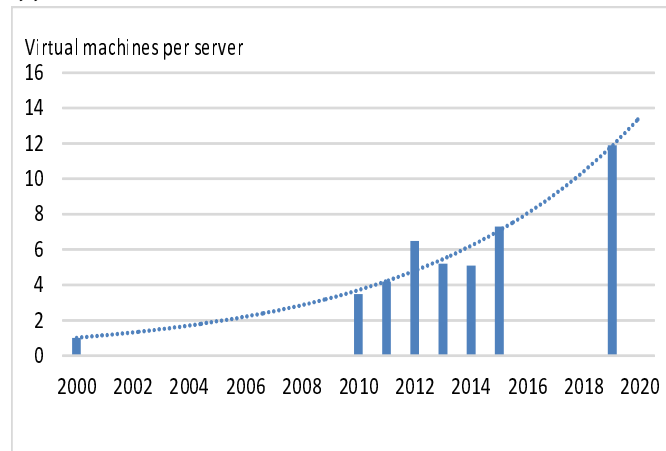
19 According to the National Institute of Standards and Technology, “cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service provider interaction” (Mell and Grance, 2011).

Chart 3: Capital Expenditure by Cloud Providers and Server Application Workload in the United States

Panel A: Global Capital Expenditure by Amazon, Microsoft, and Google, 2003Q1-2017Q2



Panel B: Average Application Workload of Global Cloud Datacenters, 2000-2020



Sources: Panel A: Quarterly financial reports, seasonally adjusted by authors. Panel B: 2010-2015 observations and 2019 forecast: Cisco Global Cloud Index: Forecast and Methodology 2015-2019; 2000 observation: International Data Corporation.

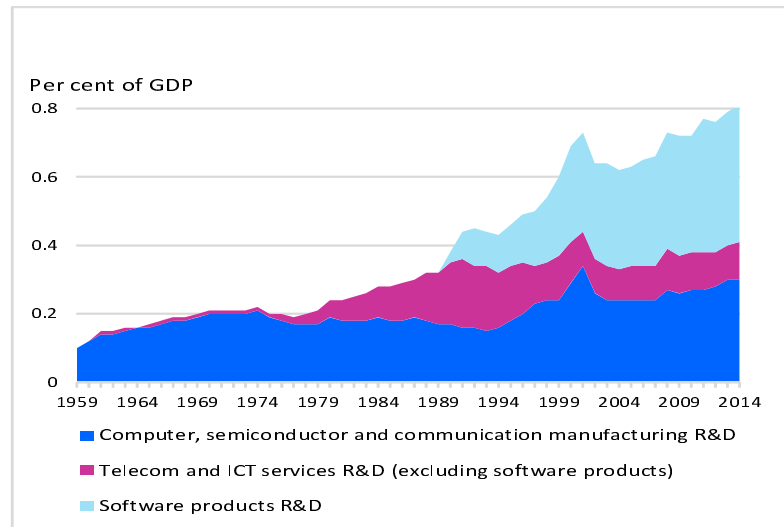
system kernel but allocates resources from actual individual machines to multiple users, enabling higher resource utilization in the data-center. A complete history is beyond the scope of this article, but virtualization and time sharing (simultaneous use of the same computer by multiple jobs) have their roots in the early history of IBM mainframes, and grid computing (applying the resources of many computers in a network to a single job) developed along with

the internet.²⁰ More recently “containerization” technology has allowed multiple platform environments to operate on the same virtual machine, increasing the speed of application development, deployment, and scalability.

As shown in Chart 3, Panel A, the increase in spending for capacity expansion among major cloud vendors has been stunning: nominal capital expenditures at Amazon, Microsoft, and Google increased 23 per cent per year between

²⁰ Grid computing was first used in 1989 to link supercomputers and thereafter grew and evolved along with the internet (De Roure *et al.* 2003).

Chart 4: Private ICT R&D investment in the United States, 1959-2014



Source: Authors' elaboration of Bureau of Economic Analysis and National Science Foundation data.

2003:Q1 and 2017:Q2.²¹ Firms that transition from traditional datacenters to a cloud platform (private or public) enjoy substantial hardware consolidation and cost savings. IT consultancies commented in 2009 that server virtualization had become the “killer app” for the business datacenter (Bailey, 2009). Cisco has estimated that the average application workload of global cloud datacenters, indicated by the number of virtual machines per server plotted in Chart 3, Panel B, more than doubled from 2010 to 2015. Companies historically ran one application workload per server (and many small and medium size firms still do).

In terms of enterprise applications, it is very early on in the application of containerization.²² International Data Corporation (IDC) estimates that in 2016 only 1 per cent of enterprise applications were running on containers that could readily be scaled. Within the ICT-producing

sector, however, containerization and related microservices have been central to boosting the productivity of new software development, i.e. boosting the productivity of software R&D investments.

R&D investments in ICT

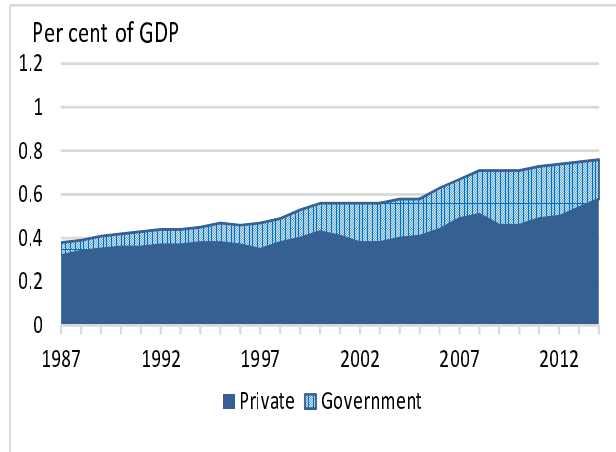
The trend of ICT R&D investment, as shown in Chart 4, is consistent with a very brisk pace of change. The overall trajectory for ICT R&D depicted in Chart 4 is not a readily observable component of the U.S. national accounts' estimate for R&D investment. The estimates in Chart 4 were developed by the authors and reflect (1) private R&D investment by the industries listed in Table 1 as reported in the U.S. national accounts *plus* (2) software products R&D presented as own account software investment. National accountants regard software products R&D as captured in own-account software investment. Consequently, they exclude

21 Amazon, Microsoft and Google accounted for 40 per cent of global capital expenditures by large cloud computing firms in 2015. (Firms classified as “hyperscale” by Cisco Systems Inc.)

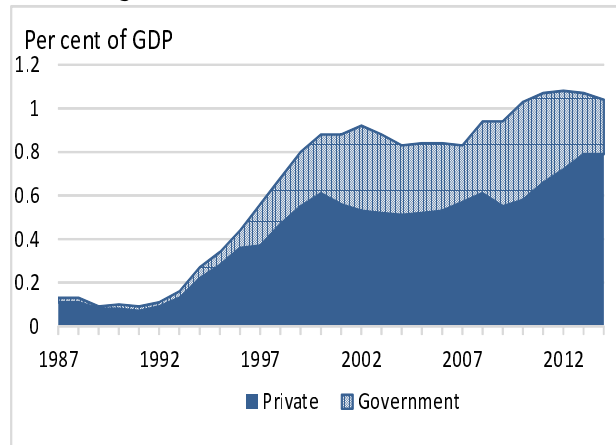
22 Containerization — a scalable form of virtualization technology — generally was not widely understood in the business world outside cloud vendors until the release of open source LINUX formats (Docker 1.0) in March 2013. Docker transformed container technology into a product for enterprise use.

Chart 5: Intermediate Uses of Information and Computer Services in the United States, 1987-2014, per cent of GDP

Panel A: Data processing and related services



Panel B: Computer systems design



Note. Estimates are net of own sector, i.e., ICT-producing sector, use; see Table 1 for industries comprising the ICT-producing sector.

Source: Authors' elaboration of data from U.S. BEA

software products R&D from the R&D source data when estimating private R&D investment.

Most software products R&D is carried out in the ICT-producing industries listed in Table 1. For the United States, estimates of software products R&D are derived from cross tabulations of the National Science Foundation's R&D survey data by industry of funder and technological focus; Chart 4 plots the time series for these

estimates reported in Crawford, Lee, Jankowski, and Moris (2014: Table 2).²³

For the analysis of the ICT sector, indeed for the analysis of R&D in general, including software products R&D with other R&D is a more logical presentation of the available data — and not doing so excludes an area where increases in R&D have been among the most rapid. The rate of investment in ICT R&D in recent years con-

²³ The relevant cross-tabulation of R&D survey data has been published by the National Science Foundation (NSF) for 2012. This recently published statistics are consistent with estimates reported in Crawford *et al.* (2014), which included figures through 2013. The figure for 2014 in Chart 4 is an extrapolation by the authors based on total private own-account software investment.

tinues unabated in this presentation. This suggests that ICT innovation could not have slowed for lack of investment in the development of new ICT technologies and products.

ICT services and software investment

Intermediate uses of ICT

ICT R&D historically has been oriented toward producing better and faster computers and more powerful productivity-enhancing computer software (installed locally) for businesses and other organizations. But with the locus of ICT R&D having shifted toward software apps and services enabled by high-speed communication and high-performance computing systems, one should not be surprised to also see an associated shift in ICT spending.

Private demand for data processing, hosting, and related information services (NAICS 5182, 51913) and for computer systems design services and related computer services (NAICS 54152, 54153, 54159) rose sharply relative to GDP in the United States in recent years (the solid dark shaded areas of Panels A and B of Chart 5, respectively). These developments reflect both the growth of cloud services (which is in NAICS 5182 and has seen steady growth) and a remarkable surge in systems design services. This latter development is likely to be related to the demand for cloud-based IT systems to the extent that systems design services are co-investments with the demand for cloud computing.²⁴ All told, the analysis in section 1 suggested that the relative growth of ICT services industries would be strong if there were real productivity gains to reconfiguring IT departments to capture cost savings due to cloud

technologies. The prospective cost savings, along with a growing demand for data analytics and revenue momentum of the “subscription” business model that has been widely used to deliver ICT services, all underscore that the relative growth of ICT services since 2000 is unsurprising.²⁵

Trends in intermediate and final uses of telecommunications and broadcasting services are shown in Chart 6. Traditional wireline telephone services ideally would be excluded from this analysis, but a split of traditional versus IP telephony and internet access services in data on intermediate purchases by industry is not available. As may be seen in Panel A, business demand for wireless services is robust, especially from 2010 on, whereas total private telecommunications services (which adds in wireline telecom and internet access services) has moved down since peaking in 2000. By contrast as shown in Panel B, consumer total telecom demand has not declined since 2000 but the relative pattern of consumer total telecom versus consumer wireless demand is similar to private industry. A breakdown of wireline telephone and internet access services is available for consumers, and the detail shows, as expected, that wireline telephone services are a sharply declining component of total consumer NAICS 515 and 517 services spending whereas internet access is a growing component.

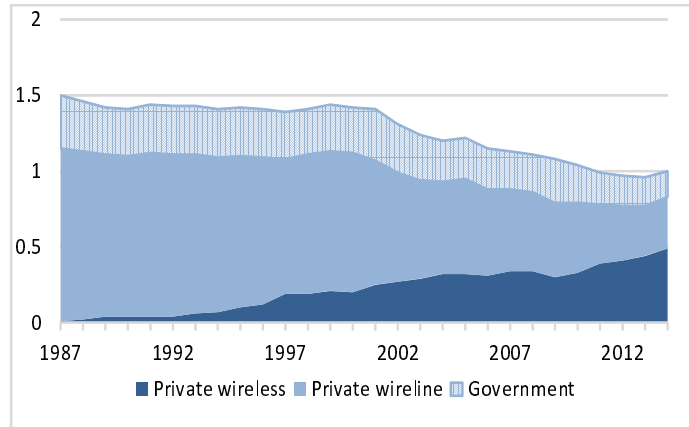
All told, information, computer, and wireless communication services supplied to private industries net of the ICT-producing sector’s own use has increased .06 percentage points per year relative to nominal GDP during the past 19 years, i.e. the ratio of such services to GDP rose from 0.7 per cent in 1995 to 1.9 per cent in 2014.

24 To be clear, spending on computer systems design is not counted in the national account definition of investment even though in principle it would be included in expanded frameworks that recognize a portion of consulting services as investment in new business process improvement (Corrado, Hulten, and Sichel, 2005 and 2009).

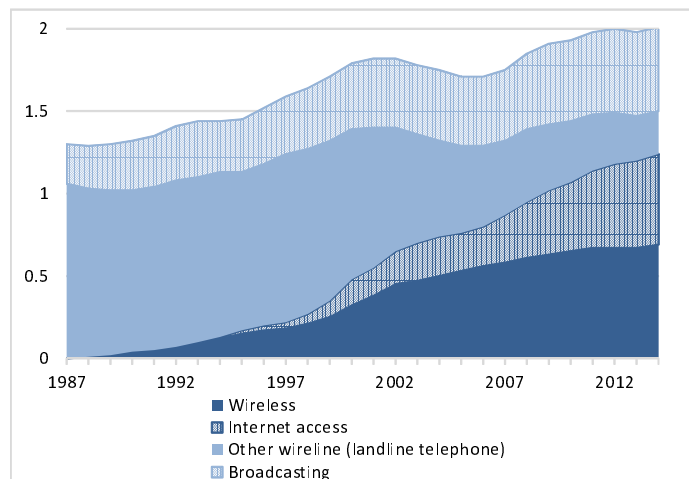
25 For further discussion of the role of business models in ICT services provision, see OECD (2014, chapter 4).

Chart 6: Intermediate and Final Uses (PCE) of Telecommunications and Broadcasting Services in the United States, 1987-2014, per cent of Nominal GDP

Panel A: Intermediate Telecom Use



Panel B: Final Telecom and Broadcasting Use (PCE)



Note. Estimates are net of own sector, i.e. ICT-producing sector, use; see Table 1 for industries comprising the ICT-producing sector. Broadcasting is in Panel B only because intermediate uses of the output of this industry are essentially nil.

Source: Authors' elaboration of data from U.S. BEA

To put this in perspective, consider again Panel A of Chart 1. This increase in ICT business services use by other private producers is in fact a tad larger than the long-term increase in private spending on ICT investment goods (relative to GDP), i.e. the coefficient on time in the regression trend line plotted in Chart 1 (Panel A) is .05.

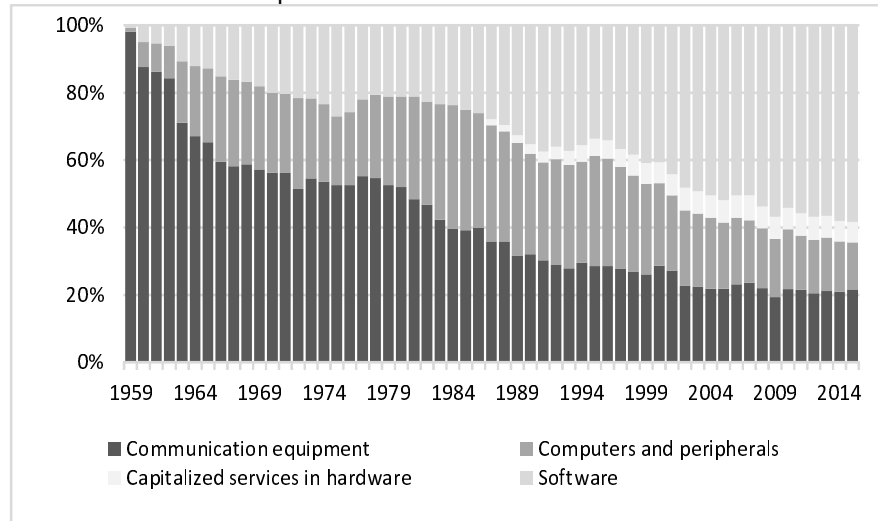
Final investment in software assets

Nearly 60 per cent of total ICT investment in 2015 was for acquisition of new software assets,

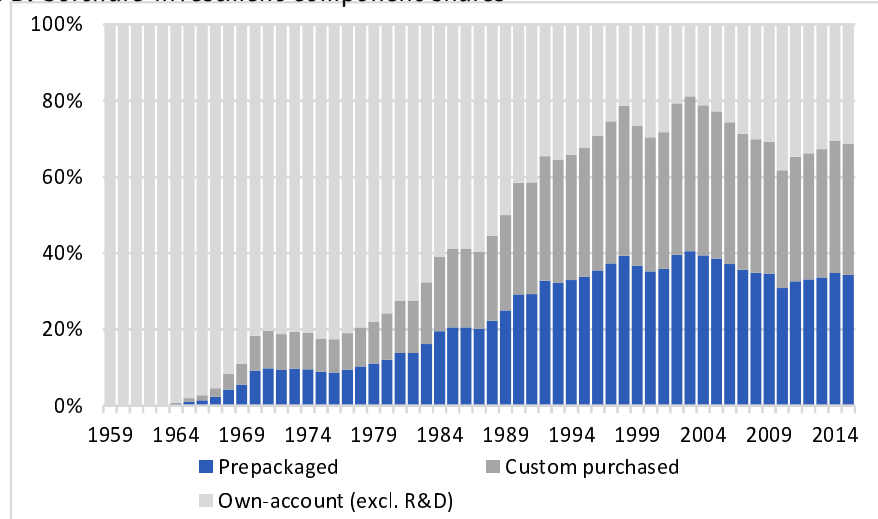
a dramatic turnabout from 1995 when 65 per cent of total ICT investment was for equipment and equipment-related capitalized services (Chart 7, Panel A). Between 1995 and 2005, the pure equipment share of total ICT investment dropped dramatically (20 percentage points). The computing equipment spending share has continued to trend down since 2005 — it was only 14 per cent in 2014 — whereas the communication equipment share stopped dropping in

Chart 7: Private ICT and Software Investment Shares in the United States, 1959-2014

Panel A: ICT investment component shares



Panel B: Software investment component shares



Note. Excludes software products R&D.

Source: Authors' elaboration of data from U.S. BEA.

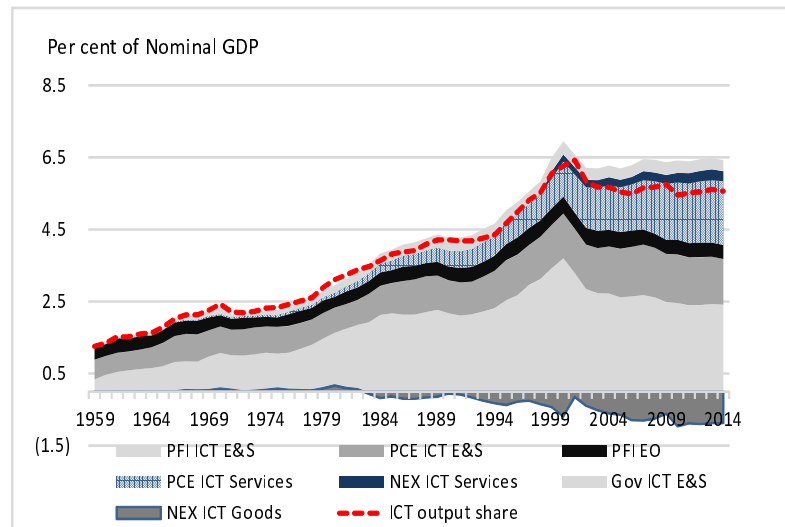
the early 2000s and has fluctuated between 21 and 22 per cent since then.²⁶

Within new software assets, purchases of marketed, standardized (prepackaged) software products are about one third of total software, as illustrated by the dark shaded area in Panel B of Chart 7. The lion's share of software is custom

produced, whether as purchased services or performed on own account. Price measures for these custom components do not exist. BLS does not produce prices indexes for NAICS 541511, or any part of 5415 for that matter. The BEA estimates these price indexes based in part on its price index for prepackaged software products.

²⁶ Note that the emergence of the cloud business model may have led ICT equipment investment to be underestimated. Byrne, Corrado, and Sichel (2017a) calculate that if electronic components purchased by the ICT services sector are used to build server farms, total ICT equipment investment may be understated by as much as 25 per cent in 2015. This does not change the picture of weakness in the non-ICT sector investment.

Chart 8: ICT Final Output Share in the United States, 1959-2014



Note: E&S is equipment and software. PFI = private fixed investment. PCE = personal consumption expenditure. NEX= net exports. EO = entertainment originals. PFI ICT E&S excludes software R&D. PCE ICT components include video and cellular equipment and exclude wireline telecommunications.
Source: Authors' elaboration of BEA's NIPA data.

The companion paper (Byrne and Corrado, 2017b) reviews these prices, but suffice it to say BEA's price indexes for software investment fall 2 per cent per year, not the 15 to 20 per cent that high-tech equipment prices do. All told, the dramatic shift in overall ICT investment from computing equipment toward software illustrated in Chart 7 suggests that the rate of overall ICT investment price change *should* have slowed over time.

Sector final output and capital income

ICT final output share

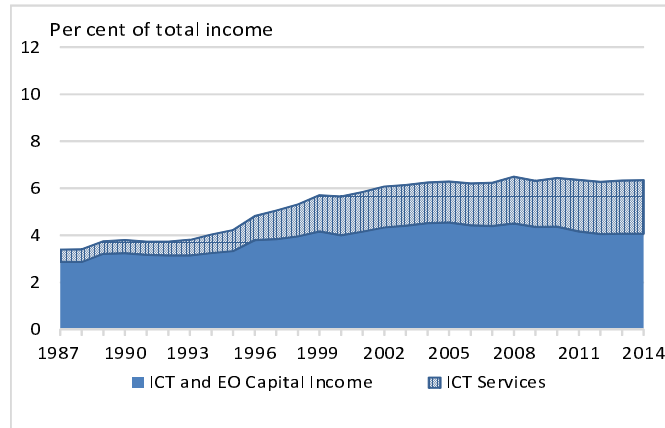
Consider first the ICT sector final output share $\bar{w}_T$, which captures what the domestic tech sector supplies to final demand. A substantial share of ICT investment and consumption goods are produced abroad however and do not add much to the sector's final output share. Note, too, that even though the overwhelming share of ICT intermediate services are domestically produced in the United States, services

only enter $\bar{w}_T$ via final consumption and net exports. Final consumption includes digitally-provided entertainment services as well as telecommunication services sold to consumers.

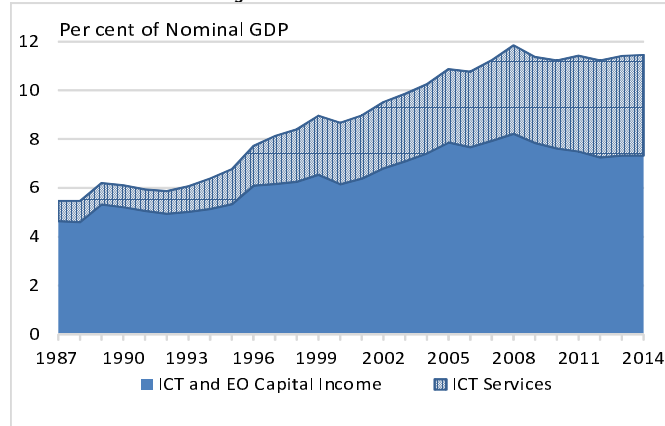
The inclusion of digital entertainment services in ICT final output raises the question of whether investments in digital entertainment originals (EO) should also be considered part of ICT final output — and correspondingly, how to treat R&D investments in ICT. Our thinking is that EO assets are more akin to software assets than to the software original that is used to produce the software assets. The purchasers of software assets (software products) use the assets to generate (ICT) services for a period of time, just as the owners of entertainment originals use their assets to generate (entertainment) services for a period of years. EO investments are therefore included in ICT final output but R&D investments that produce new blueprints or original code for manufacturing/reproducing ICT equipment and software products are not.

Chart 9: ICT Services and Capital Income in the United States

Panel A: ICT services and ICT and EO capital income shares



Panel B: Panel A shares divided by labour share



Source: Authors' elaboration of capital and labor income data from U.S. BLS productivity major sector and total economy systems and U.S. BEA input-output data. BLS capital income for software is adjusted to exclude software products R&D.

The ICT final output share $\bar{w}_T$ and its major components are shown in Chart 8. As may be seen, the share trended down in the early 2000s, but has been about flat at 5.6 per cent of GDP for the past ten years (2004 to 2014). The ICT goods net exports component has been stable of late, while ICT final services (PCE and net exports) has expanded to offset the downward drift in ICT final goods (PCE and PFI E&S, the dark and lightblue shaded areas). Note that if ICT final PCE services and EO capital were not included in the analysis, the ICT final output share would average 2.6 per cent per year from 2004 to 2014 — just a tad higher than the final

output share of software over the same period (2.4 per cent per year according to NIPA table 9.3U).

ICT income and services shares. Consider now the shares defined in equation (5): ICT and EO capital's share of total income ($\bar{v}_{K_T}$), labour' share ($\bar{v}_L$), and ICT services share net of sector own use ($\bar{v}_T^N$). Consistent with the pattern shown by the ICT investment rate, the share of capital income earned by ICT (and EO) capital has edged down since the mid-2000s, after having climbed steadily over the 1990s (the dark shaded area in Panel A of Chart 9).

Capital income is the nominal value of the flow of services provided by capital assets owned and used in production. It is typical to regard $\bar{v}_{K_T}$ as a basic indicator of the extent to which ICT has diffused via use in production in an economy. ICT business services also are inputs to production but may be marketed versions of the same services provided via direct ownership of ICT capital. As may be seen, the trajectory of the total income generated by the use of ICT capital assets in the U.S. economy changes rather dramatically with the inclusion of marketed services, suggesting that $\bar{v}_{K_T}$, alone, is an insufficient indicator of ICT use in production. Panel B in Chart 9 plots the capital income share relative to the labour share (a ratio of the compensations for ICT capital and labour). This combination of parameters is applied to the ICT productivity differential captured by the steady state rate of decline in real ICT asset prices (or effective asset prices) to determine the contribution of the ICT “use and diffusion” effect to labour productivity growth. The parameter combination averages 11.3 per cent for the past 10 years, considerably higher than the 7.7 per cent share implied by ICT capital ownership alone.

ICT Investment Prices

Accurate ICT asset prices are required for the quantitative evaluation of equation (7). The objective in this section is to present newly developed ICT product price measures, confirm their alignment with the trends in technology and R&D discussed in the previous section, and contrast them where relevant to official statistics. Then we examine new ICT investment research price indexes built from the new product price indexes.

The new product price indexes reflect work that either (a) was conducted by the authors as part of the work for this study or (b) appears in the literature but has not yet been fully incorpo-

rated into BEA’s official ICT price statistics, e.g. Berndt and Rappaport (2003); Abel, Berndt, and White (2007); Copeland (2013); Byrne and Corrado (2015a). Further information on the sources and methods used to construct the new ICT product and investment price indexes are in our companion paper (Byrne and Corrado, 2017b).

New ICT product prices and implications for ICT services prices

Table 2 reports prices for selected ICT products. More than a dozen new research price indexes are shown. Four are price indexes for the telecom products newly developed and analyzed in Byrne and Corrado (2015a,b); the computer storage device index was introduced in Byrne (2015). The remainder are price indexes newly developed for this study and whose construction is discussed in the companion paper (Byrne and Corrado, 2017b). Of these, the indexes for servers, enterprise software, enterprise wireline telecom services, along with telecom products, are particularly relevant for understanding developments over the last decade.

The following observations emerge from Table 2. First, prices for telecom equipment products (lines 1 to 4) fall relatively rapidly — between 12 and 18 per cent per year over the 2004-2014 period (column 2). Although these are noteworthy rates of decline — especially for cellular networking equipment, the item circled in column 2 — they are slower than price declines estimated for computing equipment (lines 5 to 7).

Second, computer price declines have slowed in the past decade and the gap between rates of decline for computers and communications equipment has dwindled from about 20 to 10 percentage points.

Third, the greatest computer declines, and the greatest gap, occurs in the 1994 to 2000 period, when MPU prices were falling especially fast

**Table 2: Price Change for Selected High-tech Products in the United States, 1994-2014
(average annual rate of change)**

	1994- 2004	2004- 2014	1994- 2000	2000- 2004	2004- 2008	2008- 2014
	(1)	(2)	(3)	(4)	(5)	(6)
<i>Research indexes:</i>						
1. Data networking (a)	-13.5	-12.1	-13.6	-13.0	-9.7	-13.6
2. Local loop transmission	-18.4	-14.2	-13.8	-24.7	-14.4	-14.1
3. Cell networking	-17.5	18.4	-18.6	-15.8	-13.5	-21.5
4. Cell phones	-19.4	-15.9	-17.7	-21.9	-15.3	-16.3
5. Computer servers	-29.4	-26.1	-28.4	-30.7	-30.8	-22.8
6. Computer storage	-49.2	-26.1	-54.5	-40.1	-30.1	-23.4
7. Personal computers	-30.3	-23.7	-36.8	-19.3	-30.2	-19.1
8. Prepackaged software	-9.6	-7.0	-10.3	-8.4	-6.8	-7.1
9. Desktop	-5.8	-4.0	-5.3	-6.5	-3.9	-4.0
10. Enterprise and related	-11.4	-8.4	-12.6	-9.4	-8.2	-8.5
11. Telecom services, wireline (b)	-1.5	-5.8	-2.2	-3.4	-5.6	-5.9
12. Enterprise only (c)	-	-8.2	-	-	-8.4	-8.1
13. A/V equipment	-9.0	-16.3	-7.1	-11.8	-15.8	-16.7
<i>Memo:</i>						
14. Computer mfg. industry (d)	-25.2	-19.8	-30.7	-22.7	-26.3	-15.1
<i>Official indexes</i>						
15. Computer servers	-22.2	-10.7	-24.8	-18.1	-17.9	-5.6
16. Computer storage	-13.3	-4.7	-14.8	-11.1	-5.6	-4.0
17. Personal computers	-25.1	-9.6	-29.0	-18.9	-16.9	-4.4
18. Prepackaged software	-5.2	-2.5	-5.0	-5.4	-2.3	-2.7
19. Telecom services, wireline (e)	-1.8	1.5	-2.2	-1.3	1.8	1.3
20. A/V equipment (f)	-7.8	-13.2	-6.2	-10.3	-13.0	-13.3
<i>Memo:</i>						
21. Computer mfg. industry (d)	-17.4	-11.8	-23.8	-17.4	-19.6	-6.1
<i>Performance measures (annual per cent change):</i>						
22. Microprocessor Units (MPUs) (g)	-59.9	-38.9	-64.2	-52.4	-36.9	-40.2
23. Smartphone storage (h)	23.9	-	16.5	49.5	90.9	-
24. Top500 computers (median) (i)	88.4	69.1	81.8	98.7	92.4	55.2

Sources: Lines 1-4 Byrne and Corrado (2015a,b); Lines 5-14 Byrne and Corrado (2017b), using McCallum (2002) and Byrne (2015) to inform line 6, Berndt and Rappaport (2001, 2003) to inform line 7, Abel et al. (2007) and Copeland (2013) to inform line 9, Gordon (1990) to inform line 13, and Grimm (1998) and Byrne, Oliner and Sichel (2015) to inform line 22. The source for lines 15 to 21 is BEA. The source for line 23 in Hilbert and Lopez (2011). The source for line 24 is authors' estimates using data from <http://www.top500.com>.

Notes: a. Column 1 is from start date of series (1986). b. Nonresidential. c. Columns 2 and 5 are from start date of series (2006). d. NAICS 334111. e. Nonresidential, calculated by authors. f. PCE index excluding recording media, calculated by authors. g. Quality-adjusted price index using performance measures from 2000 on. h. Capacity in MB. i. MFLOPS per second.

(line 23). The post-2004 slowdown in microprocessing units (MPU) prices is not evident in servers (line 5) or PCs (line 7) until the 2008-

2014 period however. Price declines for storage equipment also slowed in the post-2004 period as technical challenges emerged for advancing

both the magnetic density of hard disk drives and the feature density of flash memory used in solid state drives (Byrne, 2015). Finally, and by contrast, prices for enterprise and other software products (which includes systems software as well as application software) maintained relatively strong declines through the most recent period (the items circled in line 10).²⁷

From equation (9), prices for cloud computing and storage services are closely tied to the asset prices just discussed. However, imperfect competition and other fixed costs (in the form of non-ICT assets) create potential for these prices to deviate from the prices of the underlying ICT assets. Services of non-ICT capital assets (including land) are not an appreciable fraction of total capital income in the information processing services industry (16 per cent), which includes cloud computing and storage services, but they are more material (33 per cent) for the broadcasting, telecom and internet access services industry.²⁸

What direct evidence is available for ICT service prices? Press reports have highlighted declines of 20 to 30 per cent per year at major cloud service providers.²⁹ Silicon Valley's Mark Andreessen, co-founder of Loudcloud, the first cloud computing company, wrote in the Wall Street Journal in 2011, "... the cost to a customer running a basic internet application [at Loudcloud] was approximately \$150,000 per month [in 2000]. Running that same application today in Amazon's cloud costs about \$1,500 per month" (Andreessen, 2011). Andreessen's fig-

ures imply a price drop of more than 40 per cent per year during the first decade of the 2000s. Byrne, Corrado, and Sichel (2017b) construct price indexes for storage, computing, and database services offered by Amazon, Microsoft and Google from 2009 forward and find average prices declines on the order of 10 to 15 per cent per year, with notable acceleration when Google and Microsoft achieved significant scale in the commercial market.

We also examined prices for the enterprise segment of wireline telecom service using data from a telecommunications consultancy, Telegeography, who reports prices of individual service offerings for four groups of enterprise business services (virtual private network; dedicated internet access; IP private line, domestic; and IP private line, international) from 2006 onwards. The results of computing a matched model price index for enterprise wireline telecom services yields a price index that falls 8.2 per cent per year from 2006 to 2014.

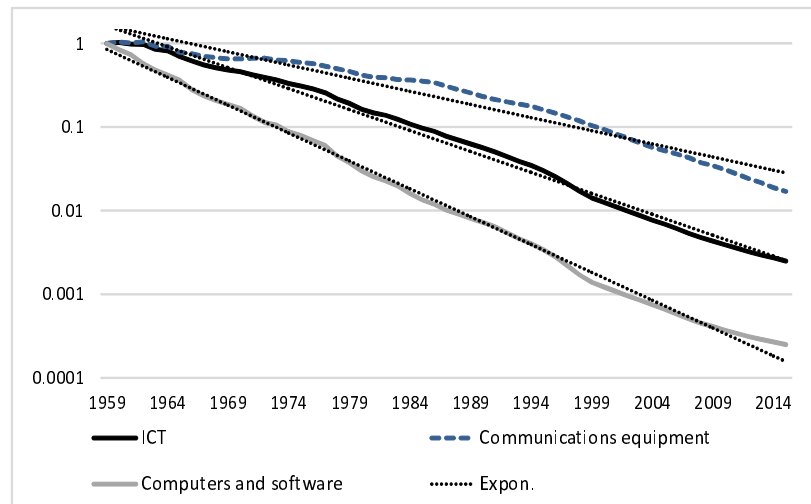
The results summarized in the previous paragraph are on par or slightly faster than the results of the price index for enterprise software (line 10); the results are also similar to the price indexes for the relevant telecom equipment (lines 1 and 2) and somewhat below the relevant computing equipment prices (lines 5 and 6). These comparative results suggest that the aggregate ICT asset price index might be a reasonable proxy for ICT services price change, consistent with the model and analysis in section 1.

27 The software products price measures were developed for use in this study, and the new indexes are documented in our companion article (Byrne and Corrado, 2017b). The inclusion of system software, whose prices are falling relatively rapidly, and the construction of an explicit component for enterprise software are the major innovations; the enterprise software price measure is an important anchor in our analysis of ICT services prices.

28 Non-ICT capital income asset shares are derived from the detailed capital measures for the NAICS 515 and 517 and NAICS 518 and 519 industries from 2004 and 2014 as reflected in the BLS MFP database (accessed July 1, 2016).

29 In March, 2014, Google announced price cuts for "virtually all" its cloud computing and storage services of 30 per cent, only to be followed in May, 2015, by further cuts in the 20 to 30 per cent range (Lardinois, 2014; Yegulalp, 2015).

Chart 10: Real ICT Investment Prices in the United States, 1959-2014, 1959=1



Source: Nominal price change reported in Appendix Table A2 available at http://www.csls.ca/ipm/33/Byrne_Corrado%20Appendix.pdf, whose construction is described in Byrne and Corrado (2017b). Real prices are relative to BEA's GDP deflator.

New ICT Investment Prices Indexes

To assess the macroeconomic implications of the ICT goods and services prices just discussed, the indexes must be folded into national accounts-style investment price indexes. Detailed components of the investment price indexes are reported in the Appendix, where it may be seen that the results are largely presaged by the results presented in Table 2.³⁰

Chart 10 and Table 3 report key results in terms used to assess the course of the relative productivity differential of the ICT sector (p) and its current and historical misstatement. The real price of communication equipment falls below its simple long-term trend after 2000 and has remained there since then. The combined real price for computers and software has not shown large deviations from trend, but note it did fall below trend beginning in the mid-1990s but returned to it by about 2004 and flattened further after that. The aggregate real ICT price index is spot on its long-term trend in 2014 — 11.5 per cent per year (in log changes).

Table 3 shows that while real ICT price declines have gradually slowed at 9.9 per cent per year in the 2004-2014 period compared to 12.7 per cent in the 1987-2004 period (line 1, column 3), the recent experience is not all that far from the long-term trend shown in Chart 10. From 2004 to 2014, the estimate of real ICT price change is 5.8 percentage points per year lower than suggested by official data (line 8, columns 3 and 2). In terms of component contributions to real ICT price change (lines 5 to 7), the contribution of software from 1994 on is particularly noteworthy and owes, in part, to its growing share. But all told, in terms of differences relative to BEA (lines 9 to 11), all three components make similar contributions to the estimated nearly 6 percentage point per year understatement of overall ICT price declines in recent years (column 6).

Implications

Chart 11 updates the picture of real ICT price change in Panel B of Chart 1 to include the new

30 The Appendix can be found at www.csls.ca/ipm/33/Byrne_Corrado%20Appendix.pdf

Table 3: Real ICT Investment Price Change in the United States, 1963-2014 (average annual rate of change)

	1963- 1987	1987- 2004	2004- 2014	1994- 2004	2004- 2008	2008- 2014
	(1)	(2)	(3)	(4)	(5)	(6)
1. ICT investment	-9.5	-12.7	-9.9	-14.1	-11.3	-8.9
2. Communications equipment	-4.5	-9.4	-10.5	-10.7	-9.9	-11.0
3. Computers and peripherals	-21.2	-23.0	-19.0	-25.4	-23.9	-15.6
4. Software	-5.8	-6.6	-5.7	-7.3	-6.1	-5.5
<i>Contributions to line 1:</i>						
5. Communications equipment	-2.4	-3.1	-2.7	-3.4	-2.7	-2.7
6. Computers and peripherals	-5.8	-7.0	-4.0	-7.6	-5.4	-3.0
7. Software	-1.3	-2.6	-3.2	-3.1	-3.2	-3.2
<i>Memos:</i>						
<i>Line 1 less BEA estimates:</i>						
8. ICT investment	-2.1	-4.2	-5.8	-4.8	-5.5	-5.9
<i>Contributions to line 8:</i>						
9. Communications equipment	-1.7	-1.4	-1.6	-1.3	-1.2	-1.8
10. Computers and peripherals	-0.1	-1.9	-2.2	-1.8	-2.3	-2.1
11. Software	-0.3	-0.9	-2.0	-1.7	-2.0	-2.1

Note: Contributions are in percentage points. Real prices are relative to BEA's GDP deflator as of May 2016.

Source: Authors' estimates. The corresponding nominal prices are shown in Appendix A2 found at http://www.csls.ca/ipm/33/Byrne_Corrado%20Appendix.pdf. Their derivation is set out in Byrne and Corrado (2017b).

estimate reported on line 1 of Table 3. According to the new estimate real ICT price change is still estimated to have gradually lost force in recent years, but the current pace of change remains in strongly negative territory. From a macroeconomic perspective as highlighted by the two-sector model, this is the crucial result for continuing to regard ICT — either via investment, purchased services, or production — as a driver of economic growth in the future. Chart 11 further suggests that the newly estimated pace of real ICT price change from the mid-1990s through the early 2000s was extraordinary, and the experience likely is a poor indicator of relative ICT productivity going forward.

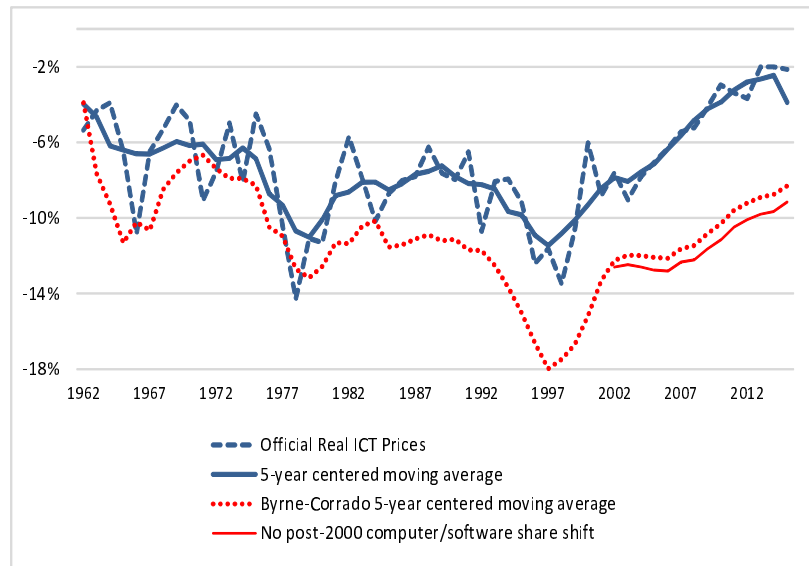
A calibration of the solution to the two-sector model set out in equation (7) based on parameters drawn from the most recent ten-year period

for which data are available implies a still large contribution of ICT to output per hour growth — 1.4 percentage points per year. This of course assumes that these parameters are reasonable, which we shall detail in a moment. Regarding the assumption of balanced growth, empirics will be sensitive to the actual over-the-period changes in factor utilization and/or the cost of capital from 2004 to 2014, and these changed little on balance.³¹ The balanced growth assumption is in this sense not unreasonable, and we use calculations for the 2004 to 2014 period as indicative of what we might expect ICT to contribute to growth in total economy labour productivity growth going forward.

Column 2 of Table 4 shows the components of this estimated ICT contribution. (Column 1 shows calculations for the prior ten-year period

31 See updated figures for the utilization adjustment in Fernald (2012) at <http://www.frbsf.org/economic-research/indicators-data/total-factor-productivity-tfp/> and updated figures of stock market returns in Shiller (2000) at <http://www.econ.yale.edu/~shiller/data.htm>, respectively (accessed September 2017).

Chart 11: Real ICT Price Change in the United States, 1963-2014, Redux



Source: Authors' calculations.

for reference only.) The first component of the contribution is the sum of the ICT use and diffusion effects, which is 1.1 percentage points per year (line 2, column 2). As shown on lines 2(a) and 2(b), this reflects the large income share for ICT assets and ICT services revenues (also shown in Chart 9) multiplied by a productivity differential for ICT assets that is nearly 10 percentage points per year (taken from Table 3, line 1, column 3). The second component is the production effect — 0.3 percentage points per year. This reflects a productivity differential for ICT production in the United States (software products, EO originals, and consumer ICT services) of 5.75 percentage points per year and a rather small final output share. Factory production of ICT equipment in the United States all but dried up since 2004, and the software productivity differential is applied to other domestically-produced ICT components of final demand following the logic of the two-sector model.

The memo items in Table 4 shed light on why our calculation of the ICT contribution is so high. There are three reasons. First, the conven-

tionally calculated contribution of ICT to labour productivity growth (i.e. via the rate of growth of ICT capital per worker) does not factor in business use of cloud computing; nor does it factor in purchases of ICT consulting services that capture design services for private clouds, and possibly data analytics and related Artificial Intelligence services. Collectively, we call this the “ICT diffusion effect.” The channel is estimated to be 0.4 percentage points per year, line 2 less line 4b, (after rounding) and is measured by an appropriate weight times the relative ICT productivity differential. A second reason why our calculation of the ICT contribution is high is our inclusion of EO capital, which is worth 0.2 percentage points per year, line 2 less line 4b, (after rounding). Together these sum to a tidy 0.5 percentage points per year.

The third reason for our large estimated ICT contribution is the new estimates of ICT price change that imply that the growth rate of output per hour would be higher by 0.22 percentage points per year from 2004 to 2014 if official measures were adjusted to reflect the research

Table 4: ICT Contributions to Growth in Output Per Hour in the United States (percentage points, average annual rate)

	1994 to 2004 (1)	2004 to 2014 (2)
1. Total ICT	1.8	1.4
<i>of which:</i>		
2. ICT use and diffusion effect	1.2	1.1
(a) Weight (ratio): $\frac{\bar{v}_{K_T} + \bar{v}_{S_T}^N}{\bar{v}_L}$	0.085	0.113
(b) Productivity differential: $-\dot{p}$	14.0	9.9
3. ICT production effect	0.6	0.3
(a) Weight (ratio): $\bar{w}_T$	0.055	0.056
(b) Productivity differential: $-\dot{p}$	10.6	5.8
<i>Memos:</i>		
4. Line 2 excluding:		
(a) Diffusion effect	0.9	0.8
(b) EO capital	1.0	0.9
(c) Both diffusion and EO	0.7	0.6
5. Effect of ICT price misstatement on:		
(a) Growth in output per hour	0.27	0.22
(b) Use effect	0.30	0.44

Notes: Contributions are based on equation (7) where the diffusion effect is the contribution of ICT business services to productivity growth. Line 2 (a) is ratio to labour share of total domestic income, and line 3 (a) is ratio to total nominal GDP. Lines 2 (b) and 3 (b) are estimates of productivity differentials in annual percentage changes. Line 2 (b) is the differential for all ICT assets whereas line 3 (b) is an estimate for final ICT goods and services.

Source: Calculations use estimates reported in Table 4 and Chart 9.

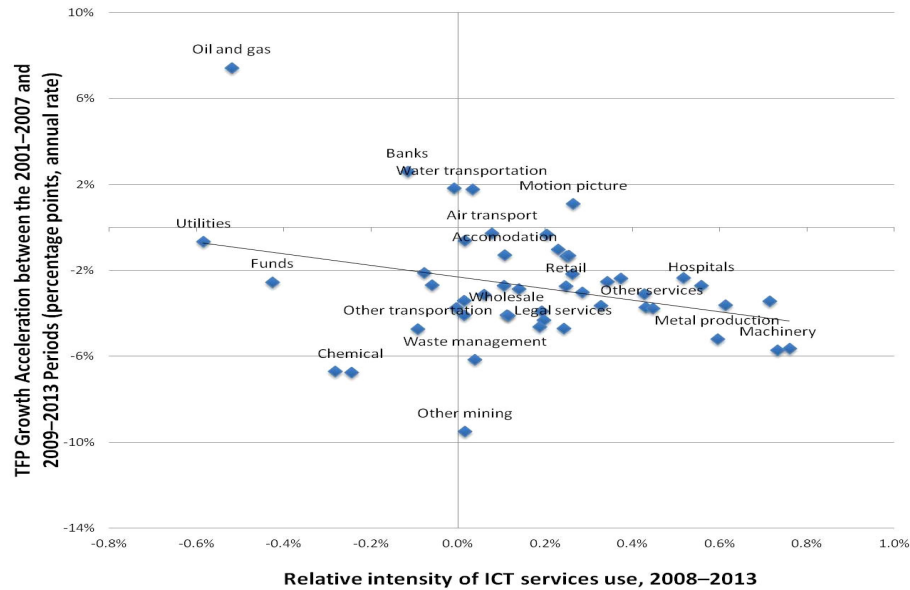
reported in this article (Table 4, line 5(a), column 2).³² But as shown on line 5(b), the conventional use effect (or ICT capital deepening) would be 0.44 percentage points higher — and this in turn implies that growth in total factor productivity (the difference between the adjustment to growth in output per hour and the adjustment to capital deepening) has been 0.2

percentage points more dismal than recorded in official estimates.³³ Moreover, the implied contribution of the non-ICT-producing sector to total factor productivity growth is unbelievably dismal after accounting for the ICT asset price misstatement and excluding the expected ICT diffusion effect via purchased services, -0.18 percentage points per year. In the prior ten-year

32 The precise calculation is the 2004 to 2014 ICT final output share $\bar{w}_T$ reported on line 3 (a) (and shown in Chart 8) times 3.9 percentage points, which is this study's estimate of software asset price change from 2004 to 2014 (sign reversed, i.e. -3.8 per cent per year less the change in BEA's official index of 0.1 per cent per year). This result is in the same ballpark as the findings reported in Byrne *et al.* (2016).

33 According to BLS figures for "output per unit of combined inputs" in their Total Economy Production Account Tables dated March 24, 2016, TFP for the total U.S. economy grew 0.4 per cent per year from 2004 to 2014, compared with 1.3 per cent per year from 1994 to 2004. Thus, the ICT price measures reported in this article, given existing GDP in all other regards, imply that TFP for the total U.S. economy likely edged up only 0.2 percentage points per year from 2004 to 2014.

Chart 12: TFP Growth Acceleration in the United States Between the 2001-2007 and 2009-2013 Periods and ICT Services Use, 2008-2013



Notes: Relative intensity is the use or investment rate averaged over the period indicated relative to its trend over the previous decade. ICT-producing industries and outlier industries are excluded. The outlier industries are: apparel, leather and allied product manufacturing; securities, commodity contracts, and investments; rental and leasing services and lessors of intangible assets; and management of companies.

Sources: Authors' elaboration of data from the US Bureau of Labor Statistics and US Bureau of Economic Analysis.

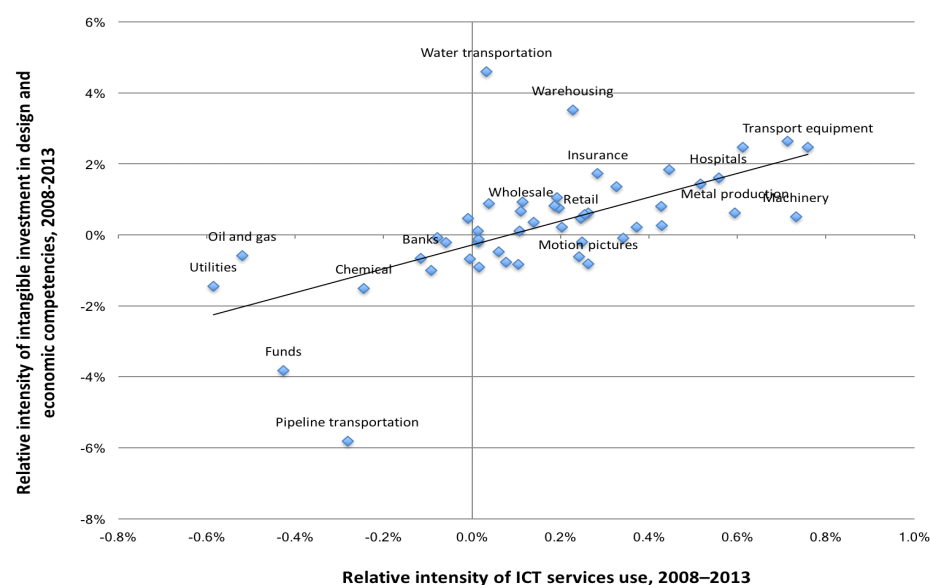
period, the comparably calculated contribution was 0.95 percentage points per year.

Having suggested that comparing the 2004-2014 period with the preceding 10 years period was problematic, consider now temporary factors that may have disturbed productivity outcomes during recent years. In particular, from the discussion of macroeconomic implications in section 1 consider that:

- computer demand is unlikely to remain as weak looking ahead as it has been during a period when firms have been adjusting to a cloud platform;
- weak demand and slow income growth during the Great Recession obscured non-ICT producers' cost savings from increased ICT capital utilization owing to adoption of cloud technologies.

With regard to the first point, the bottom line in Chart 11 shows a counterfactual for the post-2000 period for real ICT price change in which the computer and software investment shares did not shift after 2000. The counterfactual closes the gap between the end point of the centered moving average of real ICT price change (about 9 per cent) and the long-term trend used to determine the contribution of ICT to growth in output per hour (about 10 per cent). We believe this mitigates the concern that ICT price change continued to slow over the 10 year period used to calibrate the model, i.e. that the calibrations are based on an adjustment phase during which growth in unit computer demand has been substantially diminished by the spread of cloud technologies, leading actual ICT price declines to have been unusually slow (per the

Chart 13: Intangible Investment and ICT Services Use in the United States, 2008-2013



Notes: Relative intensity is the use or investment rate averaged over the period indicated relative to its trend over the previous decade. ICT-producing industries and outlier industries are excluded. The outlier industries are: apparel, leather and allied product manufacturing; securities, commodity contracts, and investments; rental and leasing services and lessors of intangible assets; and management of companies. Business competencies refer to design and economic competencies such as brand, organizational structure, and firm-specific employee training.

Sources: SPINTAN (EU FP7 project under grant agreement No. 612774); INTAN-Invest per Corrado et al (2016); and elaboration of data from the US Bureau of Economic Analysis.

discussion of the impact of declines in underutilization on effective prices in section 1).

With regard to the second point, Chart 12 uses industry-level changes in total factor productivity growth before and after the Great Recession and relates them to the increase in intensity of ICT services use. The chart suggests that non-ICT producers have not reaped the gains in productivity that should have been enjoyed by the adoption of cloud platforms.³⁴ And Chart 13 suggests that the failure of non-ICT producers to reap productivity gains was not due to a lack of co-investments in the intangible assets that are especially crucial during the installation phase of new ICT platforms, e.g. investments in business process change and

employer-specific training (Brynjolfsson, Hitt, and Yang, 2002).

It is unclear why industries whose usage of ICT services increased the most after 2007 had weaker (or no greater) rates of change in productivity from 2009 to 2013 relative to prior performance despite their co-investments in ICT-related intangibles, but several possibilities are likely. First, the very swift pace of change in the ICT sector may have created adjustment costs that temporarily offset gains from adapting to the rapid pace of digital innovation.³⁵ Second, it is possible some ICT spending may be defensive, for example in cyber security. Third, the Great Recession may have induced firms to “pull forward” their plans to adopt cloud-based ICT

34 Although this study has shown a disturbing degree of price mismeasurement that would feed directly into the TFP estimates plotted in Chart 11, these concerns are somewhat ameliorated because the chart uses changes in the rate of productivity growth and examines non-ICT-producing industries only.

35 Adjustment costs were used to analyze the Solow paradox and step-up in productivity growth in the 1990s (e.g. Greenwood and Yorukoglu, 1997; Basu, Fernald, and Shapiro, 2001; Hall, 2001; Kiley, 2001).

systems, and the savings from doing so may have only staunched losses that were particularly severe among adopters. All told, the “diffusion” portion of the model’s “use and diffusion” effect of 1.1 percentage points per year contribution of ICT to labour productivity growth seems to have not only shut down, but may even be temporarily generating negative productivity spillovers. Because it is common, even fundamental, to regard innovation in upstream sectors as diffusing to downstream sectors through intermediates use, there is no reason to believe that this channel will not return in full force in the years ahead.³⁶

Summary and Conclusion

This article set out a two-sector model that illustrated how the ICT sector can have an outsized influence on economic growth via its relative productivity growth; the model, originally developed by Oulton (2012), was expanded to include ICT services for improved relevancy. A central feature of the model is that relative ICT asset prices reflect the relative productivity of the sector. Official measures of ICT prices suggest that the relative productivity of ICT capital has been gradually eroding since 2004 and that its current advantage is close to nil. We found no evidence in support of this central implication of the current official ICT price measures.

The article first found that ICT R&D has not only been well-maintained, but that software products R&D has been enjoying a stunning rise. If technical change in the ICT sector has ground to a halt, then the return to software R&D must have fallen dramatically, which seems unlikely in the face of more than a decade of relative growth in investments in this area and the advent of cloud technologies that should have boosted productivity in the conduct of software R&D.

Second, our model predicted strong growth in ICT services use and strong relative growth of ICT design services to the extent that cloud technologies has taken hold. The overt, first order macroeconomic effects of the transition to cloud technologies — weak computer hardware demand and increase in ICT capital utilization — are not easy to detect in macro-data. But strong relative growth in cloud services and systems design services (i.e. relative to GDP) is a key feature of the current ICT landscape and one sign that innovation is still driving the sector. All told, via the user cost relationship as well as the article’s two-sector model, we also found that ICT services price change is driven by ICT asset price change; the alternative ICT asset price change measures reported — especially the 26 per cent annual decline in real prices for servers and storage equipment (15 and 21 percentage points faster, respectively, than drops in official prices for these assets; as reported in Table 2) — are consistent with press reports that suggest prices for cloud services are dropping rapidly.

More broadly, the article introduced new measures for ICT asset price change that incorporated available research as well as new work conducted expressly for this study. The ICT asset price measures were based on more than a dozen new ICT product price indexes, and the new ICT investment price indexes for communication equipment, computers, and software were developed to be as coherent as possible with national accounts practices. The new results feature substantial innovations for total telecom equipment, computer servers, software products, and enterprise telecom services (wireline). Although much new evidence on ICT asset prices and ICT services prices was marshaled for the analysis reported in this article, large gaps in evidence remain — enterprise soft-

36 Byrne, Oliner and Sichel (2017) also discuss the dismal pace of TFP growth in the non-ICT sector. Braenstedder and Sichel (2017) point to several emerging technologies as potential sources of improving TFP.

ware products and differentiated computer design services are notable examples of these holes.

The article's primary conclusion that real ICT price declines remain squarely in negative territory suggests that the sector will continue to deliver an out-sized contribution to growth in output per hour — 1.4 percentage points per year in balanced growth. This figure is substantial in light of historical average output per hour growth of 2 per cent and compared to the extraordinarily weak productivity growth in recent years.

The figure emerges from two sources documented in this study: first, an ICT income share that has continued to expand along with the relative growth of ICT services, and second, a rate of real ICT price change that has declined more than 10 per cent per year since 1959 and currently is understated by nearly 6 percentage points.

Although the current weakness in output per hour growth owes at least in part to headwinds unrelated to ICT, correlations in the available industry-level data show that total factor productivity in non-ICT producing industries has not been improving along with increased ICT services use. Additional research is needed to deepen our understanding of the linkages between measured productivity, firm performance and firm spending on ICT assets and ICT services.

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Appendix

A1 The steady-state solution of the two-sector model

Model. Lower case variables are per hour versions of inputs and outputs introduced in the text, i.e., $x_i^j = X_i^j/H^j$ is the per hour form of variable X where $i = T, N$ denotes type of good or service where relevant (i.e., ICT or other types), and $j = T, N$ denotes sector of use (ICT-producers or other producers). As in the Oulton model, the sector production functions are Cobb-Douglas and written here in per hour form as :

$$(A1) \quad q_N = A_N (k_T^N)^\alpha (k_N^N)^\beta (s_T^N)^\gamma (h_N)^{1-\alpha-\beta-\gamma}$$

and

$$(A2) \quad q_T = A_T (k_T^T)^\alpha (k_N^T)^\beta (s_T^T)^\gamma (h_T)^{1-\alpha-\beta-\gamma}$$

The functions for the two sectors are identical except for TFP (the Hicksian shifter) whose growth rates μ_T and μ_N are exogenous.

The supply-use equations for the open economy version of the model are

$$(A3) \quad Y = C + I + X - M ; \quad Y = Y_T + Y_N \quad \text{where} \\ Y_T = C_T + I_T - M_C - M_I ; \quad Y_N = C_N + I_N + X_C + X_I .$$

Imports $M = M_C + M_I$ are imports of ICT goods, and exports $X = X_C + X_I$ are exports of all other goods, i.e, the economy is an (net) importer of ICT and a (net) exporter of all other types of output. Next, we assume input supplies must equal demands, so that $H = H_N + H_T$ and $K_i = \sum_j K_i^j$, $j = T, N; i = T, N$. Accumulation equations are given by

$$(A4) \quad \dot{K}_N = I_N - \delta_N K_N$$

$$(A5) \quad \dot{K}_T = I_T - \delta_T K_T$$

Recalling that $p = P_T/P_N$, a steady state in this model is when trade is balanced $X = pM$ and when the real interest rate r and proportions of total hours allocated to each sector H_i/H ($i = T, N$) are constant. With sectoral hours shares constant in steady state growth, for sectoral and overall output per hour to grow at a constant rate it follows that the services share of ICT production must also be constant. This follows from the definitions:

$$(A6) \quad Q_T \equiv Y_T + S_T^N \quad \text{and} \quad Q_N \equiv Y_N$$

where in the steady state, the growth rate Q_N and Y_N (and thus q_n and y_n) are identical by definition. The growth rate of Q_T is a (constant) share-weighted average of the growth rates of Y_T and S_T^N , which grow at the same rate, and thus imply $\dot{q}_T = \dot{y}_T$ in steady growth.

Note also that with sectoral hours shares constant in steady state growth, output-per-hour (OPH) growth in the total economy is a share-weighted average of the growth rates of OPH growth in each of the sectors, i.e., accounting for “labor reallocation” due to shifts in hours shares is not needed.

Growth rate of relative ICT prices ($\dot{p}$). Given the model's assumption that production functions are the same up to a scalar multiple, it is easy to see that the rate of change in relative ICT prices $\dot{p}$ (where recall $p = \frac{P_T}{P_N}$) is given by

$$(A7) \quad \dot{p} = \mu_N - \mu_T < 0$$

Equation A7 is proved by total differentiation of the payments equations, text equation (4), with respect to time. With μ_N and μ_T constant by assumption, so too is $\dot{p}$.

Growth rate of output per hour. To obtain the steady state growth rates of labor productivity, first differentiate equation (A1) and (A2) with respect to time, which gives

$$(A8) \quad \dot{q}_N = \mu_N + \alpha \dot{k}_N^N + \beta \dot{k}_T^N + \gamma \dot{s}_T^N + (1 - \alpha - \beta - \gamma) \dot{h}$$

$$(A9) \quad \dot{q}_T = \mu_T + \alpha \dot{k}_N^T + \beta \dot{k}_T^T + \gamma \dot{s}_T^T + (1 - \alpha - \beta - \gamma) \dot{h}$$

where from (A6) we have

$$(A10) \quad \dot{q}_N = \dot{y}_N \quad \text{and} \quad \dot{q}_T = \dot{y}_T \quad .$$

Consider first the N sector. Profit maximization requires that the real user cost equals the real marginal product of capital, which for nonICT and ICT capital are given by

$$(A11) \quad (i + \delta_N) = \alpha \frac{q_N}{k_N^N} \quad \text{and} \quad (i + \delta_T - \dot{p})p = \beta \frac{q_N}{k_T^N} \quad .$$

where i is the nominal rate of interest and the real interest rate is the nominal rate minus the growth rate of the N sector price P_N , expressed in terms of the relative price p in (A11).

In steady state where the real interest rate is constant and factors are paid their marginal products, the solutions for sector N are then

$$(A12) \quad \dot{q}_N^* = \dot{y}_N^* = \dot{k}_N^{N*}$$

$$(A13) \quad \dot{q}_N^* = \dot{y}_N^* = \dot{k}_T^{N*} + \dot{p}$$

where $*$ denotes a steady state solution (recall $\dot{p}$ is constant by assumption).

Consider now the T sector. Equality of the real marginal product of ICT capital in T sector production with real user cost implies

$$(A14) \quad (i + \delta_T - \dot{p}) = \beta \frac{q_T}{k_T^T}$$

Because the left hand side of (A14) is constant, it follows that $\dot{q}_T = \dot{k}_T^T$ from which it follows:

$$(A15) \quad \dot{q}_T^* = \dot{y}_N^* - \dot{p} \quad .$$

In steady state growth, output per hour in sector T grows faster than output per hour in sector N .

Finally, equality of the real marginal product of ICT intermediate services across the two sectors implies that

$$(A16) \quad \frac{\partial q_N}{\partial s_T^N} = \gamma \frac{q_N}{s_T^N} = \gamma \frac{Y_N}{S_T^N}$$

must be identical to

$$(A17) \quad \frac{\partial q_T}{\partial s_T^T} = \gamma \frac{q_T}{s_T^T} = \gamma \frac{Y_T + S_T^N}{S_T^T}$$

Equation (A16) implies that $\dot{s}_T^N$ is equal to $\dot{y}_N$ in steady state growth but from (A15), we know that q_T , of which s_T^N is a component, grows at a faster rate than $\dot{y}_N$. It is readily seen that the condition $\dot{q}_T = \dot{y}_T$ solves this dilemma and implies

$$(A18) \quad \dot{s}_T^N = \dot{y}_N - \dot{p}$$

$$(A19) \quad \dot{y}_T = \dot{y}_N^* - \dot{p} \ .$$

Now substitute equations (A12), (A13), and (A18) into (A8), the expression for growth in output per hour in sector N :

$$\dot{y}_N = \mu_N + \alpha \dot{y}_N + \beta(\dot{y}_N - \dot{p}) + \gamma(\dot{y}_N - \dot{p}) + (1 - \alpha - \beta - \gamma)\dot{h}$$

which after rearranging terms yields

$$(A20) \quad \dot{y}_N = \frac{\mu_N - (\beta + \gamma)\dot{p}}{(1 - \alpha - \beta - \gamma)} + \dot{h} \ .$$

Define the steady state output share of the T sector as

$$(A21) \quad \omega_T^* = \frac{pY_T}{Y_N + pY_T}$$

in which case the steady state OPH growth rate for the total economy may be written as

$$(A22) \quad \begin{aligned} \dot{y}^* &= (1 - \omega_T^*)\dot{y}_N^* + \omega_T^*\dot{y}_T^* \\ &= \dot{y}_N^* + \omega_T^*(\dot{y}_T^* - \dot{y}_N^*) \ . \end{aligned}$$

Substituting (A19) into (A22) yields

$$\dot{y}^* = \dot{y}_N^* - \omega_T^*\dot{p}$$

and substituting (A20) into this expression and combining terms yields our final result, an expression for the contribution of the ICT sector to total OPH growth:

$$(A23) \quad \begin{aligned} \dot{y}^* &= \frac{\mu_N - (\beta + \gamma)\dot{p}}{(1 - \alpha - \beta - \gamma)} + \dot{h} - \omega_T^*\dot{p} \\ &= \frac{\mu_N}{(1 - \alpha - \beta - \gamma)} + \dot{h} + \underbrace{\frac{(\beta + \gamma)(-\dot{p})}{(1 - \alpha - \beta - \gamma)} + \omega_T^*(-\dot{p})}_{\text{Contribution of ICT to total OPH growth}} \end{aligned}$$

The final term in equation (A23) appears as text equation (7) where $\beta, \gamma, (1 - \alpha - \beta - \gamma)$, and ω_T are replaced by their empirical counterparts $\bar{v}_{KT}, \bar{\zeta}_T^N, \bar{v}_L$, and $\bar{w}_T$.

Contribution of ICT to growth in TFP The amended model's solution for aggregate TFP μ also is different than that implied by the original Oulton model. Under the usual neoclassical growth accounting assumptions in the presence of intermediates (e.g., Hulten 1978), the growth of aggregate

TFP is the sum of the growth of each sector's TFP growth times its Domar-Hulten weight, which is the ratio of each sector's sectoral production (gross output net of own use) to aggregate value added, $P_i Q_i / PY$. From (2) and (5), these weights are expressed as:

$$\frac{P_T Q_T}{PY} = \bar{w}_T + \bar{\zeta}_T^N \quad ; \quad \frac{P_N Q_N}{PY} = 1 - \bar{w}_T$$

whose sum is greater than one by the relative size of ICT services supplied to nonICT producers.

The growth of aggregate TFP μ is then given by

$$(A24) \quad \mu = \underbrace{(\bar{w}_T + \bar{\zeta}_T^N) \mu_T}_{\text{Contribution of ICT sector}} + (1 - \bar{w}_T) \mu_N$$

The contribution of the ICT sector to overall TFP growth is larger than the sector's share in final demand $\bar{w}_T$ to account for the diffusion of the sector's innovation via use of ICT services (intermediate inputs) by other producers in the economy.

A2 Nominal ICT investment deflators

The table below shows detailed components of the nominal national accounts-style price deflators calculated for the analysis in this paper. The methods used to construct these deflators are described in detail in our companion paper (Byrne and Corrado, 2017b).

Table A1: **Nominal ICT Investment Price Change (annual rate)**

	1963 to 1987 (1)	1987 to 2004 (2)	2004 to 2015 (3)	1994 to 2004 (4)	2004 to 2008 (5)	2008 to 2015 (6)
1. ICT investment	-4.9	-10.6	-8.0	-12.4	-8.9	-7.5
2. Communication equipment	.4	-7.3	-8.7	-9.1	-7.4	-9.5
3. Telecom	-.3	-11.7	-12.4	-14.3	-10.1	-13.7
4. Other equipment	.4	-8.3	-9.3	-10.3	-8.1	-10.0
5. Capitalized services	—	1.1	-3.7	-.1	-2.5	-4.3
6. Computers and peripherals	-17.1	-21.2	-17.0	-24.0	-21.8	-14.1
7. Servers and storage	-18.1	-25.2	-25.7	-31.0	-30.6	-22.7
8. PCs	—	-27.9	-23.4	-30.3	-30.2	-19.2
9. Other equipment	-9.0	-9.3	-3.3	-8.8	-5.4	-2.0
10. Capitalized services	—	-2.0	-2.2	-3.1	-1.5	-2.6
11. Software	-1.0	-4.4	-3.9	-5.5	-3.5	-4.1
12. Prepackaged	-9.8	-9.0	-7.0	-9.6	-6.8	-7.2
13. Custom and own-account	.0	-2.0	-2.2	-3.1	-1.5	-2.6
<i>Memos:</i>						
14. ICT excluding PCs	-4.5	-8.4	-6.5	-9.9	-6.6	-6.4
15. Computers excluding PCs	-16.6	-17.1	-11.6	-19.8	-14.5	-9.9
16. BEA ICT	-2.7	-6.4	-2.1	-7.5	-3.3	-1.4
17. BEA ICT excluding PCs	-2.6	-4.5	-1.4	-5.2	-1.9	-1.2
18. Computers excluding PCs	-16.6	-11.0	-3.6	-12.7	-6.6	-1.8

NOTE: Figures reported as "BEA" are authors' calculations based on BEA data.

Productivity Measurement in Global Value Chains

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ABSTRACT

Increasing fragmentation of production is posing new challenges to the measurement of productivity. Traditional approaches focus on firms, industries or countries as the unit of analysis. In this article we argue that studies of global value chains (GVCs) are needed. We introduce the GVC accounting approach as a complement to traditional KLEMS type productivity studies. We define cost shares and productivity growth and show how they can be empirically implemented using synthetic input-output tables. We discuss advantages of the new approach, provide caveats and outline new areas of research and statistics in order to better understand today's global production systems.

Increasing fragmentation of production processes is posing new challenges for the analysis and measurement of productivity. Traditional approaches focus on firms, industries or countries as the unit of analysis. In this article we argue that studies of global value chains (GVCs) are needed in situations where production is highly fragmented across firms and geographical borders.

Global value chains refer to the combined set of production stages that are needed to produce a final good. Due to improvements in information and telecommunication technologies, production processes increasingly fragment across borders in order to gain from access to cheap resources, both natural and human, as well as to acquire customer market access.

This process was boosted in the 2000s as major emerging economies like China and India

opened up borders and became integrated into the world economy. As a result now a production process of a good typically consists of a set of different activities in various stages of production which can be carried out in many places around the world. For example, an iPad is designed in California, but assembled in Shenzhen, China on the basis of more than a hundred components manufactured around the world, with logistics handled by a Hong Kong firm. This is referred to as global value chain (GVC) production.

The emergence of GVCs raises many new questions and its analysis requires novel methodologies and data. In this article we will review the conceptual and empirical issues that arise in analysing productivity in the context of international production fragmentation. We discuss how patterns of substitution and productivity growth can be measured in such chains and illus-

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trate this by empirical exercises using new data from the World Input-Output Database (WIOD). To this end, we will build upon the standard tool kit of production analysis, known as the KLEMS approach.

In their classical study of the US economy Jorgenson, Gollop and Fraumeni (1987) introduced this approach which is built around the concept of a gross output production function with two groups of factor inputs, capital (K) and labour (L), and three groups of intermediate inputs, energy (E), materials (M) and services (S). This approach offers useful insights into the changes in efficiency with which the inputs are being used in the production process of the industry (or firm) as measured by productivity growth. It also offers the conceptual framework to analyse econometrically the various substitution elasticities between inputs, as well as possible biases in productivity change. The KLEMS approach has become a standard tool in the applied economist's tool kit.

However, modelling and measuring patterns of substitution and productivity growth at the industry (or firm) level has become both more difficult and less meaningful. With increased outsourcing and offshoring, the share of industry value added in gross output is declining such that analysis based on industry value added have to rely on strong assumptions of separability. Conditions that are jointly necessary and sufficient for the existence of sectoral value added functions are typically rejected, and intermediate inputs should be treated symmetrically with factor inputs (Jorgenson, Gollop and Fraumeni, 1987; Diewert and Wales, 1995). As ratios of imported intermediate input to gross output continue to increase, the robustness of this approach becomes increasingly dependent on proper price measurement of intermediate inputs. However, tracking prices of intermediate inputs is challenging, in particular when they

are imported and/or contain intangible characteristics (Houseman and Mandel, 2015).

In this article we outline how the existing KLEMS methodology can be modified to analyse GVC production and what type of data would be needed. We argue that in order to understand trends in productivity and technical change in global production, one needs to go beyond the traditional analysis of separate industries (or firms) and focus on a set of discrete activities in distinct locations, which altogether form a global value chain starting at the conception of the product and ending at its delivery. Unfortunately, our official statistical systems are not well equipped to identify the emergence and existence of these global production chains. We outline an approximation method to derive cost shares in GVCs, based on a linear system of cost equations rooted in the input-output approach introduced by Leontief (1936). Simply put, the production function G in the KLEMS approach is given by:

Gross output of industry = G (factor inputs in domestic industry, intermediate inputs)

Instead we will analyse a production function F where final output is produced based on factor inputs only, including both domestic as well as foreign factors.

Final output of product = F (factor inputs in all industries domestically and abroad)

Basically, in this approach the flow of intermediate inputs will be netted out such that the production function of a final good can be written in terms of factor inputs only. These factor inputs are located in the industry where the last stage of production takes place as well as in other industries (domestic and foreign) contributing in earlier stages of production. This opens up the possibility to study the various substitu-

tions of factor inputs and the possible biased nature of productivity change.

This GVC modelling approach will allow us to focus on three important issues. First, the increasing importance of intangible capital. GVC production entails not only a flow of goods and materials, but also of information, technology and managerial knowledge. It not only includes physical production processes but the full set of activities both in the pre- and post-production phases. This includes research and development, software, design, branding, finance, logistics, after-sales services and system integration. Recent case studies of electronic products such as the Nokia smartphone (Ali-Yrkkö and Rouvinen, 2015) and the iPod and laptops (Dedrick *et al.*, 2010) suggest that it is especially in these activities that most value is added. With international production however it has become more difficult to trace the profits for these capital assets. Due to among other factors transfer pricing and shifting of accounting profits, analyses of a single firm or industry might be inadequate. For example, a multinational might record its profits in a production facility abroad such that an analysis on domestic data will not reveal the importance of its capital inputs. This can only be accounted for in an analysis of cost shares of all factors of production used in any stage of production. Using this approach, Timmer *et al.* (2014) has shown that compensation for capital assets has been increasing, in particular in emerging economies.

Second, and related to the first, there is mounting evidence that suggests that advanced countries are increasingly specializing in skill- and capital-intensive activities within global value chains, more popularly described as a process of turning into "headquarter economies". This indicates that together with fragmentation the nature of production processes is changing: a firm or industry can no longer be characterised by its outputs (the products it is selling), but

only by what it does in terms of activities. Production fragmentation goes hand-in-hand with functional specialization across firms, regions and countries, and this needs to be studied in a coherent framework with explicit modelling of inter-industry linkages.

More generally, increasing international production fragmentation limits our understanding of the substitution and complementarity of various inputs in the production process, and the measurement of possible biases in technical change. Rather than studying this from the perspective of individual firms, industries or countries, one needs an approach in which the various stages of production are analyzed together.

General Approach and Terminology

A global value chain of a product is a description of all the factor inputs needed for its production, taking into account all phases of production, starting at conception and ending at its delivery. As such it can be viewed as a special case of vertically integrated production (Williamson, 1971), characterized by the fact that production stages are carried out in at least two countries. The coordination of the various stages can be done within a multi-national cooperation or it can be market mediated through arms-length transactions. Typically, it has a governance mode that lies within these two extremes (Antras and Yeaple, 2014). It is important to stress that our approach refers not only to the physical production process but to the full set of activities both in the pre- and post-production phases including research and development, software, design, branding, finance, logistics, after-sales services and system integration. Therefore Timmer *et al.* (2014) have proposed to use the term "global value chains" to distinguish this approach from studies of "global supply chains" or "international production

chains" that typically refer only to the physical production stages.

To analyse vertical integrated production we rely on a standard methodology that allows for a decomposition of the value of a final product into the value added by all factors (labour and capital) in any country that is involved in its production process. This decomposition method is rooted in the analysis introduced by Leontief (1936) in which the modelling of input-output (IO) structures of industries is central. The IO structure of an industry indicates the amount and type of intermediate inputs needed in the production of one unit of output such that one can trace the gross output in all stages of production that is needed to produce one unit of final demand. To see this, take the example of car production in Germany. Demand for German cars will in the first instance raise the output of the German car industry. But production in this industry relies on car parts and components that are produced elsewhere, such as engines, braking systems, car bodies, paint, seat upholstery or window screens, but also energy inputs, and various business services such as logistics, transport, marketing and financial services. These intermediate goods and services need to be produced as well, thus raising output in the industries delivering these, say the German business services industry, the Czech braking systems industry and the Indian textile industry. In turn, this will raise output in industries delivering intermediates to these industries and so on. These indirect contributions from both manufacturing and non-manufacturing sectors will be explicitly accounted for through the modelling of input-output linkages across sectors. When we know the gross output flows associated with a particular level of final demand, we can derive the value added by multiplying these flows with the value-added to gross-output ratio for each industry. By construction the sum of value added across all industries involved in production will

be equal to the value of the final demand. Following the same logic, one can also trace the number of workers that is directly and indirectly involved in GVC production, or the amount of capital (Timmer *et al.*, 2013, 2014).

Technical exposition

This section gives a mathematical exposition of our measurement framework grounded in the older literature on input-output accounting with multiple regions surveyed in Millar and Blair (2009). We start with the fundamental input-output identity and use this to derive an expression for the factor cost shares in the production of final products. Output in each country-sector is produced using domestic production factors and intermediate inputs, which may be sourced domestically or from foreign suppliers. Output may be used to satisfy final demand (either at home or abroad) or used as intermediate input in production (either at home or abroad as well). To track the shipments of intermediate and final goods within and across countries, it is necessary to define source and destination country-sectors. For a particular product, we define i as the source country, j as the destination country, s as the source sector and t as the destination sector. Each country(N)-sector(S) produces one good such that there are SN products. We use the term country-sector to denote a sector in a country, such as the French chemicals sector or the German transport equipment sector. Although we will apply annual data in our empirical analysis, time subscripts are left out in the following discussion for ease of exposition.

Product markets clear, so the quantity of a product produced in a particular country-sector must equal the quantities of this product used domestically and abroad. This condition can be written as

$$y_i(s) = \sum_j f_{ij}(s) + \sum_j \sum_t m_{ij}(s, t) \quad (1)$$

where $y_i(s)$ is the output in sector s of country i , $f_{ij}(s)$ the products shipped from this sector for final use in any country j , and $m_{ij}(s,t)$ the products shipped from this sector for intermediate use by sector t in country j . Note that the use of products can be at home (in case $i = j$) or abroad ($i \neq j$). Using matrix algebra, the market clearing conditions for each of the SN goods can be combined to form a compact global input-output system. Let y be the vector of production of dimension $(SN \times 1)$, which is obtained by stacking output levels in each country-sector. Define f as the vector of dimension $(SN \times 1)$ that is constructed by stacking world demand for final output from each country-sector $f_i(s)$. World final demand is the summation of demand from any country, such that $f_i(s) = \sum_j f_{ij}(s)$. We further define a global intermediate input coefficients matrix A of dimension $(SN \times SN)$. The elements $a_{ij}(s,t) = m_{ij}(s,t)/y_j(t)$ describe the output from sector s in country i used as intermediate input by sector t in country j , expressed as a ratio of output in the latter sector. Columns in the matrix A describe how the products of each country-sector are produced using a combination of various intermediate products, both domestic and foreign.

Using this we can rewrite the stacked SN market clearing conditions from (1) in compact form as $y = f + Ay$. Rearranging, we arrive at the fundamental input-output identity

$$y = (I - A)^{-1} f \quad (2)$$

where I is an $(SN \times SN)$ identity matrix with ones on the diagonal and zeros elsewhere. The matrix $(I - A)^{-1}$ is famously known as the Leontief inverse. The element in row m and column n of this matrix gives the total production of sector m needed for production of one unit of final output of product n . To see this, let z_n be a column vector with the n th element representing a euro of global consumption of goods from country-se-

ctor n , while all the remaining elements are zero. The production of z_n requires intermediate inputs given by Az_n . In turn, the production of these intermediates requires the use of other intermediates given by A^2z_n , and so on. As a result the increase in output in each sector is given by the sum of all direct and indirect effects $\sum_{k=0}^{\infty} A^k z_n$. This geometric series converges to

$$(I - A)^{-1} z_n \quad (3)$$

Using the Leontief inverse we can derive the total factor requirements of a unit of final output by netting out all intermediate input flows. Let us define $l_i(s)$ as the labour per unit of gross output in sector s in country i and create the row-vector l containing these 'direct' labour coefficients, and similar for capital coefficients k . Then the total (direct plus indirect) labour and capital requirements per unit of final output can be derived as

$$\Lambda = \hat{l}(I - A)^{-1}$$

and

$$K = \hat{\kappa}(I - A)^{-1}$$

in which a hat-symbol indicates a diagonal matrix with the elements of the vector on the diagonal. Λ is the matrix of dimension $(SN \times SN)$ with an element (i,j) indicating the amount of labour in country-sector j needed in the production of one unit of final output by country-sector i , referred to as the total labour coefficient, and similar for the matrix of capital inputs K .

Due to the linearity of the system, these total factor requirements have the useful property that when multiplied with the actual levels of final demand f , they sum up to the overall quantity of labour and capital available in each country-sector. As such this approach provides for an exhaustive accounting decomposition of global

final demand such that all production factors in the world are accounted for.

Using these total factor requirements matrices, we can define factor cost shares in a global value chain of a final product. At this point we first need to define prices of output and factor inputs. Let $\mathbf{p}$ be a (row) vector of output prices for products from each country-sector, $\mathbf{w}$ the (row) vector of hourly wage rates and $\mathbf{r}$ the (row) vector of profit rates. The profit rate is derived as a residual such that capital compensation (the profit rate times the quantity of capital) plus labour compensation (wage times hours worked) equals gross value added. We allow output and factor input prices to differ across sectors and countries. Value added in a country-sector is defined in the standard way as gross output value (at basic prices) minus the cost of intermediate inputs (at purchasers' prices)² or $\mathbf{p}(\mathbf{I}-\mathbf{A})$. As profit rates are measured residually such that wages and profits exhaust value added for each country-sector, the following accounting identity holds:

$$\mathbf{p}(\mathbf{I}-\mathbf{A}) = \mathbf{w}\hat{\mathbf{l}} + \mathbf{r}\hat{\mathbf{k}} \quad (4)$$

Post-multiplying both sides of (4) with the inverse of $(\mathbf{I}-\mathbf{A})$ and substituting from (3) we arrive at an important result: the output price of a final product (from a given country-sector) can be rewritten as a linear combination of the prices of all factors that were directly and indirectly needed in its production, or

$$\mathbf{p} = \mathbf{w}\mathbf{\Lambda} + \mathbf{r}\mathbf{K} \quad (5)$$

with $\mathbf{\Lambda}$ and $\mathbf{K}$ the matrices with total labour and capital coefficients. The identity in equation (5) forms the basis for deriving cost shares of labour and capital in the GVC of a particular

product. Multiplying the left- and right-hand side by final output quantity, the share of wage and capital costs in total costs is generated for each final product. Through appropriate selection of elements in the matrices $\mathbf{\Lambda}$ and $\mathbf{K}$, one may trace the country-sector origins of these factor costs. We will use this decomposition in the next section to investigate the shifting factor shares in GVCs of manufacturing products.

The cost shares and quantities derived above can also be used to measure total factor productivity (TFP) growth in the production of a final good (following Wolff, 1994). The consolidated data provides the opportunity to use the standard approach in growth accounting in measuring TFP assuming a final output production function with arguments based on total (direct and indirect) labour and capital used. Let F be a translog production function for a final product j : $f_j = F_j(\lambda_j, \kappa_j, T)$ where λ_j the column vector of total labour requirements for product j from $\mathbf{\Lambda}$ and similarly κ_j a column of $\mathbf{K}$. T denotes technology. Under the standard assumptions of constant returns to scale and perfect input markets, we can define productivity growth π in the GVC of product j by the weighted rate of decline of its total labour and capital requirements

$$\frac{\delta \pi_j}{\delta t} \equiv -\alpha_j^L \frac{\delta \ln \lambda_j}{\delta t} - \alpha_j^K \frac{\delta \ln \kappa_j}{\delta t} \quad (6)$$

where $\delta \ln \lambda_j / (\delta t)$ is a (column) vector containing the differentials of the logarithms of all elements in λ_j . The weights are given by α_j^L , a (row) vector of value shares with elements reflecting the costs of labour from all country-sectors used in the production of one unit of product j , and similarly for the capital value shares given in α_j^K . Summed over all contribut-

2 For ease of exposition we assume here that there is only one price for the output of each country-sector, and this price is paid by all intermediate and final users. This assumption is loosened up in the empirical application later.

ing sectors and countries, the elements in α_j^L add up to the labour share in final output of j , and similarly for capital. As all factor inputs are accounted for the labour and capital share add up to unity. Since productivity growth rates are measured over discrete time periods rather than instantaneously the average value shares over the sample period can be used to measure productivity, generating the so-called Tornqvist-Divisia productivity index (Jorgenson *et al.* 1987). The productivity measure in (6) essentially shows the rate of productivity growth in the composite sector producing good j if all the sectors that contributed directly or indirectly to sector j 's final output were fully integrated.³

At this point it is instructive to compare the GVC productivity measure to the more traditional measure used in growth accounting studies in the KLEMS tradition. The main point to notice is that in standard applications only one stage of production is analysed. It relates the output of a sector (firm) to the inputs used by this sector (firm) consisting of the factor inputs in the sector (firm) itself and intermediate inputs produced elsewhere. The direct factor requirements as well as the value shares are now expressed in value added of the sector, not final output of the product as in (6). The traditional productivity measure thus reflects only changes in direct factor requirements instead of the total requirements. This is a valid measure of the rate of productivity growth in the case when technical change only affects factor inputs, and when the prices of intermediate inputs are well measured, that is, any decline in the factor requirements in upstream sectors will be translated in a lower price for intermediates used by sectors downstream. Only in that case the price of value added can be properly measured through sepa-

rate deflation of gross output and all intermediate inputs, also known as double deflation.

However, double deflation is becoming increasingly difficult as production fragmentation progresses. There is increasing doubt about the reliability of price indices for imported intermediates due to the practice of intra-firm transfer pricing and more generally inadequate statistical systems to monitor prices of imports (Houseman *et al.* 2011). A particular instance of this is the measurement of intangible service flows such as the use of knowledge, disembodied technology brand names and software. Intangibles are becoming increasingly important in production, but so far their measurement is elusive.⁴ For example, Foxconn in China is producing iPhones using intangible designs and technology from Apple. These services are typically not recorded in production and trade statistics, such that any study of the productivity of the Chinese or the US electronics industry is seriously hampered. The attribution of productivity growth to either industry will crucially depend on the measurement of intermediate inputs and their prices. In fact this reflects a more general issue of attribution of productivity growth across industries when intermediate input prices are not well measured. Triplett (1996) has forcefully shown that in the case of measuring productivity in the US production of computers, the use of alternative quality-adjusted prices leads to radically different assessments of the location of productivity, which may be in the computer industry itself, or in the semi-conductor industry that delivers the main inputs to the computer industry, or even further back in the chain, namely the manufacturing of semi-conductor machinery. The GVC approach based on an integrated assessment will thus provide a useful alternative to measure pro-

3 Analyses of productivity in vertically integrated chains harks back to the work by Pasinetti (1977). See also Wolff (1994). Gu and Yan (2017) provide a recent empirical application.

4 See Corrado *et al.* (2012) for pioneering attempts.

ductivity growth in modern integrated production systems.

An illustrative example: GVC production of German automobiles

We illustrate our GVC methodology by analysing the production of German cars. Throughout this article we will use data from the World Input-output database (WIOD). This database provides data for 40 countries as well as for the rest-of-the-world region such that all inputs can be accounted for (Timmer *et al.*, 2015). We decompose the value of output of all final products delivered by the German transport equipment industry (NACE rev. 1 industries 34 and 35) in short "German cars". This includes the value added in the last stage of production, which will take place in Germany by definition, but also the value added by all other activities in the chain which take place anywhere in the world. To decompose value added in production, we make use of Leontief's decomposition method outlined in section 2 and given in equation (5).

The geographical origin of the value added in production of German cars in 1995 and in 2008 reveals striking developments. Between 1995 and 2008, the share of domestic value added decreased rapidly from 79 to 66 per cent of the value of a German car. Conversely foreign value increased from 21 to 34 per cent. With the availability of cheap and relatively skilled labour, firms from Germany relocated parts of the production process to Eastern Europe. At the same time, the industry quickly globalized by sourcing more and more from outside Europe. Countries outside Europe actually accounted for more than half of the increase in foreign value added.

With additional information on the quantity of factors used in each country we can provide a growth accounting decomposition of the growth rate of final output of German automobiles using equation (6). Data on workers is measured by the number of hours, classified on the basis of educational attainment levels as defined in the International Standard Classification of Education (ISCED): low-skilled (ISCED categories 1 and 2), medium-skilled (ISCED 3 and 4) and high-skilled (ISCED 5 and 6). Capital stock volumes are measured on the basis of capital stocks of reproducible assets as covered in national account statistics (thus including physical assets, software and R&D, but excluding other intangibles), measured at 1995 constant price. Capital income is derived as gross value added minus labor income.

The results are shown in Table 1: final output volumes of German automobiles increased by 59 log points (81 per cent points) over the period from 1995 to 2007.⁵ This was mainly due to increases in the use of capital both domestically and abroad, together accounting for 41 per cent of the increase in final output. The number of workers employed in production increased as well, both within Germany and abroad, with higher growth rates for more skilled workers. Growth in workers in Germany contributed to 19 per cent of final output growth, and workers abroad contributed another 21 per cent. Note that although the number of high-skilled workers located abroad increased much faster than the number of German high-skilled workers, their contribution to final output growth is much less. This follows from the assumption of perfect competition in factor markets in the KLEMS approach such that the lower wages of foreign workers is presumed to reflect lower quality compared to German workers.⁶ Capital input was growing rapidly, both within Ger-

5 The data in WIOD is in current US\$. The volume growth rate is based on constant prices in euros using the official exchange rate and the gross output deflator of German transport equipment manufacturing as deflators.

Table 1: Growth Accounting for Verticle Production of Automotives from Germany

	Cost shares (%)		Quantities (1995 = 1)		Contribution to final output growth	
	1995	2007	1995	2007	log pts	%
<i>Factors in Germany</i>	78.9	67.7				
Low-skilled labour	7.3	4.5	1.00	1.05	0.3	0.5
Medium-skilled labour	34.5	24.7	1.00	1.18	4.8	8.2
High-skilled labour	16.4	15.8	1.00	1.44	5.8	9.8
Capital	20.7	22.7	1.00	1.84	13.3	22.4
<i>Factors outside Germany</i>	21.2	32.2				
Low-skilled labour	4.0	3.8	1.00	1.99	2.7	4.5
Medium-skilled labour	6.1	8.6	1.00	2.05	5.3	8.9
High-skilled labour	2.8	5.3	1.00	3.02	4.5	7.5
Capital	8.3	14.5	1.00	2.57	10.8	18.2
Total factor productivity			1.00	1.13	11.8	20.0
Final output	100.0	100.0	1.00	1.81	59.2	100.0

Note and source: Own calculation based on equations (5) and (6) using data from WIOD, November 2013 release. The shares and volumes for foreign factors are based on summations across 39 countries and the rest-of-the-world region. Capital growth is proxied by growth in capital stocks. Input quantities are set to 1 in 1995. Growth rates are in logs. Numbers may not add due to rounding.

many and abroad. The cost share of domestic capital even rose, whereas labour shares declined and domestic capital contributed 22 per cent to final output growth for the period 1995-2007. Capital abroad grew even faster but given its lower cost share contributed 18 per cent. Total factor productivity growth is derived as a residual as in equation (6). It corresponds to an annual rate of 0.99 per cent and is shown to contribute 20 per cent of final output growth over this period.

Has total factor productivity growth mainly taken place within Germany, or did it affect all production factors in the chain? To answer this question we may compare productivity growth in the last stage with productivity growth in the

whole GVC. Productivity in the last stage can be computed by subtracting growth in factor inputs from growth in real value added in the German car industry. Factor inputs are weighted by their cost shares and real value added should be derived using the double deflation method based on final output and intermediate input prices.⁷ Annual productivity growth thus derived from the German transport equipment industry data in the EU KLEMS database is a strong 2.62 per cent. Under the assumption that intermediate input prices have been well measured and the GVC production is separable in the last stage factor inputs, one can derive the part of productivity growth due to the last stage by multiplying the productivity growth rate in last stage by the

6 While this might be true for higher-skilled worker, this can reasonably be doubted for less skilled workers. Integration of labour markets across countries is still incomplete such that wage differentials are not necessarily arbitrated away. Econometric estimation of output elasticities (as done in Timmer and Ye, forthcoming) provides an alternative way to arrive at estimates of marginal productivity.

7 Note that conceptually, the figures should refer to inputs related to the production of final output of the industry, and not to overall output and all factor inputs used in the industry, as part of output may be used as intermediate input elsewhere. There is no separate data on production of final and intermediate products and we assume production technologies to be similar.

ratio of last stage value added to final output. Averaged over the period, this ratio was 0.28 such that 0.73 ($=2.62 \times 0.28$) percentage points out of 0.99 per cent GVC productivity growth was realised in the German car industry, and the remainder of 0.26 in other industries in the GVC. However, as mentioned, the validity of this analysis into the industry location of productivity growth in the GVC depends heavily on the quality of the intermediate input deflator.

Concluding Remarks

Production systems have evolved from a one-stage process taking place in a single location to a multi-stage process involving multiple locations in various countries. This is posing new challenges to analyses of factor incomes, substitution and productivity growth. The canonical KLEMS modelling framework (as in Jorgenson *et al*, 1987) needs to be amended as it provides few insights into the effects of changing production linkages across industries and countries. Its central concept is a single firm or industry in one-stage production. Moreover, its empirical validity depends crucially on the tracking of prices and quantities of intermediate goods and services flowing across plants and borders. With low value-added to gross output ratios, accurate measurement of prices of intermediates becomes paramount to measure productivity. These are increasingly hard to measure due to the practice of transfer pricing within multinational enterprises, the difficulty to price the flow of intangibles as well as an inadequate statistical system to track prices of intermediates when quality is improving (Houseman and Mandel, 2015)

An approach using final products as the unit of observation offers a first step towards a framework to study the important but elusive characteristics of modern production systems. In this article we introduced the GVC accounting approach as a complement to traditional

KLEMS type of analyses. Apart from being conceptually appealing, the GVC accounting approach bypasses some of the empirical problems that confront traditional analyses. We have defined cost shares, factor substitution and productivity growth in GVC production, providing a structural foundation in Leontief's input-output model. We showed that these measures can be empirically implemented using synthetic input-output tables and that the results offer new insights into the nature of today's global production systems.

It should be emphasised however, that the outlined GVC approach serves only as a first attempt. Arguably, the input-output model derives its popularity from the clear intuition of its measures in the case of "snake" production systems where industries produce only one output and deliver to only one industry. But in case of joint production and multiple product output, it has to rely on strong (linear) proportionality assumptions in allocating the use of inputs. More generally, the Leontief approach traces the value added without explicitly modelling the interaction of prices and quantities of intermediates that are central in a full-fledged general equilibrium models. While CGE models are richer in the modelling of behavioural relationships, there is the additional need for putting restrictions on the various key parameters of production and demand functions. The Leontief model is an attractive and tractable alternative but further research into more general alternatives would be worthwhile.

Firm-level studies are needed for a better understanding of substitution and productivity in international production systems. Unfortunately, there is very little direct detailed information on plant-to-plant transactions in multiple stages of production. Given firms' secrecy or even ignorance about their own position in global value chains, this situation will not easily improve without major new data collec-

tion efforts. Recent new data sources based on value added tax data provide fresh evidence on firms' interaction at the transaction level (see Dhyne and Duprez, (2017) for an example) and provide an interesting avenue for further research.

A particular appealing approach is the task-approach simultaneously arising in the literature on international trade and in labour economics. The task approach centres around a mapping from factor inputs to tasks and then from tasks to output so as to provide a structure on the possible substitution between labour and capital, both at home and abroad. Acemoglu and Autor (2011) outline a general framework that revolves around differences in comparative advantages of factors in carrying out tasks: all workers can carry out all tasks, but some are relatively better at carrying out certain tasks. Substitution of skills across tasks is possible, such that there is an endogenous mapping from workers to tasks depending solely on labour supplies and the comparative advantages of the various labour skill types. Capital may compete with labour in the supply of certain tasks such as routine activities. International specialization arises naturally as skilled workers in advanced countries have a comparative advantage in headquarter activities, while less skilled workers in emerging economies have a comparative advantage in carrying out low-tech activities like assembly, testing and packaging. In our view, the future in our understanding of international production systems lies in the combination of the new emerging task-approach to production with the sophisticated empirical tools developed in the KLEMS tradition.

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