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# Global and Regional Productivity and Economic Growth: The Fifth World KLEMS Conference

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This issue of the *International Productivity Monitor* includes a selection of papers presented at the Fifth World KLEMS Conference, held at the Kennedy School of Government, Harvard University, on June 4-5, 2018.[2] The World KLEMS Initiative was established at Harvard at the First World KLEMS Conference, held at the Kennedy School of Government in 2010.[3] Five World KLEMS Conferences have discussed data on capital (K) and labour (L) services, as well as inputs and outputs of energy (E), materials (M), and services (S) for more than forty countries. These have been grouped into three major regions—EU (European Union) KLEMS, LA (Latin America) KLEMS, and Asia KLEMS.

A novel feature of the Fifth World KLEMS Conference was the focus on a conceptual framework and data for the global economy. The first article in this issue on the conceptual framework for the global economy is by Jon Samuels and Erich Strassner (2019), "Toward a Global Integrated Industry-Level Production Account: A Proposal." The key feature of this framework would be a world input-output table in current and constant prices, together with constant quality prices for capital and labour inputs by industry. The prices would be linked by conceptually appropriate purchasing power parities. These data could provide industry and country sources of global economic growth as well as measures of cross-country industry competitiveness. The data could also provide productivity level

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2 The conference program with links to all papers presented is available on the World KLEMS website: https://scholar.harvard.edu/jorgenson/schedule-presentations-papers.

3 For more information about the World KLEMS Initiative, see Jorgenson (2012).

comparisons and the analysis of global production chains.

The second article in this issue is an empirical data set for the global economy, presented by Robert Inklaar, Pieter Woltjer, and Daniel Gallardo Albarron (2019) in their article, "The Composition of Capital and Cross-Country Productivity Comparisons." This is based on the Penn World Table (PWT), a long-established data set with aggregate output and input for individual countries, covering the global economy.[4] The latest version of this data set presents, for the first time, capital services and its price as a measure of capital input. This replaces capital stock as a homogeneous measure of capital input. The authors show that, when properly measured, differences in capital input can account for a greater share of income variation across countries but that total factor productivity still remains dominant in accounting for differences in GDP per worker.

The first regional component of the World KLEMS data set was the EU KLEMS data set, published in 2010 by Marcel Timmer, Robert Inklaar, Mary O'Mahony, and Bart van Ark, in their monograph, *Growth of the European Economy: A Comparative Industry Perspective*.[5] Europe is represented in three new contributions in this issue of the *International Productivity Monitor*. The first of these is by Cecilia Jona-Lasinio and Valentina Meliciana (2019) in their article, "Global Value Chains and Productivity Growth: Does Intangible Capital Matter?" This article links participation in global value chains with productivity growth through investment in intangible assets for 18 sectors of nine European economies for 1998-2013. The striking empirical finding of this research is the successful integration of investment in intangible assets and participation in global value chains, two previously separate bodies of empirical research on the sources of economic growth.

The second contribution on productivity and economic growth in Europe is by Gang Liu (2019) in his article, "Structural Change and Productivity in the Market Economy of Mainland Norway, 1997-2014." An increased share of skilled labour in value added is found for the market economy as a whole, as well as almost all industrial sectors. The shares in value added for the total market economy have increased for software and research and development, while the

4 More information is available on the Penn World Table website maintained by Groningen University: https://www.rug.nl/ggdc/productivity/pwt/.

5 For a summary of the monograph, see Timmer *et al.* (2011)

share of hardware has decreased. Investment in intangible capital, combined with human capital, has played an increasingly important role in economic growth in Norway during the period of this study.

The third contribution on productivity and economic growth in Europe is by Nicholas Oulton (2019) in his article, "The UK and Western Productivity Puzzle: Does Arthur Lewis Hold the Key?" Oulton identifies the productivity puzzle in the United Kingdom as the combination of slow growth in labour productivity since the end of the last boom in early 2008, combined with an outstanding performance of the labour market during this period. The decline in labour productivity growth depends negatively on the growth of labour input and positively on the growth of export demand. In the UK labour input continued to rise at the same rate as before the crisis, while the growth of output fell. In continental Europe in contrast, the growth of labour input was constrained by slow growth of the working age population in most countries. The slowdown in labour productivity growth was less pronounced in continental Europe than in the UK. Oulton argues that the Great Recession produced the slowdown in TFP growth. The next article considers the data for Japan, presented by Joji Tokui and Takeshi Muzuta (2019) in their article, "Japan's Prefectural-Level KLEMS: Productivity Comparisons and Service Price Differences." This article presents KLEMS-type data for the forty-seven prefectures of Japan. Using the Regional-Level Japan Industrial Productivity Database (R-JIP),[6] which includes observations on service prices for different regions, Tokui and Muzuta estimate cross-regional price differences for each industry. The dataset also includes regional differences in the composition of labour input and wage levels. Finally, the study includes a test of the Balassa-Samuelson effect that consumer prices are higher in more developed economies because they have greater variation in traded good sectors than in non-traded sectors. This effect holds within Japan on the basis of prefectural differences in service prices.

The next article discusses how education affects economic growth, namely, through industry educational intensity. Educational intensity is defined as the share of an industry's work force with a college degree or above. The article by Jorgenson, Ho, and Samuels (2019), "Ed-

6 A detailed description of the Regional-Level Japan Industrial Productivity Database (R-JIP) is presented in a new book edited by Tokui (2018).

ucational Intensity, and the Sources of and Prospects for U.S. Economic Growth," shows that the contribution of education intensive industries to growth in value added exceeds that of non-education intensive industries. This is driven by the larger share of growth in capital and labour services and growth in total factor productivity in education intensive industries. The shift toward educationally intensive industries is insufficient to revive growth in labour productivity and aggregate output. Growth over the next ten years will be constrained by the growth of capital and labour quality.

The article by Corby Garner, Justin Harper, Tom Howells, Matt Russell, and Jon Samuels (2019), "New BEA-BLS Estimates of the Sources of U.S. Economic Growth between 1987 and 2016," presents new historical statistics for the BEA-BLS integrated industry-level production account. The dataset includes KLEMS-type data and integrated multi-factor productivity data for 1987-2016 by industry. The most important source of growth over the period was capital input; labour input was the second most important growth source. Multifactor productivity growth accounted for about 20 per cent of U.S. economic growth. Empirical results are presented for nine major sectors and less detail is provided for 63 industries. The article finds that the decline in the aggregate income share of labour input over the period of the study was due to the decline of the income share of workers without a college degree.

The final contribution to this special issue of the *International Productivity Monitor* is the article by Matilde Mas, André Hofman, and Eva Benages (2019), "Knowledge Intensity in a Set of Latin American Countries: Implications for Productivity." Knowledge intensity is measured by the economic valuation of productive services that incorporate knowledge, specifically, human capital and information and communication technologies. The contribution of each asset is determined by the price of services that they provide. This methodology is applied to four Latin American countries. Brazil, Chile, Columbia, and Mexico. Spain and the United States are used as benchmarks for these measurements. This methodology can be applied to countries that have databases developed within the framework of World KLEMS. The picture that emerges is one with sharp differences among the six countries. Developing economies are moving towards a more knowledge intensive pattern of production and the speed with which they approach more mature economies differs substantially.

I conclude that important new directions are emerging for the analysis of growth and productivity within the World KLEMS Initiative. The three regional organizations—EU (European Union) KLEMS, LA (Latin America) KLEMS, and Asia KLEMS—are continuing to generate new data for the world's leading economies. However, the global economy as a whole is attracting greater attention, especially with the dramatic decline in the importance of the advanced economies of Europe and North America, relative to the rapidly emerging economies of Asia. The relative importance of investment and productivity has changed with investments in human and nonhuman capital assuming much greater significance than total factor productivity as sources of economic growth. The growth of capital input is more important than the growth of labour input with capital input measured in terms of capital services rather than capital stock. Finally, the income share of labour is declining relative to the share of capital.

Government statistical agencies, such as the U.S. Bureau of Economic Analysis and Statistics Canada have developed KLEMS-type data sets within their systems of national accounts. International organizations have integrated this information with statistics on international trade. The task that remains is to give appropriate significance to economic links among countries and how these are evolving. The links among countries are increasingly taking the form of elaborate global value chains that began as regional trade organizations and have grown into world-wide systems that involve numerous transitions across international boundaries.

The evolution of these systems is increasingly driven by investments in forms of capital that emphasize rising flows of capital services. Meanwhile investments in human capital in advanced economies are showing signs of saturation, so that there is limited potential for further increases in average levels of educational attainment. Human capital investments in emerging economies are increasingly important in maintaining the rapid growth that would enable these economies to achieve the maturity of the advanced economies that have preceded them in economic development. The next step for the World KLEMS Initiative is to integrate world-wide production systems with World KLEMS data.

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# Toward a Global Integrated Industry-level Production Account: A Proposal

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Abstract

This article develops the framework for a global production account. We describe the relationship between existing KLEMS approaches and databases, international guidelines on GDP and productivity measurement, and our proposal toward a global integrated production account. The key feature of the account is an integrated world input-output table in current and constant prices, augmented with constant quality prices and quantities for primary factor inputs by industry, all converted with conceptually appropriate purchasing power parities. Uses of the framework include: 1) industry and country-level contributions to world economic growth, 2) price level indexes that serve as measures of industry-level competitiveness across countries, 3) total factor productivity level comparisons at the industry level, and 4) global production chain analysis. None of these are applications are currently possible with existing country-industry-level KLEMS databases.

Growth accounting at the industry level applied to KLEMS (Capital, Labour, Energy, Materials, and Services) accounts has proven to be an extremely useful tool for analyzing the sources of economic growth and cross-country comparisons of growth. Jorgenson (2017) describes the "World KLEMS initiative" as a consortium of national accountants, statistical offices, and researchers from academic and non-academic settings that has worked to produce consistent industry-level databases on economic outputs and inputs for more than 40 countries. The major takeaways from this line of research are that "capital and labour inputs have emerged as the predominant sources of economic growth in both advanced and emerging economies," and that "productivity continues to play an important role

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as a source of economic growth, but this role has diminished sharply in the aftermath of the Great Recession." The focus on World KLEMS to date has been on economic growth decompositions based on industry datasets at the country-level.

The purpose of this article is to develop the framework for a global production account. We describe the relationship between existing KLEMS approaches and databases, international guidelines on GDP and productivity measurement, and our proposal toward a global integrated production account. Our approach to discussing work toward a global integrated production account is example driven. The examples that we give provide useful context and background information for readers less familiar with the basic issues involved in measuring global production.

A contribution of our article is that it demonstrates valuable next steps for the World KLEMS consortium. We demonstrate proof of concept by appealing to existing work on productivity accounting within a KLEMS framework and on new research that integrates country-level KLEMS into bilateral productivity comparisons. In essence, our proposal argues that extending the two country (United States and Japan) model described below to the world economy amounts to proof of concept toward a global integrated world production account.

We describe data needs and conceptual issues, and important uses of such a dataset. These uses include: 1) industry and country-level contributions to world economic growth, 2) price level indexes that serve as measures of industry-level competitiveness, 3) total factor productivity (TFP) level comparisons at the industry level, and 4) global production chain analysis. None of these applications are possible with existing country-industry-level KLEMS databases.

One of our major conclusions is that much of the necessary data are available to construct a global production account; but an important next step is to assemble new data on industry-level purchasing power parities (PPPs). Building conceptually appropriate PPPs is not a trivial task.

A simple example of the difficulty in measuring output PPPs is consider the PPP for the production of paper. Let us say that we observe that the purchase price of paper is \$5 for a ream of paper in the United States and Y500 in Japan, and both countries also produce paper. Comparing production of paper requires information on relative price levels, not just national price indexes that are indexed to one in the base year.

Let us say that the United States

imports paper from China, and Japan imports paper from Canada. Flows of international trade across industries from the global production account allows for stripping these imported purchases (with their respective prices) from the relative purchase price of paper ($5/Y500) to infer domestic output prices of paper production in the United States relative to Japan to construct conceptually appropriate industry-level PPPs.[2] Extending this simple example to multiple countries and multiple trading partners demonstrates the need for global input output tables.

The article proceeds along the following outline. Section 1 overviews how the world production account is related to the production account in the system of national accounts (SNA). Sections 2 and 3 provide information on the building blocks of the world production account, starting with country-level production accounts and then industry-level production accounts at the country level. Section 4 is the core of the article and ties all of the information together to demonstrate the requirements for a global integrated production account. Once the framework is in place, section 5 covers selected applications of the global integrated production account, and section 6 presents some of the basics of implementation and other practical issues. Section 7 wraps up by covering potential extensions.

## The Production Account as an Organizing Framework

The organizational framework for the global integrated production accounts is a production account for the world economy. The production account for the world economy is an extension of a production account at the national level. At the national level, the production account displays how income is generated, distributed, and used throughout a national economy (United Nations, 2008). The product side of the production account corresponds to country level Gross Domestic Product (GDP) and includes expenditure on personal consumption, private investment, net exports, and government consumption and investment. The income side of the account corresponds to Gross Domestic Income (GDI) and includes information on compensation of employees, net taxes on production and imports, operating surplus, and consumption of fixed capital.

From the outset, it is useful to distinguish between the production

2 Nomura, Miyagawa, and Samuels (2018) have a detailed accounting model to determine PPPs for the United States and Japan. This is discussed below. Inklaar and Timmer (2014) employ a simpler version that makes stronger assumptions.

account described in the System of National Accounts (SNA) and a KLEMS-based production account. The point of departure from a production account in the SNA and a KLEMS-based aggregate production account is that the KLEMS-based production account requires price deflators for both final outputs and primary inputs, while this is not strictly required in the SNA. By including price deflators for outputs and inputs, the KLEMS-based production account permits internally consistent measures of total factor productivity, which is defined as the ratio of real output to real input.

A purpose of integrating KLEMS into a world production account is to provide a national accounts consistent production account for the world economy, in current and constant prices that is consistent with information in the country-level KLEMS accounts. With this framework, the World Production account that we describe provides an internally consistent decomposition of the sources of world economic growth, and economic growth across world regions.

The production account in Chapter 6 of the SNA (United Nations, 2008) has two sides that are in balance by construction. The first is the Resource side that includes the value of output of goods and services. The other side of the account is the Uses account which records intermediate consumption, and the balancing item Value Added. In the SNA, the generation of income account shows how resources in the economy (value added) equate to income in the form of compensation of employees, taxes on production and imports and subsidies, operating surplus, consumption of fixed capital, and mixed income.

These represent the three approaches to measuring GDP. In nominal terms, putting these accounts together yields the nominal side of the production account for KLEMS accounting. Specifically, the output side of the production account in KLEMS is the GDP, and the input side imposes the accounting identity that incomes generated in production are exhausted across capital and labour services. This is, in fact, how the SNA conceptualizes production: as activity that uses inputs of labour, capital, and goods and services to produce outputs of goods and services. In nominal terms there need not be any differences between production measured in the SNA and that required to construct an aggregate production account: nominal output is the value

3 Splitting income between self-employed labor and capital is an important component of constructing the KLEMS production account, but the key point is that total income corresponds to factor payments in the aggregate.

of production, and payments to inputs correspond to gross domestic income.[3]

For a production account to include information on productivity, nominal values of output and input must be decomposed into price and quantity. As a reminder, within the context of a single country, these prices and quantities are index numbers and thus are useful only to construct growth rates. Output price measurement is covered in chapter 15 of the SNA. Approaches to price measurement of inputs are included in chapters 19 and 20 of the SNA, although these are not a requirement of the system of national accounts. Total factor productivity is the ratio of the quantity of output to the quantity of input. Chapter 19 of the SNA discusses quality-adjusted labour input, which provides the labour input measure within the production account, while chapter 20 discusses capital services, which provides the quantity input measure within the account.

An industry-level production account at the country level permits a bottom-up analysis of the sources of economic growth within a country. The foundation of a country-level industry production account is a set of country-level supply-use accounts that include the value of outputs and intermediate inputs used by industry. Construction of the supply-use accounts in nominal terms is covered by the UN's "Handbook on Handbook on Supply, Use and Input-Output Tables with Extensions and Applications" (United Nations, 2017) and the Eurostat "Manual of Supply, Use, and Input-Output Tables" (Eurostat, 2008).

The output side of the account includes nominal and real industry output and value added. By aggregating over industries, the account yields an estimate of economy-wide country-level growth and industry contributions to GDP growth. The input side of the account includes nominal and real estimates of intermediate and capital and labour inputs used by industry. By aggregating inputs over industries, the account yields estimate of economy-wide input contributions.

Using a growth accounting model, the account can be used to decompose output growth to its sources across inputs. The growth in real output less real input is defined as total (or multi) factor productivity growth and accounts for the portion of economic growth not accounted for by input accumulation.[4] Significant progress has been made on constructing industry-level production accounts based on

4 We will note later that under the assumption of an aggregate production possibility frontier, aggregate TFP growth is not simply the weighted sum of industry level TFP growth. Aggregate TFP growth embeds a reallocation effect.

this method: work on this is covered under the World KLEMS initiative and has yielded industry-level production account KLEMS data for over forty countries.

Next, we relate ongoing KLEMS research and data development to the global production account that is the focus of this article. We term the global production account at the industry level the Global Integrated Production Account. While we will lay out the basic conceptual framework for such an account, it will not serve a comprehensive instruction manual on all of the topics used to frame and implement the account. Furthermore, the article is descriptive in nature about the data and related research and does not touch on policy related motivations for such work or the policy implications of findings.[5]

The foundation of the global production account is a world-input output (IO) account that shows how outputs are being produced and inputs are being used throughout the world economy. One of the most widely-used applications of world IO tables is to produce estimates of trade in value added (TiVA). The system of world input output accounts was introduced by Leontief (1974) and has been implemented recently by the Global Trade Analysis Project (GTAP),[6] the World-Input Output Database (WIOD) (Dietzenbacher, Los, Stehrer, Timmer, and De Vries, 2013), and the OECD-WTO initiative to measure trade in value added.[7]

Because country-level input-output accounts are in local currency units, a crucial aspect of the world input output accounts in the context of world production is conversion of country-level accounts to comparable units using purchasing power parities for outputs and inputs. Combing a system of world input-output tables with prices for industry outputs and inputs (including primary inputs) essentially yields the global integrated production account. We discuss how this works in the subsequent sections.

## Country-level Production Accounts

We start with the description of a

5 A formal complementary examination of index number issues in multi-country comparisons of total factor productivity is available in Inklaar and Diewert, (2016).

6 The first official GTAP-MRIO tables to be produced by the GTAP consortium werescheduled to be released in the summer of 2017. The earlier GTAP-MRIO tables were part of the initiative of Peters, Andrew, and Lennox (2011).

7 There are other global initiatives as well including Lenzen, Moran, Kanemoto, and Geschke (2013), Tukker, et al. (2013), Meng, Zhang, and Inomata (2013), and Bruckner, Giljum, Lutz, and Wiebe (2012). Also, there was an update of EUKLEMS which was released in summer 2017. Another update is scheduled for summer 2019.

country-level production account because the same basic concepts are used in formulating the global production account. A production account at the country level includes data on the production on final goods and services and the primary inputs used to produce these goods and services in current and constant prices.

To obtain some intuition for the economic questions that production account data can help address, it is useful to review some of the more recent results. Jorgenson, Ho, and Samuels (2019) find that the preponderance of U.S. growth (about 80 per cent) is accounted for by the accumulation of inputs, while the remainder is accounted for by increases in TFP.

That study also uses the production account to analyze the dynamics of growth over post-war U.S. economic history. It identifies the IT investment boom from 1995-2000 and quantifies the disproportionate effects of the Great Recession on workers without a college degree within the GDP accounting framework. Importantly, because the contributions of the output and inputs sides are constructed to be consistent with the GDP accounts, the production account framework yields an internally consistent accounting of contributions. This has clear advantages over disparate measures related to employment, education, and investment that are tied to growth and productivity, but not linked to the national accounts.[8]

Moving past the United States example, similar production account data at the aggregate level is assembled by the Conference Board in its Total Economy Database (TED). The TED contains underlying aggregate production account information on output and inputs by most countries in the world economy.[9] Most of the measures are consistent with and built off national accounts data.

One major finding from this line of research is that, like the United States, the preponderance of growth is accounted for by the accumulation of inputs. It is important to note that the Conference Board TED database relies on the information available in individual country's national accounts, so that the TED database could not exist without all of the data produced by statistical offices throughout the world.

If aggregate country-level information were sufficient to analyze

8 The BLS in the U.S. produces official estimates of aggregate MFP growth for the U.S. economy, but these measures are not consistent with the official GDP estimates because they are designed to cover the business sector. The section below on industry-level production accounts notes a relatively new integrated industry-level produced jointly by the BEA and BLS that is consistent with the GDP accounts.

9 See https://www.conference-board.org/data/economydatabase/index.cfm?id=27762 for the latest data coverage.

world economic growth, the information gathered in the Total Economy Database would be nearly sufficient. For analyzing global production, however, a major missing component is information on the role of individual industries in the sources of economic growth. From a global perspective, without the industry dimension there is no way to track the interactions (and supply chains) that are the major point of emphasis in the analysis of global production.

## Industry-level Production Accounts at the Country Level

An aggregate production account includes information on aggregate production and the sources of growth but does not permit industry-level comparisons that are important for understanding world production, competitiveness, and comparative advantage. The importance of distinguishing industries in the analysis of growth is intuitive. The production process for information technology equipment is different than the production of hotel accommodations on the output side and on the input side. This is evidenced by the different skill mix in labour input, asset composition in capital input, and the types of intermediate goods and services used in production. Production chains span industries across countries.

The international statistical community has made significant progress on assembling industry-level production account data at the country level. As discussed earlier, much of this activity has taken place by a consortium of researchers and economic statisticians within the World KLEMS and EUKLEMS initiatives. These initiatives are described by Jorgenson (2012) and O'Mahoney and Timmer (2009), with more recent results and analysis presented in Jorgenson, Fukao, and Timmer (2016) and Fall 2017 Special Issue of the *International Productivity Monitor* (Jorgenson and Sharpe, 2017). The major features of these KLEMS accounts are national accounts consistent production account data in current and constant prices at the industry level, decomposed into the inputs used in production: capital (K), labour (L), Energy (E), Materials (M), and Services (S), and TFP. Thus, the KLEMS approach provides an internally consistent decomposition of economic growth across industries within an economy and factors of production used by each industry.

Jorgenson, Ho, and Samuels (2019) construct an industry-level production account and use the account to analyze the sources of U.S. economic growth over the post-war period in the United States. They divide the economy into producers of Information Technology (IT), users of IT, and non-IT industries. This shows the rising contribution of IT production in U.S. GDP growth over the period. The shift of production of IT equipment to outside the United States reinforces the importance of having comparable accounts for other countries to track world production of IT equipment, which is now mostly imported into the United States.

Their results show the disproportionate share of aggregate U.S. total economy total factor productivity growth originated in IT-producing industries since the technology became commercialized. That is, the IT producing sector accounted for about 5 per cent of nominal aggregate value added, but a substantially larger share of aggregate TFP growth. Productivity analysis based on aggregate data would miss this important distinction between IT and other types of production and perhaps erroneously conclude that TFP growth was balanced across sectors of the economy. The authors argue that accounting for the industry dimension is important in assessing the prospects for economic growth going forward.

KLEMS work has now been adopted into official national accounting statistics by Australia, Sweden, Finland, Denmark, Italy, the U.K., the Netherlands, and Mexico. In the United States, the BEA and BLS produce an integrated industry-level KLEMS production account that is consistent with the official GDP accounts. This includes internally consistent accounting data on industry output and KLEMS inputs.[10]

The EUKLEMS and World KLEMS consortiums provide proof of concept on implementing country-level production accounts. These datasets are produced by a consortium of academic researchers and statistical offices and now cover about 40 countries using consistent KLEMS methodology. Research studies using these datasets confirm the importance of these data for basic macroeconomic analysis. For example, the findings based on the EUKLEMS database in van Ark, O'Mahony, and Timmer (2008) show that a large portion of the labour productivity gap between Europe and the United States is driven by a gap in TFP growth of the service industries.

## Global Accounting and the World Production Account

The previous sections have provided a basic motivation for KLEMS

10 Some of the data is posted here http://www.worldklems.net/data.htm.

work and covered existing work that has used KLEMS to build production account data. But a key component of a global KLEMS framework is the accounting for international transactions of goods and services used in production across industries and countries. By combing country-level KLEMS accounts with information on world trade and trade prices in an integrated input-output system we are able to define a global integrated production account.

As noted earlier, to analyze economy wide aggregate production (GDP), the framework of the Conference Board TED and Jorgenson and Vu (2005) would be nearly sufficient. But isolating the role of individual industries within and across countries requires a framework that measures industry-level production and the linkages between industry purchases and sales and particular countries. A major impetus for this is the increase in offshoring of components production. For example, identifying the role of imports from China in U.S. manufacturing requires a framework that separately identifies intermediate flows across borders. Identifying the role of cross border flows of intangibles in production, for example blueprints used for a single period to produce a complicated semiconductor would be treated in an analogous way if there is a market transaction.[11]

To accommodate these linkages, the global KLEMS accounts expand the domestic input-output system to a set of world input output tables. Comparing TFP and price levels across countries and industries integrated into the global value chain requires tables adjusted for purchasing power parities.[12]

The foundation of the world production account is an extended set of supply, use, and input-output accounts. The extension from the country-level tables to the world account involves two basic modifications. The first is identifying which transactions represent flows across borders. To give a clarifying example: consider international linkages in the use of chemicals in U.S. production. The current Use table in the official BEA industry accounts shows the chemicals used by each industry, and the import use matrix estimates how imported chemicals are used by U.S.

11 If there is not a market transaction or if the intangibles are an investment purchase rather than an intermediate this becomes more complicated.This paper includes some preliminary discussions on this below.

12 Price level comparisons at the industry level are useful for analyzing international competitiveness. Jorgenson, Nomura, and Samuels (2016) implement this for the U.S. and Japan based on price level indexes for industry output and inputs. Price level indexes in the global production account are described in section 5 below.

producers. But the table does not include information on the country of origin of the imports, nor on the destination country for exported chemicals.[13] These country-specific links are critical for understanding interdependencies in the global economy. The second modification is to impose consistency in the measures of cross border flows across countries, such that the value of exports of a producing country corresponds to the value of imports in the purchasing country. This implies that a global production account with internal consistency requires an agreed upon method to resolve discrepancies in the measurement of trade flows.

Figure 1 gives an example of a partially extended use table for a single country. Each row of the table corresponds to a commodity used in production, and each of these is subdivided into the country of origin. The allocation of intermediate uses by country is important for two reasons. First it allows one to tabulate the contribution of imports by country to growth at the industry level, and second allows for the possibility that import prices may differ by country.[14]

Before implementation issues are covered, it is worth noting that the extended KLEMS accounts do not necessarily require extended supply, use, and input-output accounts for every country in the world economy. Missing countries can be grouped together in a Rest of World (ROW) sector. Obviously, for countries that are grouped in the ROW sector, country-level contributions at the industry level cannot be separately identified.

It may be of interest to split the capital services into service flows by original sourcing country. The basic idea would be to track the country origins of investment spending and trace this through to the purchasing industry. In this setup, the investment good is sourced from another country, but the capital services it generates are a component of domestic value added. This is potentially relevant for addressing questions such as the contribution of intellectual property produced in the United States and purchased in China, for example.

Conceptually, trade in investment

13 Currently published statistics do not include information on industry of origin and country-industry-destination. Administrative data in the United States may include some information on this (in particular, industry of origin and country of destination), but because trade often flows through the wholesale sector, this is difficult to measure directly.

14 Under the assumption that import prices do not differ by country, the use of commodities by country could be collapsed but with this one would lose the capability of tracking the importance of a country's role in global trade.

15 Kuroda and Nomura (2004) discuss this basic idea in an application to Japan.

**Figure 1: Extended Use Table**

| Extended Use Table | | | | | | C | I | G | X | | | | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Country c: | Industry 1 | Industry 2 | .... | Industry J | | | | Country 1 | Country 2 | .... | Country N | |
| Commodity 1 | Country 1 | $V_{X11t11}$ | $V_{X12t11}$ | .... | $V_{X12t11}$ | $V_{C1\#t1\#}$ | $V_{I1\#t1\#}$ | $V_{G1\#t1\#}$ | $V_{E1\#t11}$ | $V_{E1\#t12}$ | .... | $V_{E1\#t1N}$ | $V_{M1\#t11}$ |
| | Country 2 | $V_{X11t12}$ | $V_{X12t12}$ | .... | $V_{X12t12}$ | | | | | | | | $V_{M1\#t12}$ |
| | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | | | | | | | | ⋮ |
| | Country N | $V_{X11t1N}$ | $V_{X12t1N}$ | .... | $V_{X12t1N}$ | | | | | | | | $V_{M1\#t1N}$ |
| Commodity 2 | Country 1 | $V_{X21t1N}$ | $V_{X22t1N}$ | .... | $V_{X22t1N}$ | $V_{C2\#t1\#}$ | $V_{I2\#t1\#}$ | $V_{G2\#t1\#}$ | $V_{E2\#t11}$ | $V_{E2\#t11}$ | .... | $V_{E2\#t1N}$ | $V_{M2\#t11}$ |
| | Country 2 | $V_{X21t12}$ | $V_{X22t12}$ | .... | $V_{X22t12}$ | | | | | | | | $V_{M2\#t12}$ |
| | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | | | | | | | | ⋮ |
| | Country N | $V_{X21t1N}$ | $V_{X22t1N}$ | .... | $V_{X22t1N}$ | | | | | | | | $V_{M2\#t1N}$ |
| Commodity I | Country 1 | $V_{XI1t1N}$ | $V_{XI2t1N}$ | .... | $V_{XI2t1N}$ | $V_{CI\#t1\#}$ | $V_{II\#t1\#}$ | $V_{GI\#t1\#}$ | $V_{EI\#t11}$ | $V_{EI\#t12}$ | .... | $V_{EI\#t1N}$ | $V_{MI\#t11}$ |
| | Country 2 | $V_{XI1t12}$ | $V_{XI2t12}$ | .... | $V_{XI2t12}$ | | | | | | | | $V_{MI\#t12}$ |
| | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | | | | | | | | ⋮ |
| | Country N | $V_{X21t1N}$ | $V_{X22t1N}$ | .... | $V_{X22t1N}$ | | | | | | | | $V_{MI\#t1N}$ |
| VA | Capital Asset 1 | $V_{K11t1}$ | $V_{K12t1}$ | .... | $V_{K12t1}$ | | | | | | | | |
| VA | Capital Asset 2 | $V_{K21t1}$ | $V_{K22t1}$ | .... | $V_{K22t1}$ | | | | | | | | |
| VA | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | | | | | | | | |
| VA | Capital Asset I | $V_{KI1t1}$ | $V_{KI2t1}$ | .... | $V_{KI2t1}$ | | | | | | | | |
| VA | Labor Type 1 | $V_{L11t1}$ | $V_{L12t1}$ | .... | $V_{L12t1}$ | | | | | | | | |
| VA | Labor Type 2 | $V_{L21t1}$ | $V_{L22t1}$ | .... | $V_{L22t1}$ | | | | | | | | |
| VA | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | | | | | | | | |
| VA | Labor Type I | $V_{LI1t1}$ | $V_{LI2t1}$ | .... | $V_{LI2t1}$ | | | | | | | | |
| VA | Taxes on Production and Imports | $V_{T\#1t1}$ | $V_{T\#2t1}$ | .... | $V_{T\#2t1}$ | | | | | | | | |
| | | | | .... | | | | | | | | | |
| | Gross Output | $V_{Y\#1t1}$ | $V_{Y\#2t1}$ | .... | $V_{Y\#2t1}$ | | | | | | | | |

Source: Authors' construction.

goods is trade in current and future capital services.[15] For example, if country B relies on capital originally produced in country A, analyzing changes in world demand requires taking into account that the investment good may only be produced in a single country.

The framework described above assumes that the pertinent economic transactions across borders are captured in a way that is consistent with the production arrangements that are of interest. But, it is widely recognized that global production arrangements are difficult to measure. A conceptual framework for measuring global production is described in United Nations (2015). This article does not go into detail on the conceptual and practical issues involved in measuring production arrangements, such as contract manufacturing that spans borders.

Combining a time series of extended country-level supply, use, and input-output tables with the price deflators for each cell of the tables, including the primary inputs, produces a global industry level production account. The production account includes output and inputs in current and constant prices.

Constructing the input quantity index that forms the basis of TFP measurement requires aggregating over heterogeneous input quantities. This aggregation is analogous to aggregating over heterogeneous components of final demand on the expenditure side of GDP calculations. Implementation issues surrounding price measurement and aggregation over inputs are covered in the implementation section below. One noteworthy issue is that the production account is constructed from the perspective of the producer so that the value of output should be valued at basic prices while the inputs used are valued a purchaser prices.[16]

The global production account described so far (in national currency units) expands the growth accounting to trace the role of inputs to its sources across countries. Within the basic framework, industry output growth occurs as a function of accumulating additional capital, labour, and intermediate inputs, and via the growth in total factor productivity.

With the global country-level industry production account, the contribution of imports by individual country is separately identifiable. The benefit of this additional level of accounting is that it traces the role of individual countries in the production process of individual industries. Examples of questions that this account can address include: what is the contribution of primary metal production in a specific foreign country to production of machinery in the home country. By aggregating contributions across commodities imported from a given country, the home country global country-level KLEMS account measures the total contribution of a foreign country to industry or aggregate production in the home country. Recent examples of work related to these questions are Timmer (2017) and Gu and Yan (2016).

In summary, the global production account deflated with local (conceptually appropriate price indexes) provides additional detail on the contribution of imported inputs from individual countries. But this account in national currency units fails to address many issues related to global production, such as country contributions to world production, price competitiveness, comparative advantage, and labour, capital and TFP level comparisons. For example, the country-level account in national currency units can describe the growth rate of industry TFP, but cannot identify the relative position of two countries TFP levels. Addressing these requires a World Production Account adjusted for purchasing power parities.

A world production account requires prices adjusted for purchasing

16 For example, sales taxes are excluded from the value of production, but property taxes are included as a cost of employing capital input. See for example, Jorgenson and Landefeld (2006).

power parities to deflate inputs and outputs at the industry level. The intuition is that comparisons of production across countries require that the outputs and inputs in production be in consistent units. For example, the production of cars in Japan in Yen and cars in Germany in Euros cannot simply be added together to create the total real production of cars in the two countries.

While there is considerable work on expenditure side PPPs, and exchanges rates are readily available, these are not appropriate conceptually for industry-level comparisons. Exchange rates capture the relative price of each country's currency, but even after conversion using nominal exchange rates, price gaps for individual products exist and these price gaps reflect the relative costs of production in each country. This leads to the use of PPPs to make comparisons across countries.

The basics on the construction of PPPs is given in the OECD and Eurostat manuals. The World Bank International Comparison Program produces PPPs for most countries (World Bank, 2005). Expenditure side PPPs capture the relative price differences for final demand, but there is not a one-to-one correspondence between these prices and industry-level output price relatives. For example, the final price of fruit consumed in the United States is a bundle of fruit produced in the United States and imported fruit and includes the retail margin. It is the production price that is necessary to compare price competitiveness of fruit production on world markets. As another example, automobile parts could be produced by the fabricated metals industry, the electrical equipment industry, the miscellaneous manufacturing industry, the plastics industry or others, so a single expenditure side PPP for auto parts bundles the prices of the auto parts produced by different industries (and the margin).

We do not go into detail about the construction of the PPPs for outputs and inputs, but this is a critical component of the World Production Account because industry price competitiveness measures require industry-specific output price relatives and productivity measures require information on real outputs and inputs. One approach, used by Nomura, Miyagawa, and Samuels (2018) is to build a system of accounting relationships that determine the PPPs for each cell of the input-output table given a subset of information on price relatives. The anchor of their PPP measurement system is an internally consistent bilateral input output table covering the United States and Japan. Thus, an extension of this approach to determine world economy PPPs would require a similar set of tables for the world economy. Given the significant progress of initiatives like the World Input Output Database, GTAP, and OECD-WTO, one would think that this is a surmountable obstacle.

The key intuition for the need of a global input output system is that 1) the global accounting ensures consistency in measures of interest (for example, the contribution of a country's exports to countries that use these imported intermediate inputs are consistent), and 2) in cases where there are missing data, global accounting relationships can be used to infer unavailable data.[17] A simple case is when import prices for a country are unavailable, but export prices from its main trading partners are available; the export prices could be used to infer the unmeasured import prices.

For a relatively small set of products like agricultural and mining commodities, unit prices can be used to determine output PPPs directly.[18] But for most products a price accounting model, like that in Nomura, Miyagawa, and Samuels (2018) must be used to determine conceptually appropriate PPPs for each cell of the IO table. Using unit prices more broadly not only would result in the well-known unit value bias, but conceptually appropriate price relatives are generally unavailable in the data.[19]

In the majority of cases, the price model works by transforming PPPs for final demand published by the International Comparisons Program (ICP) at the World Bank to product level prices, which are then aggregated to industry output price relatives using weights from the bilateral input-output table. To give a stylized sense for how the model works: given a data point on a purchase price relative from the ICP, the accounting model strips off trade margins, import prices, and any relevant taxes paid in Japan and the United States from the purchase price to construct a domestic output price relative.

Importantly, not all PPPs can be derived using information on final purchase prices because not all products are sold to final demand. Semiconductors are an important example of a product that is not sold to final demand. In cases like these, Nomura, Miyagawa, and Samuels (2018) rely on a unique dataset produced by METI (2012) that gives information

17 An example here is the work of Nomura, Miyagawa, and Samuels (2018) where import prices from China are used to infer unavailable industry output price relatives in the United States and Japan.

18 Inklaar and Timmer (2014) also have an approach for linking industry output and expenditure PPPs.

19 See Diewert and von der Lippe (2010) for a basic discussion on the issues related to unit value bias.

on purchase price relatives for intermediate uses. Similar to the price data on final demand, the price accounting model transforms these purchase prices for intermediates to domestic output prices. The detailed PPPs are matched to KLEMS Use tables to construct PPPs for industry outputs and intermediate inputs by aggregating over detailed PPPs while maintaining the appropriate price concepts. For example, PPPs for intermediate inputs reflect prices of domestic production, but also the prices of imported intermediate inputs; domestic output price PPPs must split out the intermediate price component.

PPPs for capital and labour are required as well. For labour PPPs, details on rates of labour compensation cross classified by each type of worker in the production account form the basis of the PPP. For capital PPPs, relative prices of investment goods are converted to relative services prices using the user cost of capital annualization factor. Relevant work on this is described in Jorgenson, Nomura, and Samuels (2016). Once PPPs for the base year are assembled, these can be extrapolated backwards and forwards over time using the country-level price deflators that underlie the industry-level production account at the country level.[20]

## Applications of the World Production Account

This section discusses some of the applications that are feasible after assembling the World Production account data described above. The applications include measures of price competitiveness at the industry level, industry-level TFP level comparisons, and industry, country, and regional contributions to world economic growth.[21] The world production account also permits global value chain (GVC) analysis, like that of Timmer, Erumbam, Los, Stehrer, and de Vries (2014) and Timmer (2017), but with real measures of global trade and production in addition to the nominal measures that are more typically employed in GVC analysis. With the global production account, one could trace the impact of total factor productivity to downstream industries across the world economy.

20 In practice, relying on a singe benchmark PPP can open up room for errors that compound over time because benchmark PPPs take into account a combination of weights across countries while national deflators use only national weights. We thank the referees for the suggestion to highlight this point.

21 The examples discussed here mostly focus on bilateral comparisons. If a single country is chosen as a numeraire for a Global Production account, this is generalizable in terms of comparisons to the reference country. Multilateral comparisons, however, bring rise to well-known index number issues. See Inklaar and Diewert (2016) for a discussion of TFP level comparisons in a multilateral context.

For example, one could examine the impact of improvements in chip processing total factor productivity in China to the computer industry in Japan. Analysis of production chains hinges on consistent information on world production with a complete accounting of sources across countries.

### Industry-level Comparisons of Price Competitiveness

The World Production Account as described includes a time series of industry gross output, constant quality industry output prices, and base-year PPPs for industry output. By extracting this information for two countries and combining it with information on the nominal exchange rate for the two countries, it is straight forward to produce industry-level comparisons of price competitiveness. In the base year, the PPP divided by the exchange rate yields the price level index (PLI). If the price level index is above 1.0, the output of that country is relatively expensive in comparison on international markets. The price level index in the base year can then be extrapolated backwards and forwards in time using time series observations of the industry output prices in local currency units and the exchange rate to form a time series of PLI for industry output. Nomura, Miyagawa, and Samuels (2018) includes a PPP level comparison between the Japan and the United States in 2011. Their results show that the prices of agricultural production are significantly higher in Japan, as are the prices of wholesale and retail services and utilities (relative to the nominal exchange rate of 79.8 Yen/$ in 2011), while the prices for miscellaneous manufacturing products are often lower in Japan.

Comparisons of industry output price competitiveness embed the competitiveness of prices of goods that are used as intermediate inputs. In recognition of this, Jorgenson, Nomura, and Samuels (2016) focus on price level comparisons for industry value added, which by construction aggregate to GDP-level price differences.[22] Jorgenson, Nomura, and Samuels (2016) present price level indices for value added by industry comparing Japan and the United States. These results demonstrate that at the exchange rate of 2005, the trade industries in Japan were the largest contributors to the overall price gap between Japan and the United States while the motor vehicles and medical care industries had the largest dampening effects on the overall price gap.

22 These are built off the Nomura and Miyagawa (2015) PPP system.

### Industry-level TFP Level Comparisons

To examine how the global KLEMS account can be used to compare TFP levels across countries, it is useful to reorganize the country level supply, use, and input-output tables into a bilateral table that aligns the outputs and inputs of the two countries being compared. Figure 2 shows such a reorganized table. Using this reorganized table and the PPPs for the two countries from the World Production Account, it is possible to construct the relative TFP level between any two countries. Jorgenson, Nomura, and Samuels (2016) describe the detailed steps in making TFP level comparisons. The basic steps are:

- Define the PPP for each elemental item.
- Define the price level index for each cell as the ratio of the PPP to the nominal exchange rate.
- Define the volume measure for each component cell as the ratio of the nominal value in local currency units divided by the price level in national currency units; for example, the nominal value in dollars divided by the price per unit in dollars and the nominal value in Yen divided by the price per unit in yen. Note that this is not the price indexed to one in the base year; this is the actual nominal price level per unit.
- Define the volume level index for each cell of the input-output table and each component of primary inputs as the as the ratio of the volume measure in one country relative to the other.
- Define industry-level volume level indexes by constructing a tornqvist aggregates of volumes across elemental items, using the average share in each country as weights.
- The TFP level index is defined as the volume level index for output divided by the volume level index for inputs.

Jorgenson, Nomura, and Samuels (2016) find that industries in Japan that are insulated from international competition like wholesale and retail trade are TFP laggards. Results of this nature reinforce the importance of TFP level comparisons constructed within the framework of an industry-level production account.

### Industry Contributions to World Economic Growth

A major motivation for the World Production account is that it enables a consistent comparison of the contributions of individual industries, countries, and regions to world economic growth. (Jorgenson and Vu, 2013)

**Figure 2: Extended Input-Output Table Reorganized for Industry TFP Level Comparison**

| | | Country 1 | Country 2 | Country 1 | Country 2 | | Country 1 | Country 2 |
|---|---|---|---|---|---|---|---|---|
| | | Industry 1 | Industry 1 | Industry 2 | Industry 2 | .... | Industry J | Industry J |
| Commodity 1 | Country 1 | $V_{X11t11}$ | $V_{X11t21}$ | $V_{X12t11}$ | $V_{X12t21}$ | .... | $V_{X12t11}$ | $V_{X12t21}$ |
| | Country 2 | $V_{X11t12}$ | $V_{X11t22}$ | $V_{X12t12}$ | $V_{X12t22}$ | .... | $V_{X12t12}$ | $V_{X12t22}$ |
| | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| | Country N | $V_{X11t1N}$ | $V_{X11t2N}$ | $V_{X12t1N}$ | $V_{X12t2N}$ | .... | $V_{X12t1N}$ | $V_{X12t2N}$ |
| Commodity 2 | Country 1 | $V_{X21t1N}$ | $V_{X21t2N}$ | $V_{X22t1N}$ | $V_{X22t1N}$ | .... | $V_{X22t1N}$ | $V_{X22t2N}$ |
| | Country 2 | $V_{X21t12}$ | $V_{X21t22}$ | $V_{X22t12}$ | $V_{X22t22}$ | .... | $V_{X22t12}$ | $V_{X22t22}$ |
| | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| | Country N | $V_{X21t1N}$ | $V_{X21t2N}$ | $V_{X22t1N}$ | $V_{X22t2N}$ | .... | $V_{X22t1N}$ | $V_{X22t2N}$ |
| Commodity I | Country 1 | $V_{XI1t1N}$ | $V_{XI1t2N}$ | $V_{XI2t1N}$ | $V_{XI2t2N}$ | .... | $V_{XI2t1N}$ | $V_{XI2t2N}$ |
| | Country 2 | $V_{XI1t12}$ | $V_{XI1t22}$ | $V_{XI2t12}$ | $V_{XI2t22}$ | .... | $V_{XI2t12}$ | $V_{XI2t22}$ |
| | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| | Country N | $V_{X21t1N}$ | $V_{X21t2N}$ | $V_{X22t1N}$ | $V_{X22t2N}$ | .... | $V_{X22t1N}$ | $V_{X22t2N}$ |
| VA | Capital Asset 1 | $V_{K11t1}$ | $V_{K11t2}$ | $V_{K12t1}$ | $V_{K1221}$ | .... | $V_{K12t1}$ | $V_{K12t2}$ |
| VA | Capital Asset 2 | $V_{K21t1}$ | $V_{K21t2}$ | $V_{K22t1}$ | $V_{K22t2}$ | .... | $V_{K22t1}$ | $V_{K22t2}$ |
| VA | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| VA | Capital Asset I | $V_{KI1t1}$ | $V_{KI1t2}$ | $V_{KI2t1}$ | $V_{KI2t2}$ | .... | $V_{KI2t1}$ | $V_{KI2t2}$ |
| VA | Labor Type 1 | $V_{L11t1}$ | $V_{L11t2}$ | $V_{L12t1}$ | $V_{L12t2}$ | .... | $V_{L12t1}$ | $V_{L12t2}$ |
| VA | Labor Type 2 | $V_{L21t1}$ | $V_{L21t2}$ | $V_{L22t1}$ | $V_{L22t2}$ | .... | $V_{L22t1}$ | $V_{L22t2}$ |
| VA | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| VA | Labor Type I | $V_{LI1t1}$ | $V_{LI1t2}$ | $V_{LI2t1}$ | $V_{LI2t2}$ | .... | $V_{LI2t1}$ | $V_{LI2t2}$ |
| VA | Taxes on Production and Imports | $V_{T\#1t1}$ | $V_{T\#1t2}$ | $V_{T\#2t1}$ | $V_{T\#2t2}$ | .... | $V_{T\#2t1}$ | $V_{T\#2t2}$ |
| | | | | | | .... | | |
| | Gross Output | $V_{Y\#1t1}$ | $V_{Y\#1t2}$ | $V_{Y\#2t1}$ | $V_{Y\#2t2}$ | .... | $V_{Y\#2t1}$ | $V_{Y\#2t2}$ |

Source: Input-Output Table for Industry TFP Level Comparison

provide the foundation for this.[23]

Constructing industry contributions to world GDP requires defining World GDP growth. This necessarily involves weighting the GDP, i.e. aggregate value added growth rates of each country by its share in the world economy. Because these weights compare GDP (or industry) output across countries, they must be adjusted for purchasing power parities.

The basic steps are:

- Convert nominal output, input, and value added in the base year to the common currency via the PPPs in the base year.
- Extrapolate these using the corresponding series indexes in national currency units.
- World GDP growth is then the Tornqvist index over industry value added growth rates, each

23 The approach to aggregating across countries to define world production (and contributions to world production) is still an active area of research. Feenstra, Inklaar, and Timmer (2015) use interpolated PPPs to aggregate across countries, while Diewert and Fox (2014) present an approach that produces "harmonized" estimates that account for PPP differences over time and country-level growth and inflation rates. Thus, the final approach to a world production account will need to address these different approaches. Like other areas of implementing economic accounts, open areas of research should not be an impediment to producing statistics that incorporate reasonable and defensible practices.

weighted by its share of nominal (PPP adjusted) world GDP.

- The contribution of an individual country is its share times its growth rate.

### Sources of World Economic Growth

A fundamental reason for constructing an integrated world production account in current and constant prices is to understand the sources of economic growth via the lens of the growth accounting model. The growth accounting models posits that world economic growth is a function of the growth of capital, labour, and TFP growth across countries. The Conference Board Total Economy database constructs estimates of the sources of growth across countries at the world level under the assumption of a common PPP for outputs and inputs, while Nomura (2017) demonstrates a sources of growth method that incorporates PPPs for inputs as well as outputs. Both of these approaches are possible under the global production account described above, with the important benefit that the global industry account yields industry level contributions to growth.[24]

## Implementation

The basic framework described above does not address many of the practical and implementation issues that are involved in constructing the global integrated industry level production account. This section lays out some of the issues that need to be resolved before such an account can be made fully consistent.

### Implementation Basics

A fundamental requirement is a common classification scheme. Industries and commodities must be classified in a common way to match up comparable production processes. The primary inputs (capital by asset and labour by demographic group) in the value added row should be classified on the same scheme across countries. This is necessary for the construction of the purchasing power parities. That is, the underlying assumption of the framework is that at the level in which the prices of outputs and inputs are being used to construct the PPPs, the object being compared is homogenous.

The global production account requires a world input-output account. One example of this is the approach described in Dietzenbacher,

24 This discussion abstracts from reallocation effects which typically arise when imposing assumptions underlying the model of production. See Samuels (2017) for a discussion of reallocation effects across countries.

Los, Stehrer, Timmer, and De Vries (2013), termed WIOD (the World Input-Output Database). In addition to describing the basic framework, the article also covers the implementation choices that were made to integrate available data. This could serve as a model for the nominal industry outputs and intermediate inputs that are required to assemble the global production account. It is important to note a key feature that would also be required in the global industry-level production account proposed in this article: an International Trade Account of imports and exports by end use and origin-destination industry that is consistent across countries.[25] It is necessary to ensure that these goods and services are consistently classified and estimated across countries and purchaser categories.

For instance, it is often difficult to determine to which industry or final demand traded goods and services flow to. This has led to assumptions such as the import proportionality assumption, or a modified version of this that brings in information on broad economic classification of traded goods. Because information of this nature is required to estimate national level supply-use tables, this should not be a stumbling block for estimating the global industry-level production account, though a consensus on which method to use would be preferable.

One implementation choice made by WIOD is to convert data reported and constructed in national currency units to a common currency unit by using exchanges rates. Because relative prices for industry outputs and inputs differ across countries, using purchasing power parities for industry outputs and inputs is an important distinguishing characteristic between WIOD and the global production account discussed here.

A fundamental assumption of the accounts is that prices are in constant quality units. Therefore, in cases where this assumption is suspect, decisions would have to be made to bring prices available at the country level into harmonization with the rest of the world. The Conference Board TED database discusses this, and based on earlier research harmonizes certain (IT) prices across countries.

Given limited data on countries throughout the world, the prospects for constructing an input-output table with respective price indexes and PPPs are uncertain. Therefore, an important step in formulating an ac-

25 Reconciling trade flows across countries is not trivial, and is currently an area of active research. But, WIOD has implemented one approach to this, which suggests that this is not an insurmountable problem.

tion plan for implementing the global integrated production account should consider ways to reduce the data needs. One approach to this is to impose assumptions that restrict the data requirements, such as all industries in a country pay the same price for a commodity. Or that imports from a country across industries are used proportionally across industries (the import comparability assumption.) These assumptions are similar in nature to procedures currently used to assemble official input-output tables, so should not be seen as a new impediment to producing these types of statistics so long as the assumptions are transparent.

For labour input, the classification of workers across categories imposes the assumption that an hour worked by the same category of workers is of the same quality over time. Thus, once this classification is set, the index of labour input is in constant quality units by assumption. For capital inputs, investment prices must be translated into the annual user cost of capital. This formulation requires estimates of industry rates or return, depreciation, asset capital gains, and constant quality investment prices. Choices would need to be made about depreciation rates across countries and on how to calculate the rate of return.

In terms of coverage, decisions would need to be made about which countries are in the World Account and which are either grouped in a ROW classification.

A major hurdle to assembling the world account in comparable units is PPPs for outputs and inputs at the country level for all the economies to be included in the account. Nomura, Miyagawa, and Samuels (2018) implement this with extensive data on price relatives between the United States and Japan, but significant attention and perhaps resources would be needed to design a system that is capable of constructing similar PPPs for other countries at the industry level. The applications described above require a choice of the base year for the PPPs and TFP level estimates are not invariant to this choice.[26]

### Labour

The point of departure for measuring labour input in the KLEMS accounts is the recognition that not all worker hours are equivalent. One important dimension that workers differ (and is relatively easy to measure) is their educational attainment.

Research on industry TFP typically

26 As noted above, this is because weights used in PPP and the national deflators will differ. The ICP handbook provides details. See World Bank (2005).

cross-classifies workers and worker hours by industry, gender, class (employee versus self-employed), age, and education. The EUKLEMS project has a minimum classification policy of three skill groups (corresponding to education), three age groups (corresponding to experience), with each cross classified by gender and industry. Jorgenson, Ho, and Samuels (2019) employs a much finer set of characteristics to classify labour by industry. Arriving at a common classification across countries for labour hours that accounts for worker heterogeneity is an important component of constructing an integrated world production account because this ensures that worker quality is kept constant in country comparisons.

### Capital

The point of departure for measuring capital input in the KLEMS accounts is the concept of capital services. The OECD productivity manual covers issues involved in measuring capital services.

### Other Practical Issues

The PPP model in Nomura, Miyagawa, and Samuels (2018) relies on a commodity by commodity table. In constructing such a table, choices need to be made about non-comparable imports, and scrap, and translation between industry-commodity, industry-industry, and commodity-commodity tables.

As noted above, a consistent account will require a reconciliation or balancing of inconsistent flows. That is, trade flows will need to be reconciled, or balanced away to form an internally consistent account. Who will do this balancing and what choices will be made to do so? As noted above, the WIOD program and OECD Regional-Global TiVA Initiatives have circumvented this issue, and these serve as proof of concept for tractable approaches to reconciling trade statistics.

It is worth noting that while the account described in this article would be a tremendous leap from currently available accounts, the formulation does not address some very fundamental questions about productivity in the global economy. First, an underlying assumption is that at the implementation level (industry, commodity, capital by asset, labour by type of worker) output and inputs are homogeneous. In the case of United States and Japan, for example, it is easier to defend the assumption that the medical equipment commodity produced in Japan is similar to that produced in the United States, and that workers of age 45-54 with a Master's degrees have similar productivities. But this becomes more difficult in comparisons to other countries.

Classification issues and choices are made throughout national accounts. Similar choices need not be an impassable roadblock for constructing a global production account. Nevertheless, when interpreting these statistics it is important to keep these issues in mind; for example, the U.S. electronics industry could be engaging in different activity than the electronics industry in Vietnam.

Finally, one still cannot specifically identify and compare production arrangements, like Apple for example, that are spread across multiple establishments and countries with design taking place in one place, and production in another, resulting in important shipments (possibly unpriced) of intangible assets across borders. This production process is counted in the framework described in this article. However, it is not separately identifiable. Chen, Los, and Timmer (2018) do provide a method to identify the role of intangibles in value chains by backing out their contribution as a residual.

### Implementation Summary

This section has described the basic implementation issues surrounding the proposed World Production Account. It is clear that many issues, choices, and compromises would accompany building such an account. The cleanest prototype in terms of matches between conceptual framework and data is the PPP work in Nomura, Miyagawa, and Samuels (2018) and industry level comparisons in Jorgenson, Nomura, and Samuels (2016) for the two country case (United States and Japan). One path forward is to build similar source datasets for other countries. This includes bilateral input-output tables and price surveys like those conducted by METI (2012). Obviously, bilateral tables would need to be extended to cover world trading partners (like the work done in WIOD and others) and price surveys would need to cover price differences across all countries in the world economy. To this end, it would be ideal to build partnerships across statistical agencies and the academic community. One model for building relevant data is the APEC-TiVA initiative which is a public-private partnership that has taken on the issue of measuring trade in value added.[27]

## Extensions

The purpose of this article has been to introduce the basic framework required to implement a world production account at the industry level, yielding a global integrated pro-

27 See http://www.apectivagvc.org/.

duction account. The account provides the foundation for comparisons of industry-level price competitiveness, TFP-level comparisons, country and industry level contributions to world economic growth, and global production chain analysis. The World KLEMS and EUKLEMS initiatives have provided a basic proof of concept for implementing country level growth accounts. The global integrated industry-level production (KLEMS) account involves formulating an integrated set of world input-output tables in current prices and constant prices adjusted for purchasing power parities.

We have provided the basic formulations to implement the world production account. But there are potential extensions that are worth noting. A first possible extension is to build into the production account a method to assess the importance of input reallocation in economic growth. In Jorgenson, Ho, and Samuels (2019) the reallocation effect manifests as the difference between aggregate TFP growth and industry TFP growth. This is relatively small in the United States, but potentially of interest for other countries. We have not addressed how to measure reallocation in the context of the world production account.

Finally, the formulation of the world production account has assumed that, within industries, the production process of globally engaged establishments and establishments that are not globally engaged is the same. Recent work by Fetzer and Strassner (2015) suggests that it may be important to disentangle globally engaged firms in the input-output tables. One particular motivation for that work is to refine estimates of trade in value added (TiVA). If the statistical community considers this an important dimension for TiVA estimates (and the corresponding supply, use, and input-output tables on which they are based), this same classification could be incorporated into the world extended production (KLEMS) accounts presented in this article.

One way to think about this extension is that it would require a new classification into globally-engaged establishments and other establishments for all of the components of the global production account. The OECD Expert Group on Extended Supply-Use Tables has addressed this issue as well (OECD 2015), but results from the World KLEMS initiative demonstrate the importance of growth accounting using currently available supply-use tables.[28] This in-

28 See https://www.oecd.org/sti/ind/tiva/eSUTs_TOR.pdf.

dicates that next steps on the global production account could make use of the existing input-output structures and data without having to build new supply use-tables from the ground up.

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# The Composition of Capital and Cross-country Productivity Comparisons

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Abstract

The role of physical capital is typically found to be limited in accounting for differences in GDP per worker, but this result may be because capital is customarily assumed to be a homogenous unit. This assumption is misleading, as different types of capital assets have different marginal products and richer countries tend to invest more in high-marginal product assets. We take this perspective to a global dataset, the Penn World Table, to improve cross-country productivity comparisons. We show that, properly measured, differences in capital input can account for a greater share of income variation, but (total factor) productivity differences remain dominant.

Income levels differ greatly across countries: the average income level in 2011 in Denmark (at the 90th percentile of the cross-country income distribution) was about 30 times higher than in Haiti (at the 10th percentile). We can aim for a better understanding of these differences by trying to account for as much as possible of these income differences using the tool of development accounting. In development accounting, income differences are partly attributed to differences in observed levels of human and physical capital with the remainder attributed to differences in total factor productivity (TFP).[2] A typical result is that approximately half of income differences are due to differences in (human and physical)

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2 See in particular Caselli (2005) and Hsieh and Klenow (2010) for overview articles.

capital input and half due to TFP differences.

Yet there are good reasons to believe that the role of physical capital in development accounting is underestimated. This is, in part, because usually only the contribution from standard 'National Accounts' assets are considered, while there are good reasons to expand asset coverage to include other intangible assets (Chen, 2018) and subsoil assets (Freeman, Inklaar and Diewert, 2018). But even when focusing on the set of assets covered in the National Accounts, we may still be underestimating the role of (physical) capital.[3] This is because countries differ systematically in their investment patterns: high-income countries tend to invest more in short-lived assets, such as computers and software, and less in long-lived assets like office buildings or roads. These differences are due to the higher relative cost of short-lived assets in low-income countries (Hsieh and Klenow, 2007) and lack of complementary assets, such as human capital (Caselli and Wilson, 2004). Yet the impact of these differences for development accounting are not yet well understood.

To gauge the impact of these differences on comparative levels of capital input and productivity, we rely on the conceptual tools introduced by Jorgenson and Nishimizu (1978) and in particular their methodology.[4] These tools have—so far—only been partially implemented in comparing productivity levels on a global scale. Most notably, the Penn World Table (PWT), (Feenstra, Inklaar and Timmer, 2015) compares productivity across countries using a measure of capital input that does not appropriately account for differences in the marginal product of the various capital assets.[5] In this article, we go a step further by estimating the user cost of capital and comparing the rental price of capital and the level of capital services rather than capital stocks. While this is not the first article to do so, we cover a much broader set of countries than previously in the literature, which means we can speak to the broader development accounting

3 Note that this set has changed over time. In the accounting rules of the System of National Accounts (SNA) 1993, much of spending on software was recategorized from an expense to an investment and in the SNA 2008, a major change was to recognize spending on research and development as an investment. Different countries follow different versions of the SNA, with very few still using SNA 1968 and approximately half of the countries using SNA 1993 and half using SNA 2008, according to the UN National Accounts Official Country Data.

4 See e.g. Jorgenson, Nomura and Samuels (2016), Inklaar and Timmer (2009) and Schreyer (2007) for more recent implementations of this methodology.

5 Feenstra et al. (2015) build on Diewert and Morrison (1986) and Caves, Christensen and Diewert (1982), who in turn build on Jorgenson and Nishimizu (1978).

literature.[6]

In this study, we implement the user cost/capital services methodology in a global setting over the period since 1950 and assess the impact on international differences in capital input and productivity compared with the 'capital stock' measure that is used in recent versions of PWT. In this process, we improve measurement in three areas.

First, PWT assumes that when a country's data are first observed, its nominal capital-output ratio is 2.6, based on contemporaneous evidence (Feenstra *et al.* 2015). Using historical series for 38 countries, we show that across the development spectrum, nominal capital-output ratios have been increasing over time. We implement a method for estimating initial capital stocks using country-specific information, in combination with the observed global trend to allow for more reliable estimation of capital input when a country's data are first observed.

Second, the return on capital plays an important role in the literature, in particular the Lucas (1980) paradox of why capital is not flowing towards low-income countries. More recently, Caselli and Feyrer (2007) argue that, properly measured, the marginal product of capital (MPK) does not vary with country income level. Conversely, David, Henriksen and Simonovska (2016) argue that, over the long run, low-income countries do have a higher MPK, with higher risk explaining the Lucas paradox. The method of Jorgenson and Nishimizu (1978) requires an estimate of the internal rate of return on capital (IRR), which is a more accurate measure of the return to capital than the MPK because it accounts for differences in the composition of the capital stock. Our findings accord with those of David *et al.* (2016), that low-income countries have higher (real) IRRs and we show that a single-year comparison of returns can easily be misleading for the long-run patterns.

Third, in PWT's capital stock-based methodology, the weight given to short-lived assets is too low compared to the conceptually appropriate capital services methodology. We confirm that high-income countries invest more in short-lived assets than low-income countries. By moving to a capital services methodology, capital input of high-income countries is thus increased relative to capital input in low-income countries. We show that, as a result, cross-country differences in capital input can account

6 The data we develop in this article are part of version 9.1 of the Penn World Table, available at www.ggdc.net/pwt.

for a greater share of cross-country income variation, increasing from 4.4 to 7.5 per cent in 2011. Even then, though, productivity differences remain the dominant source of income variation at 64.8 per cent.

In the following sections we will outline the conceptual framework for development accounting, productivity measurement and capital measurement. We will then discuss our implementation, with specific attention to our new method for estimating initial capital stocks and the choices necessary to estimate capital services. We finally show results for the new capital measures and the implications for the importance of cross-country differences in capital input in accounting for cross-country income differences.

## Development Accounting

As detailed in Caselli (2005), the typical starting point in development accounting is an aggregate production function for country $m$:

$$Y_m = A_m f(K_m, L_m) = A_m K_m^{\alpha} L_m^{1-\alpha} \tag{1}$$

A country's GDP, $Y$, is produced using production function $f$ with input of capital $K$ and labour $L$ and total factor productivity level $A$. In equation (1) we assume a constant-returns to scale Cobb-Douglas production function with a constant output elasticity of capital $\alpha$ for expositional simplicity. In the next section, on productivity measurement, we will move to a translog function. Similarly, the production function in equation (1) shows overall capital input and in the section on capital measurement, we will show how this is computed based on detailed asset stocks and their rental prices. Let a lowercase variable denote a quantity divided by country population, $P_m$, and let us express quantities relative to the United States, so that, for example, relative GDP per capita is defined $\tilde{y}_m = \frac{Y_m/P_m}{Y_{US}/P_{US}}$. We can then decompose a country's GDP per capita level relative to the United States into the contribution from differences in factor inputs and differences in productivity levels:

$$\tilde{y}_m = \tilde{A}_m \tilde{k}_m^{\alpha} \tilde{l}_m^{1-\alpha} \tag{2}$$

As discussed in Hsieh and Klenow (2010), this accounting for differences in GDP per capita levels answers the hypothetical question: by how much would GDP per capita increase if one of the factor inputs or productivity were to increase, holding constant the other two elements. This can be a sensible hypothetical when comparing growth over a short period of time as it is plausible to assume that the economy has not yet moved from one steady state to another. Yet when comparing across countries, it seems more plausible that the comparison is between countries in a (Solow model) steady state, i.e. where the investment response to the level of technology has worked itself out.

Hsieh and Klenow (2010) argue that a more sensible hypothetical in a cross-country context would be:

$$\tilde{y}_m = \tilde{A}_m^{\frac{1}{1-\alpha}} \left(\frac{\tilde{k}_m}{\tilde{y}_m}\right)^{\frac{\alpha}{1-\alpha}} \tilde{l}_m \qquad (3)$$

This rearranges the production function in intensive form and the hypothetical question for this decomposition is how GDP per capita would change if total factor productivity or labour input per capita were to change, allowing capital per person to adjust in response. This reduces the effect of differences in capital input, since part of the differences in capital per worker are an endogenous response to differences in productivity and labour input, whose contributions are, in turn, magnified.

Given data for all terms of equation (3), we will assess the role of each term in accounting for income differences by estimating the following regressions:

$$\frac{1}{1-\alpha}\log(\tilde{A}_m) = \beta^A \log(\tilde{y}_m) + \epsilon_m^A \qquad (4)$$

$$\frac{\alpha}{1-\alpha}\log\left(\frac{\tilde{k}_m}{\tilde{y}_m}\right) = \beta^K \log(\tilde{y}_m) + \epsilon_m^K \qquad (5)$$

$$\log(\tilde{l}_m) = \beta^L \log(\tilde{y}_m) + \epsilon_m^L \qquad (6)$$

Since the sum of the dependent variables equals the independent variable, the coefficients $\beta^A$, $\beta^K$ and $\beta^L$ add up to one and inform us of the relative importance of each term in accounting for cross-country income differences.[7] We will implement equation (3) for three alternative measures of capital input and then compare $\beta^A$ and $\beta^K$ for each alternative.

## Measuring Productivity

A common justification for the Cobb-Douglas function used in the previous section is the work of Gollin (2002). He showed that the standard estimate of the output elasticity of capital $\alpha$, the share of capital income in GDP, does not systematically vary with a country's income

7 This is an alternative to the variance decomposition used in Caselli (2005), which has as a downside that covariances between inputs and productivity need to be allocated. The approach in equations (4), (5) and (6) is applied in the context of accounting for trade patterns in Redding and Weinstein (2018) and the adding-up property means that no ad-hoc allocation of covariances is necessary.

level. However, when distinguishing multiple types of capital and/or labour inputs, assuming that all input shares are identical is unlikely to hold. Such a situation calls for a more flexible functional form and here we follow Jorgenson and Nishmizu (1978), Schreyer (2007), Feenstra *et al.* (2015) and Inklaar and Diewert (2016) and assume a translog production function. This allows us to compare the level of factor inputs, $Q$, in country $m$ relative to country $c$ as:

$$\log Q_{m,c} = \alpha_{m,c}[\log K_m - \log K_c] + (1-\alpha_{m,c})[\log L_m - \log L_c] \quad (7)$$

with $\alpha_{m,c} = \frac{1}{2}(\frac{r_m K_m}{r_m K_m + w_m L_m} + \frac{r_c K_c}{r_c K_c + w_c L_c})$ the two-country average share of capital income in GDP.[8] This implementation of $\alpha$ implies assuming constant returns to scale, so that total income equals total cost, and perfect competition in factor markets so that inputs are used up to the point where marginal product equals marginal costs. If, in addition, perfect competition in output markets is assumed, the resulting estimate of total factor productivity can be interpreted as a measure of comparative technology. We follow much of the development accounting literature and assume that labour input is well-captured by a measure of total hours worked $H_m$ multiplied by a human capital index $h_m$ that depends on the average years of schooling and an (assumed) rate of return to schooling.[9] In addition, note that this is (for expositional purposes) a two-input specification, but a key feature of this article is that we distinguish multiple types of capital assets. Extending equation (2) to cover multiple assets $K_i$ is discussed below.

Equation (2) shows the input index for a comparison between countries $m$ and $c$ but with multiple countries $c = 1, \ldots, C$, the resulting index will be dependent on the base country c. The solution is to make a multilateral comparison as discussed in, for example, Inklaar and Diewert (2016). Given the translog production function we assume, the multilateral input index can be expressed as:

$$\log Q_{m,\cdot} = \alpha_{m,\cdot}[\log K_m - \overline{\log K}] + (1-\alpha_{m,\cdot})[\log L_m - \overline{\log L}] \quad (8)$$

8 As the equation for $\alpha_{m,c}$ makes clear, this share—as all others in this article—is defined in terms of current price values.

9 We follow the standard implementation of Caselli (2005), though see Lagakos, Moll, Porzio, Qian and Schoellman (2018) for a broader view of human capital in a development accounting context.

Where $\alpha_{m,\cdot}$ is the average of the capital income share in country $m$ and of the cross-country average capital income share, $\alpha_{m,\cdot} = \frac{1}{2}(\frac{r_m K_m}{r_m K_m + w_m L_m} + \frac{1}{c}\sum_{c=1}^{C} \frac{r_c K_c}{r_c K_c + w_c L_c})$ and $\overline{\log K}$ the cross-country average of capital input levels, $\overline{\log K} = \frac{1}{c}\sum_c \log K_c$. Equation (8) gives the input index relative to a hypothetical average country, but that index can be recast relative to any reference country, such as the United States.[10]

## Measuring Capital

A key objective of this article is to estimate comparative capital input based on multiple capital assets, which involves estimating, for a range of capital assets $i = 1, \ldots, I$, capital input $K_i$ and rental prices $r_i$. Following the framework of Jorgenson and Nishimizu (1978)—and more recently discussed in the OECD (2009) capital manual—the asset rental price at time t can be approximated as:[11]

$$r_{i,t} = p^N_{i,t-1} i_t + p^N_{i,t}\delta_i - p^N_{i,t-1}(p^N_{i,t} - p^N_{i,t-1}) \quad (9)$$

where $i_t$ is the required rate of return on capital (on which more below), $p^N_i$ is the purchase price of asset $i$, and $\delta_i$ is the geometric depreciation rate.

The quantity of capital input $K_i$ is typically not directly observable. Instead it is based on estimated net capital stocks $N_i$, which are in turn based on the total accrued investment $I_i$ depreciated over time using the perpetual inventory method:

$$N_{i,t} = (1 - \delta_i)N_{i,t-1} + I_{i,t} \quad (10)$$

An important challenge in implementing equation (9) is the estimation of the capital stock in the initial year, $N_{i,1}$, which we discuss in detail below.

Assuming that the flow of capital inputs from a particular asset is proportional to the stock of that asset, $N_i \propto K_i$, we can express the income flow from asset $i$ as $r_i N_i$ and estimate relative capital input for equation (8) as:

$$\log(K_{m,\cdot}) = \sum_i \frac{1}{2}(v_{i,m} + v_{i,\cdot}) (\log N_{i,m} + \overline{\log N_t}) \quad (11)$$

where $v_{i,m} = \frac{r_{i,m}K_{i,m}}{\sum_i r_{i,m}K_{i,m}}$ is the share

10 The multilateral productivity measures we have introduced here, imply a small modification to the development accounting introduced in equations (4)-(6). Rather than relying on a single $\alpha$, we use $\alpha_{m,\cdot}$.

11 This formulation of the rental price abstracts from terms related to the tax treatment of investment and profits.

of asset $i$ in total compensation in country $m$, $v_{i,\cdot} = \frac{1}{c}\sum_c v_{i,c}$ is the cross-country average compensation share and $\overline{\log N_i} = \frac{1}{c}\sum_c \log N_{i,c}$ the cross-country average capital stock.

It is helpful to contrast the conceptually preferred measure of equation (11) to current practice in the Penn World Table, which for our analysis is the status quo. PWT's capital input measure is a measure of the overall capital stock:

$$\log N_{m,\cdot} = \sum_i \frac{1}{2}(w_{i,m} + w_{i,\cdot}) (\log N_{i,m} + \overline{\log N_i}) \quad (12)$$

where $w_{i,m} = \frac{p_i^N N_i}{\sum_i p_i^N N_i}$ is the share of asset $i$ in the total current-cost net capital stock. The main difference with our approach is that the measure of capital input in equation (12) does not consider that different assets have different rental prices. Compared to equation (11), equation (12) overstates the importance of long-lived assets, which tend to have a relatively low rental price (because of a low $\delta_i$) and a high share $w_{i,m}$. When moving from measuring capital using equation (12) to equation (11), we expect countries with a relatively high share of long-lived assets to show a decline in relative capital input levels.

## Data and Implementation

For implementing the development accounting equation (3), our starting point is the Penn World Table. Our measure of comparative GDP, population, employment, average hours worked, the share of labour income in GDP and average years of schooling are as described in Feenstra *et al.* (2015) and at www.ggdc.net/pwt. PWT (version 9.1) covers up to 182 countries from 1950 to 2017, but the maximum number of countries in our analysis is 117, because for some we do not have the requisite data to implement the development accounting method.

For estimating capital input, the starting point for both the current PWT approach and our new analysis is data on investment by asset type. Here, too, we use the same data, which distinguishes nine asset types: residential buildings, other structures, information technology, communication technology, other machinery, transport equipment, software, other intellectual property products and cultivated assets (such as livestock for breeding and vineyards).[12] As discussed in PWT documentation, these investment data are drawn from country National Accounts data, supplemented by estimates based on to-

12 See also Table 3 in the results section.

tal supply of investment goods (import *plus* production *minus* exports) and data on spending on information technology. Note that coverage is limited to assets currently covered in the System of National Accounts. This means we omit land and inventories, as well as other forms of intangible capital—such as product design or organization capital—and subsoil assets—such as oil or copper.

### Initial Capital Stocks

Our estimate of asset capital stocks is based on the perpetual inventory method, so the capital stock at time $t$ is based on all previous investments (equation 10). But given that we only observe investment data for a limited period of time (for PWT, 1950 is the earliest year), an important challenge is to estimate the capital stock in the first year of the data, $N_{i,1}$. There are two main approaches in the literature. The first is to assume the economy in the steady-state of the Solow model at time $t$, in which case the initial stock is equal to:

$$N_{i,1} = \frac{I_{i,1}}{g_i + \delta_i} \qquad (13)$$

where $I_{i,1}$ is investment in the initial year and $g_i$ is an estimate of the steady-state growth rate of investment in that asset, typically implemented as an average growth rate in the first years of the observation period.

The second method is to use a data-driven approach to select an initial capital level. The nominal capital-output ($p^N N/p^Y Y$) ratio is a helpful quantity in this approach. In the Solow model, the $p^N N/p^Y Y$ ratio is constant while capital per worker increases with income, matching two of the Kaldor facts, and observation also shows this ratio to be bounded. Feenstra *et al.* (2015) observed in the PWT data that (a) the $p^N N/p^Y Y$ ratio did not vary systematically by income level, and (b) the $p^N N/p^Y Y$ ratio did not systematically change over time. This motivated the choice for selecting an initial $p^N N/p^Y Y$ ratio based on contemporaneous data that did not vary across countries or over time. In PWT versions 8.0, 8.1 and 9.0, the initial current-cost net capital was set at a level of 2.6 times GDP at current prices for each country. This choice can be justified if the main goal is to select an $N_i$ that does not systematically over- or underestimate capital input by income level, but this approach ignores country-specific information.

Recent data development has provided further scope for improvement. Gallardo Albarrán (2018) has collected investment data for 38 countries across the world and spanning much of the development spectrum for the period before 1950, with data coverage varying between countries, from Sweden (data starting in 1800) to Korea (data starting in 1911). As a result, the $p^N N/p^Y Y$ ratio we observe in 1950 for these 38 countries can be taken as reliable initial capital stocks. The data for these 38 countries thus provides a more extensive basis for assessing the stylized facts underlying PWT, in particular the finding that there is no time trend in the $p^N N/p^Y Y$.

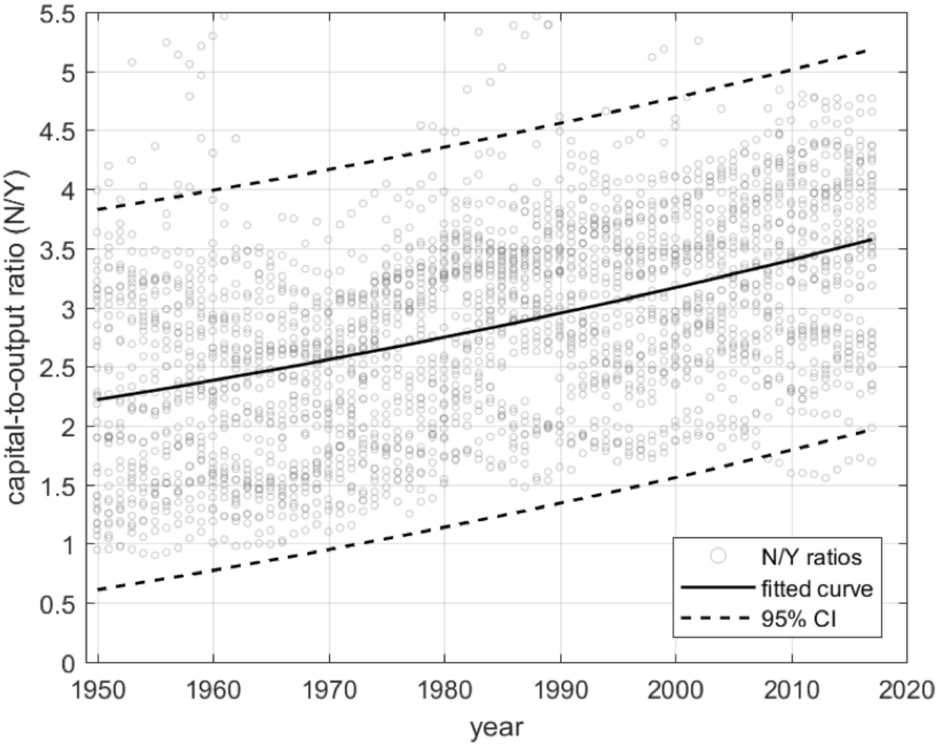
Chart 1 plots the $p^N N/p^Y Y$ ratio for the 38 countries since 1950. A first important observation is that there is a time trend: the $p^N N/p^Y Y$ ratio increases from, on average, 2.2 in 1950 to 3.5 in 2017 for an increase of approximately 0.02 per year. Second, this chart illustrates the large cross-country variation, with 1950 ratios varying between 0.9 and 4.0. The choice of 2.6 in recent PWT versions is thus only (somewhat) appropriate on average.

To estimate initial capital stocks for the countries without long-run (pre-1950) investment data in a way that does justice to the rising trend and the cross-country variation, we devise a new procedure, which we illustrate in Chart 2. First, we determine the point in each country's time series at which the choice of the initial capital stock has faded enough in importance; we denote this point by $t^*$. To determine $t^*$, we estimate $p^N N/p^Y Y$ ratios based on extreme initial stocks: an $p^N N/p^Y Y$ ratio of 0.5 on the low end and an $p^N N/p^Y Y$ ratio of 4 on the high end. These extremes are inspired by the extremes in Chart 1. Point $t^*$ is chosen as the first year for which the difference in estimated capital stocks from both extremes is less than 10 per cent. This point can come sooner or later depending on the composition of the capital stock (short- vs. long-lived assets) and the growth rate of investment. In the example for Turkey in Chart 2, $t^* = 1990$, which means that from 1990 onwards, the choice of the initial capital stock is practically immaterial.

The next step in the procedure is to take the mid-point $p^N N/p^Y Y$ ratio at year $t^*$ and project this level backwards using the average annual change in the $p^N N/p^Y Y$ ratio of 0.02 from Chart 1. We realize this growth rate will not be appropriate for each country, but over time frames of 30-40 years, most countries do show increases in the $p^N N/p^Y Y$ ratio. Compared to assuming a single initial $p^N N/p^Y Y$ ratio for every country, this procedure does more justice to each country's experiences.

We were able to apply this procedure successfully for 92 countries. For some countries the available investment series were too short in length to converge to within our defined bandwidth, so no $t^*$ could be determined.

**Chart 1: Capital-to-Output Ratios, 1950-2017**




Notes: Annual capital-to-output ratios for 38 countries for which long run (pre-1950) investment data are available.

For those cases we base the starting level of the $p^N N/p^Y Y$ ratio on the average observed for that year for the 130 countries for which we have estimates of the $p^N N/p^Y Y$ ratio.

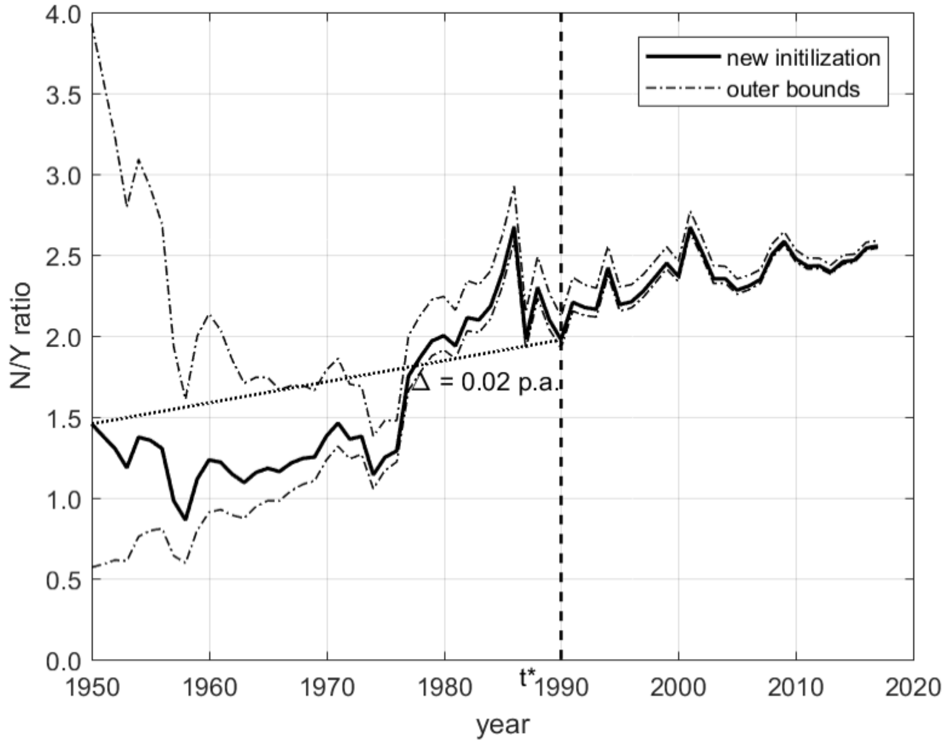
## Rental Prices

Recall that the rental prices are determined by the required rate of return on capital, the depreciation rate and a revaluation term, reflecting the change in the asset price. The revaluation term as specified in equation (9) is not ideal in practice, because asset prices can be quite volatile. Especially in the case of structures, with its low depreciation rates, this can be problematic and lead to negative rental prices.[13] To avoid this, we use a five-year moving average for the change in asset prices:

$$p_{i,t}^K = p_{i,t-1}^N i_t + p_{i,t}^N \delta_k - p_{i,t-1}^N \frac{1}{5}\left(\sum_{\tau=t-4}^{t} \widehat{p}_{i,\tau}^N\right) \quad (14)$$

13 See also Inklaar (2009).

**Chart 2: Example of Estimation Procedure Initial Capital-to-Output Ratio, Turkey**




Notes: The starting $p^N N/p^Y Y$ ratio for the upper bound is 4.0. The lower bound starts at 0.5. '$t^*$' marks the year where the lower- and upper bound converge to within a margin of 10 per cent. The slope of the dashed line represents the assumed growth of the $p^N N/p^Y Y$ ratio at 0.02 per annum between the first year [1950] and $t^*$ [1990]. The solid black line shows the resulting capital-output ratio based on the estimate for the initial $p^N N/p^Y Y$ ratio.

In the standard Jorgensonian approach to rental prices, the required rate of return on capital is chosen to exhaust the income left after subtracting labour income from GDP. This gives an internal rate of return on capital and an important advantage is that this return sets 'pure profits' to zero and is thus consistent with the maintained assumption of perfect competition. An important drawback, in a global context, is that in some countries the rents from extracting natural resources like oil and gas is a sizeable fraction of GDP (Lange, Wodon and Carey, 2018). For those countries, computing the internal rate of return based on the income that does not flow to labour would substantially overestimate the required rate of return on assets.[14] So instead, we determine the income flowing to capital as nominal GDP minus labour income minus natural resource rents:

14 Ideally, natural resources should be recognized as production factors in their own right. That is beyond the scope of this article but see Freeman, Inklaar and Diewert (2018).

15 Natural resource rents are from the World Development Indicators.

$r_t N_t \equiv p_t^Y Y_t - w_t L_t - p^Z Z$.[15] The (nominal) internal rate of return on capital is then determined to ensure capital compensation adds up to total capital income:

$$i_t = \frac{r_t N_t - \sum_i p_{i,t}^N \delta_i N_{i,t}}{\sum_i p_{i,t-1}^N N_{i,t}} + \frac{\sum_i p_{i,t-1}^N \frac{1}{5}(\sum_{\tau=t-4}^{t} \widehat{p}_{i,\tau}^N) N_{k,t}}{\sum_i p_{i,t-1}^N N_{i,t}} \quad (15)$$

For a cross-country comparison of the returns to capital we also estimate the real internal rate of return ($R$), a new variable in PWT version 9.1:[16]

$$R_t = \frac{r_t N_t - \sum_i p_{i,t}^N \delta_i N_{i,t}}{\sum_i p_{i,t}^N N_{i,t}} \quad (16)$$

The rental prices are also relevant for comparing the level of capital input in different countries. In the original PWT method (i.e. equation 12), capital stocks are made comparable across countries using data on the relative prices of investment goods, $p_{i,m}^N / p_{i,US}^N$. Yet when comparing capital input according to equation (11), the appropriate price comparison is based on the rental price from equation (14), so $p_{i,m}^K / p_{i,US}^K$. This adjusts the relative price of investment goods for differences across countries in the user cost of capital. Since we assume the same depreciation rate for a given asset in all countries, differences in the user cost of capital are due to differences in the (country-level) internal rate of return $i_t$ and due to differences in the (five-year average) rate of asset price inflation. Especially for computers, communication equipment and software, cross-country differences in asset price inflation (or deflation) can be affected by the degree to which country statistical agencies adjust for quality change. So as in previous versions of PWT, we apply US asset price changes, adjusted for differences in the change in the overall deflator for gross fixed capital formation, to all countries.

## Results

In this section, we first discuss how our new initial capital stock estimates influence capital-output ratios and how they compare to the $p^N N / p^Y Y$ ratios in the previous PWT. Next,

16 Note we also used the asset-specific investment price for the current year ($p_{i,t}^N$) instead of the previous year in the denominator for the calculation of the real IRR. Rapid inflation would otherwise cause the real IRR to fluctuate wildly. The correlation between the mean real IRR based on current year and previous year prices for countries who experienced below-average price changes is 0.998, for countries with above-average inflation this correlation is 0.794. The correlation between the standard deviations is 0.934 and 0.223 respectively. For the latter set of countries the standard deviation based on the previous-year method is much higher; 0.290 versus 0.055 for the current-year method.

we analyze the variation in the internal rates of return across countries and over time. Finally, we implement the development accounting procedure from equations (3-6) to assess to what extent our new, more conceptually appealing measure of capital input can account for more of the cross-country variation in income levels.

### Capital-Output Ratios

For selected years, Table 1 summarizes the $p^N N/p^Y Y$ ratios based on the new, country-specific initial capital stocks compared to the previous method, where all countries had the same initial capital-output ratio. For our full sample of countries, the rising trend in the $p^N N/p^Y Y$ ratios observed in Chart 1 is confirmed: the average $p^N N/p^Y Y$ ratio climbs from 2.1 in 1950 to 3.5 in 2000.[17] The standard deviation, minimum and maximum values confirm that there are indeed sizable variations in the $p^N N/p^Y Y$ ratios between countries. The comparison between the 'new' and 'original' initialization shows the average adjustment in the $p^N N/p^Y Y$ ratios is most pronounced for earlier years. This is to be expected, as the $p^N N/p^Y Y$ ratios depend ever less on the initial stock. Already by 1990, the differences between the new and original initial capital stocks have mostly disappeared. The standard deviation and range of $p^N N/p^Y Y$ ratios for the original series remain lower for the original initial stocks, which reflects that the new initialization allows for variation in the starting capital-to-output ratios reflecting country-specific factors.

### Internal Rates of Return

Chart 3 shows the development over time of the real internal rate of return $R_t$ from equation (16). As discussed above, $R_t$ is a proxy for the (expected) real returns to capital. We run an ordinary least squares regression of $R_t$ on country and year dummies and plot year dummies with their 95-per cent confidence interval in the left panel Chart 3. This show the average $R_t$ declining from 20.0 per cent in 1950 to 11.7 per cent in 2017. The distribution of $R_t$ is skewed to the right, so the trend in the median is informative as well. To that end, the right panel of Chart 3 shows the results from a least median squares regression of $R_t$ on country and year dummies. This shows the median decreasing from 14.4 per cent in 1950 to 8.5 per cent in 2017.

Table 2 reports the real IRR across three country groups (distinguished

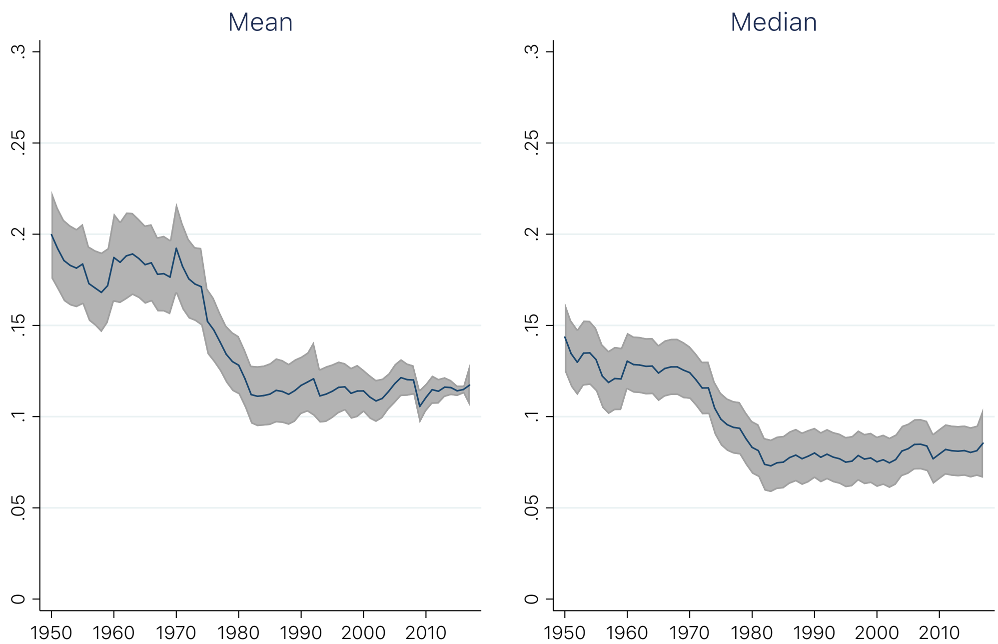
17 Note that the sample of countries for which we can estimate the capital stocks changes over time. The trend increase can still be observed if we hold the sample constant, however.

**Table 1: Comparison of $p^N N/p^Y Y$ Ratios Between New- and Original Initiatlization, Selected Years**

| Year | Countries | New initialization | | | | Original initialization | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Stdev. | Min. | Max. | Mean | Stdev. | Min. | Max. |
| 1950 | 55 | 2.1 | 0.9 | 0.5 | 4.0 | 2.6 | 0.0 | 2.6 | 2.6 |
| 1960 | 110 | 2.2 | 1.0 | 0.6 | 7.0 | 2.5 | 0.8 | 1.0 | 6.9 |
| 1970 | 156 | 2.1 | 0.9 | 0.6 | 5.4 | 2.4 | 0.6 | 0.8 | 4.9 |
| 1980 | 156 | 2.5 | 1.0 | 0.5 | 5.6 | 2.7 | 0.9 | 0.6 | 5.2 |
| 1990 | 180 | 3.0 | 1.6 | 0.6 | 18.2 | 3.1 | 1.6 | 0.6 | 17.4 |
| 2000 | 180 | 3.5 | 2.5 | 0.7 | 25.0 | 3.4 | 2.3 | 0.8 | 22.7 |
| 2011 | 180 | 3.3 | 2.5 | 1.0 | 30.2 | 3.3 | 2.3 | 1.0 | 27.6 |
| 2017 | 180 | 3.4 | 2.0 | 1.0 | 19.3 | 3.3 | 1.9 | 1.0 | 17.7 |

Note: The 'new initialization' relies on the procedure described in the 'starting stocks' section above to estimate the initial N/Y ratio for each country separately. The 'original initialization' assumes the initial level of $N/Y$ for each country is equal to 2.6, mirroring the method used for previous versions of the PWT. Both the 'new' and 'original' series apply the same PIM procedure, discussed above, to construct the capital stocks and $N/Y$ ratios for all subsequent years.

**Chart 3: Real Internal Rate of Return Time Trend, 1950-2017**




Note: The chart shows the coefficients and 95 per cent confidence interval for year dummies in an ordinary least squares regression of $R_t$ from equation (16) regressed on country and year dummies (left panel) and the year dummies from the same regression but then estimated using least median squares. The sample size increases over time from 55 countries in 1950 to 135 in 2017.

**Table 2: Real Internal Rate of Return by Income Group**

| Portfolio | 1950-2017 | | 1970-2017 | | 2011 |
|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) |
| 1 | 0.124*** | 0.112*** | 0.110*** | 0.105*** | 0.101 |
| 2 | 0.139*** | 0.127*** | 0.128*** | 0.124*** | 0.120 |
| 3 | 0.094* | 0.078** | 0.090 | 0.084 | 0.086 |
| US | 0.078 | 0.057 | 0.075 | 0.068 | 0.075 |
| Year dummies | N | Y | N | Y | N |
| Observations | 7,586 | 7,586 | 6,080 | 6,080 | 135 |
| Adjusted $R^2$ | 0.11 | 0.15 | 0.1 | 0.11 | 0.05 |

Notes: The portfolios are based on the approach of David et al. (2016), appendix F. The portfolio categories for countries missing in the David et al. dataset were estimated based the mean GDP p. capita observed between 1950 and 2008. In 2011 the (unweighted) average log of GDP p. capita for portfolio 1 was [8.1], for portfolio 2 [9.5], for portfolio 3 [10.5], and for the US [10.8]. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.

by income level) for different periods, with or without year dummies, mirroring the approach of David *et al.* (2016). The results show that for the 1950-2017 period, the real IRR for the low- and middle-income countries was significantly higher than that observed for the United States. The implicit return to capital for high-income countries (other than the United States) was also higher, but this is only significant at the 10 per cent level. The result for low- and middle-income countries holds up if we include year dummies or limit the period to 1970-2017. If we focus on 2011 alone, the differences between the real IRR across the different country groupings are no longer significant. More in general, the explanatory power of these models is limited, so other factors must have also been important. For one, the year-to-year variation in the IRR will depend on the state of the business cycle, as during downturns the realized returns on capital are typically lower. The low explanatory power can also point to the importance of omitted assets, such as land and inventories (e.g. Inklaar, 2009). All this does suggest that drawing conclusions on a single cross-section worth of data, as in Caselli and Feyrer (2007) can lead to missing out on patterns that are clear in the data once more years are taken into account.

## Capital Services

Using the internal rate of return discussed above and the asset-specific rates of depreciation listed in Table 3, we estimate the rental price of capital and the capital compensation shares ($v_i$) for the nine assets in our dataset and compare them to the average share in current-cost net capital stocks ($w_i$).

Table 3 summarizes these shares for all countries and years in our sample. As is to be expected, $v_i$ exceeds $w_i$ for assets with higher de-

**Table 3: Depreciation, Shares and the Relationship with Income Level**

| Asset | Depreciation Rate (1) | Stock Share, $w_i$ (2) | Services Share, $v_i$ (3) | Services/Stock Share, $v_i/w_i$ (4) | Coefficient log(GDP/capita) (5) |
|---|---|---|---|---|---|
| Information equipment | 31.5 | 0.2 | 1.1 | 4.8 | 0.574*** (0.0126) |
| Communication equipment | 11.5 | 1.3 | 2.3 | 1.8 | 0.251***(0.0144) |
| Other machinery | 12.6 | 11 | 17.4 | 1.6 | -0.005 (0.0054) |
| Transport equipment | 18.9 | 4.4 | 8.2 | 1.8 | -0.055*** (0.0061) |
| Software | 31.5 | 0.2 | 0.9 | 3.9 | 0.720*** (0.0144) |
| Other intellectual property | 15 | 1.2 | 2.5 | 2.1 | 0.555*** (0.0200) |
| Cultivated assets | 12.6 | 0.1 | 0.2 | 2.3 | -0.852***(0.0436) |
| Residential structures | 1.1 | 39.1 | 28.6 | 0.7 | 0.024*** (0.0049) |
| Other construction | 3.1 | 42.4 | 38.7 | 0.9 | -0.054*** (0.0047) |

Notes: The table shows (1) the asset-specific rates of depreciation; (2) the assets' average share in the total current-cost net capital stocks (for all years and countries in our sample); (3) the assets' average share in capital compensation; (4) the ratio between the capital services and the capital stock share; and (5) the beta coefficients for a regression of the log of GDP per capita on the log of nominal capital compensation ($p_i^K K_i$) over nominal output ($p^Y Y$). Robust standard errors in parentheses, *** p $<$ 0.01; ** p $<$ 0.05; * p $<$ 0.10.

preciation rates (and for assets where price deflation was more pronounced, notably IT-equipment). For example, capital compensation for other machinery accounts for 17.4 per cent on average, compared to the 11 per cent of the capital stock share, reflecting the higher service flow from such assets. In the final column we regress the nominal capital-to-output ratio for each asset on log GDP per capita. The coefficients show that high-income countries, on average, have higher stocks of short-lived assets and low-income countries have higher stocks of transport equipment, cultivated assets and other construction. This result mirrors similar earlier findings (e.g. Caselli and Wilson, 2004; Hsieh and Klenow, 2007) and suggests that employing a capital services input measure will lead to relatively higher levels of capital input in high-income countries. The only exception to this pattern is residential structures, whose stocks increase with income levels. Despite this, we would expect that capital input is more important in accounting for cross-country income differences when based on our new measure of capital services compared with the earlier capital stock measure.

## Development Accounting

Table 4 shows the results from estimating equations (4-6) on data for 2011. The first row shows capital input measured as in equation (12), $N_{m,\cdot}$, and uses the original initial capital stocks, i.e. assuming a nominal capital-output ratio of 2.6 in the first observed year. The second row still uses $N_{m,\cdot}$ from equation (12) but based on the new estimates of the initial capital stock. The final row is based on $K_{m,\cdot}$, from equation (11). The coefficient on labour input, $\beta^L$ is constant across the rows as measurement is unchanged. Changing the procedure for estimating the initial stock has very little impact on $\beta^K$ and

**Table 4: Development accounting results for 2011**

| | Capital input, $\beta^K$ | Labour Input, $\beta^L$ | Total Factor Productivity, $\beta^A$ |
|---|---|---|---|
| $N_{m,\cdot}$, original initial stocks | 0.044 | 0.277*** | 0.679*** |
| | (0.0330) | (0.0241) | (0.0445) |
| $N_{m,\cdot}$, new initial stocks | 0.050 | 0.277*** | 0.673*** |
| | (0.0340) | (0.0241) | (0.0457) |
| $K_{m,\cdot}$ | 0.075** | 0.277*** | 0.648*** |
| | (0.0311) | (0.0241) | (0.0376) |

Notes: The table show the beta coefficients for regression of capita input, labor input and productivity on GDP per capita, see equations (4-6), where instead of a single $\alpha$, we use each country's share of capital income in GDP, $\alpha_{m,\cdot}$. $N_{m,\cdot}$ is computed as in equation (12), $K_{m,\cdot}$ as in equation (11). Data are for 117 countries. Standard errors between parentheses. *** p < 0.01; ** p < 0.05; * p < 0.10.

$\beta^A$, which was to be expected from Table 1 since by 2011 there is little difference between the two approaches. Going from $N_{m,\cdot}$ to $K_{m,\cdot}$ does have a substantial impact: $\beta^K$ increases from 0.050 to 0.075, indicating that the new capital input measure can account for considerably more of the cross-country variation in income levels. At the same time, the effect on $\beta^A$ is (relatively) smaller, going from 0.681 to 0.647. So, despite accounting for more of the cross-country income variation, productivity differences remain the dominant sources of income differences.

## Conclusions

In this article, we have addressed two important shortcomings in the measurement of capital input in the widely-used Penn World Table. First, we have estimated initial capital stocks based on better data and an improved procedure that does more justice to country-specific experiences. Second, we have implemented a capital services methodology in accordance with standard productivity measurement theory. By doing so, we are able to account for more of the cross-country variation in income levels. This is because high-income countries tend to invest more in short-lived assets with higher marginal products.

Applying the capital services/rental prices methodology on a global scale for comparisons across countries highlights the challenges in this methodology. As discussed, the role of natural resources in generating income cannot be ignored, as otherwise the return that is imputed to fixed assets is considerably overestimated, in particular in resource-rich countries such as Qatar or Saudi Arabia. A related challenge is that we omit land and inventories from the set of assets due to lack of reliable data, and that, too, biases the estimated return on capital and can thus influence the comparison of capital input across countries. Yet we feel our current analysis serves a useful purpose in highlighting these challenges and pointing the way for future research in this area. And despite measurement shortcomings, our improved capital input measure can account for more of the cross-country differences in income levels.

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# Global Value Chains and Productivity Growth in Advanced Economies: Does Intangible Capital Matter?

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Abstract

This article investigates the impact of participation in global value chains (GVCs) on productivity growth considering the mediating effect of investment in intangible assets. We explore the existence of synergies between intangible capital accumulation and GVC participation and their influence on productivity in a sample of nine European economies in 1998-2013. The analysis relates the macroeconomic literature on the impact of intangibles and GVCs on productivity growth to microeconomic studies about the functions of intangibles along the value chain. The existence of complementarities between intangibles and GVC participation and their productivity effects are tested in an augmented production function framework. We find: a) positive and statistically significant productivity impact of backward participation; b) the marginal effect of GVC participation on growth is greater in countries-industries with higher intensity of intangible capital; c) non-R&D intangibles, and particularly organizational capital, exert a significant conditional effect on backward participation strengthening the productivity returns of global production activity.

Modern economies are increasingly based on knowledge and innovative technologies that are transforming how companies do business, how do they interact in the global market and consequently the drivers of international competitiveness and productivity growth.

In this respect the role of intangible capital as a source of growth

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(Corrado *et al.*, 2018) and international competition is gaining attention (Criscuolo *et al.*, 2015; Jona-Lasinio and Meliciani, 2018) and deserves a deeper investigation. At the same time, the structural and organizational changes associated with the knowledge economies have led to widespread processes of globalization of value chains which have also affected productivity in advanced and emerging countries (Criscuolo and Timmis, 2017).

In the economic literature, two unrelated areas of research have recently emerged investigating, respectively, the productivity impact of intangible capital and participation in Global Value Chains (GVCs). On one side, there is increasing evidence that intangible capital is a fundamental source of productivity growth in the United States but also in the European economies (see, e.g. Corrado *et al.*, 2018). On the other, theoretical models provide different predictions on the productivity gains accruing to countries from participation in GVCs (Baldwin and Robert-Nicoud 2014),[2] although the empirical evidence in this area supports the existence of a positive link (Kummritz, 2016; Constantinescu *et al.*, 2017).

The purpose of this article is to bridge these two areas of research by investigating whether the impact of participation in GVCs on productivity growth matters and whether it is amplified by investment in knowledge-based capital. We empirically address this research question drawing on the firm level literature on the role of different intangible assets for value generation along the supply chain (Mudambi, 2007; Shin *et al.*, 2009, 2012; Dedrick *et al.*, 2010). Further, as the managerial capabilities, design, brand and training have become crucial to firm's competitiveness in the global market (Chen *et al.*, 2017), we also test the productivity impact of the interactions between individual intangible assets and GVC participation. Intangibles might affect the productivity performance along a GVC because they generate relatively large returns to scale.

Durand and Milberg (2018) claim that intangible assets such as standards, specifications, R&D achievements, as well as software and organizational know-how are typically

2 In the model of Baldwin and Robert-Nicoud (2014), the rise of GVCs enables advanced countries to combine their superior technology with low wages in developing countries through the offshoring of some production tasks with positive gains for advanced countries. Emerging countries may also see an increase in their productivity and value added when there are technology spillovers. Differently, in Li and Liu (2014) GVCs allow developing countries to lower their unit labour requirements through a learning-by-doing process, but advanced countries experience a period of decreasing welfare because their comparative advantage deteriorates when emerging countries become more productive in tasks that are performed in advanced countries. Therefore, the overall effect of rising GVC participation on advanced countries value added can be negative.

scalable assets, imposing negligible marginal costs following the initial investment made to create them and resulting in infinite returns to scale. The difference in scale economies between tangible and intangible assets implies that the firms controlling intangible-intensive parts of the chain will be in the position of experiencing a relatively larger productivity improvement from network participation as output expands. This is why intangible capital is an essential element for productivity growth along the chain.

The empirical analysis is developed adopting an augmented production function framework and testing our model on a sample of nine European countries and 18 sectors over the period 1998-2013. Our main findings support the existence of a significant impact of participation on productivity growth and of a complementary relationship between intangible intensity and GVC participation. We find that the marginal impact of backward participation[3] on productivity is greater in industries/countries with higher intangible intensity and this result holds also for sub-categories of intangible assets.

The article is organized as follows. Section 1 reviews the literature. Section 2 describes the data and provides some descriptive analysis. Section 3 discusses the empirical strategy and the econometric results. Section 4 concludes.

## Background Literature and Research Questions

In this section we review the main results emerging from two distinct strands of the empirical literature on the productivity impact of intangible capital and GVCs participation and then formulate a research question bridging these two research fields.

### Intangible Capital, GVC and Productivity Growth

The research community and policymakers are currently paying increasing attention to intangible capital gaining fast-growing relevance on the supply side of the economy (Haskel and Westltake, 2017). The existence of a strong relation between intangible capital and productivity growth has been well documented both by micro and macroeconomic studies so far (see Thum-Tysen *et al.* (2017) for a review). Macro-level analyses support a statistically robust and significant positive link between intangible investment and productivity growth for the

3 Backward participation measures the foreign value added in domestic exports. For a more precise definition see Section 3.2.

EU economies and the United States (Corrado *et al.*, 2013 and 2018), for Japan and Korea (Chun *et al.*, 2015) as well as for China (Hao and Wu, 2018). The relevance of intangibles for productivity gains has been also demonstrated at the micro economic level by various research contributions (Black and Lynch, 2001; Bontempi and Mairesse 2008; Marroccu *et al.* 2012).

Overall, the empirical evidence demonstrates that intangible capital affects productivity growth via multiple mechanisms: directly, increasing capital deepening and interacting with other complementary assets (Corrado *et al.*, 2013 and 2018); and indirectly, being a driver of innovation and generating spillovers, mainly from non-R&D[4] intangible assets (Corrado *et al.*, 2017). Finally, intangibles are found to contribute to output growth one to three times more than tangible assets in the advanced economies thus making them strategic investment for long-run growth of single companies and the economy as a whole (Thum-Tysen *et al.*, 2017).

At the same time, the rising relevance of global value chains in modern economies stimulated new research efforts investigating the relationship between participation in GVCs by firms, industries, and countries and productivity gains. Criscuolo and Timmis (2017) identify several channels through which GVCs can help enhancing productivity. First, there is the classical argument of gains from specialization: in a value chain firms can specialise in the activities (the analogous to product specialization in the classical literature on trade liberalization) in which they are relatively more efficient and outsource the others. However, some studies have shown that, in terms of value added appropriation, the choice of the activities carried out in the GVC makes a material difference (Mudambi, 2007; 2008; Dedrick *et al.*, 2010).

A second channel through which participation in GVCs can affect productivity is by allowing firms to have access to a larger variety of cheaper and/or higher quality and/or higher technology imported inputs. Again, we can expect some heterogeneity in the ability of firms to exploit these advantages based on their core competencies and capabilities. Third, GVCs can facilitate knowledge spillovers allowing interaction of domestic firms with foreign multinational firms. Finally, similarly to the case of international trade, GVCs can give firms access to larger markets and increase competition, thus favoring the development of the most productive firms

4 Non-R&D assets include organizational capital, training, brand and design.

and inducing the exit of the least productive ones.

Empirical research in support of the theoretical predictions linking GVCs to productivity is however limited. Contributions include older strands of work focusing on benefits to countries that initiate offshoring (Feenstra and Hanson, 1996; Egger and Egger, 2006; Daveri and Jona-Lasinio, 2008; Amiti and Wei, 2009; Winkler, 2010), but also recent efforts that analyze the impact of vertical specialization on countries participating in GVCs (Formai and Vergara Caffarelli, 2016, Kummritz, 2016, Taglioni and Winkler, 2016; Constantinescu *et al.*, 2017).

Focusing on the most recent efforts, Formai and Vergara Caffarelli (2016) investigate the relationship between international fragmentation of production and (labour and total factor) productivity growth for US industries between the 1990s and the 2000s using Input-Output data provided by the Bureau of Economic Analysis (BEA). They find that participation in GVCs positively affects labour productivity and TFP in sectors with long and wide production chains in countries specialised in importing intermediate goods.

Other studies have extended the analysis to a larger sample of countries using the OECD World Input Output tables and measuring backward and forward participation in GVCs at the industry level. In particular, Kummritz (2016) shows that an increase in GVC participation leads to higher domestic value added and productivity in 54 countries independently of their income levels. Based on the preferred instrumental variable specification, he finds that a one percent increase in backward GVC participation generates an increase of 0.11 per cent of domestic value added in the average industry but does not affect labour productivity. On the other hand, a one percent increase in forward GVC participation causes an increase of 0.60 per cent of domestic value added and 0.33 per cent of labour productivity.

Finally, Constantinescu *et al.* (2017), using data on trade in value added from the World Input-Output Database, covering 13 sectors in 40 countries over 15 years find that participation in global value chains is a relevant driver of labour productivity. Differently from Kummritz (2016) backward participation in global value chains emerges as a particularly important factor affecting productivity growth.

An alternative approach has been suggested by Timmer (2017) arguing that Global Value Chains challenge the traditional approaches to productivity measurement. He suggests evaluating a production function where final output is produced using domestic and foreign factor inputs. Therefore, in this approach the flow of intermediate inputs will be netted allowing to express the production function of a final good exclusively in terms of factor inputs. The basis for this methodology is the analysis of the cost shares of the production factors that can be identified from synthetic input-output tables. This approach solves the problems linked to tracing the profits for intangible capital assets used in international production.

### Global Value Chains and Productivity Growth: the Mediating Role of Intangible Capital

This article explores the mediating effect of intangible capital in the relationship between GVC participation and productivity growth. In particular, we investigate whether a higher intangible capital intensity augments the productivity gains from GVC participation across countries and industries.

This hypothesis draws upon the micro-level literature investigating value creation along the value chain. The empirical evidence indicates that a major part of value added of a final product is created in the first and last stages of the production process (R&D, design, marketing and sales), while firms involved in intermediate stages (such as the production of components and assembly) reap only a small part of the final value of the good or service produced (Mudambi, 2007; 2008). As suggested by Everatt *et al.*, (1999); Mudambi, (2007) and Shin *et al.* (2009 and 2012), the pattern of value-added along the value chain may, therefore, be represented by the 'smiling curve' or the 'smile of value creation.' Intangible assets are essential to create value added in the supply chain playing a differentiated function along it. R&D and design are relatively more relevant upstream and marketing and advertising more downstream (Mudambi, 2008), but exerting generally a positive contribution to company's competitiveness in the global market (WIPO, 2017).

Overall, intangibles may be strategic elements in the various mechanisms through which GVC affects productivity growth. A first channel through which GVCs can enhance productivity is true gains from specialization. In this respect, the microeconomic literature quoted above shows that, in terms of value added appropriation, the activity carried out along the chain is crucial. The classic example of the iPod supply chain discussed by Dedrick *et al.* (2010) shows that Apple captures between one-third and one-half of an iPod's retail value, Japanese firms such as Toshiba and Korean firms such as Samsung capture another major share while firms and workers in China capture no more than 2 per cent from assembling the product.

The capability of these countries to appropriate a larger share of value is related to the extent of their investment in R&D, design, brand and of their organizational capabilities to control the value chain. Intangible assets are thus strategic for value added creation and appropriation. Moreover, this value is created using high-skilled labour and the ratio between value added and hours worked is also expected to be higher in intangible intensive activities. It is, therefore reasonable to expect that the productivity impact of GVC participation will be higher for industries and countries with a higher investment in knowledge-based capital.

GVCs are assumed to increase productivity also by facilitating knowledge spillovers allowing interaction of domestic firms with foreign multinational firms. However, spillover do not occur automatically, but depend on investments in absorptive capacity. While the literature has focused on the role of R&D investments for absorptive capacity (Cohen and Levinthal, 1989), also other assets, particularly training and organizational capital, may be important. As a consequence, we expect that participation in GVCs will generate more spillovers thus providing a higher growth contribution in sectors and countries where investments in R&D, training and organizational capital are relatively higher.

Finally, intangibles might affect the productivity performance along a GVC because they generate relatively large returns to scale. The difference in scale economies between tangible and intangible assets (Durand and Milberg, 2018) implies that the firms controlling intangible-intensive parts of the chain will be in the position of experiencing a relatively larger productivity improvement from network participation as output expands. This is why intangible capital is an essential element for productivity growth along the chain.

According to the OECD (2013b), intangible assets contribute differently to gains appropriation along the global value. In particular, economic competencies, including firm-specific skills such as superior management, brand equity and organizational structure, can be rather valuable since they involve more tacit forms of knowledge and may therefore be more difficult to replicate than innovative property or computerised information. Consistently with this view, a survey of Japanese firms emphasizes the importance of economic competencies, notably "manufacturing skills," "brand and customer recognition" and "agile and flexible organisation" (OECD, 2013a).

Along these lines, we expect some heterogeneity in the mediating role of intangible assets in the relationship between productivity growth and GVC participation with economic competencies (particularly training and organizational capital) playing a major role because of their relatively higher content of more tacit forms of knowledge. Moreover, the importance of governance for extracting maximum rents from GVC participation (Gereffi *et al.*, 2005) suggests that organizational capital may be an essential asset in this respect.

Notwithstanding the rich qualitative evidence pointing to the centrality of knowledge-based investment for achieving higher benefits from participation in GVCs, we are not aware of any empirical study directly testing this hypothesis[5]. The purpose of this article is to provide a contribution in this direction by empirically estimating the impact of GVC participation on productivity gains accounting for the complementary function of intangible assets.

## Data and Descriptive Statistics

### Intangible Assets

Data on intangible investment are from INTAN-Invest[6] providing harmonized estimates of intangible investments covering three broad groups of asset categories originally proposed by Corrado *et al.* (2005): computerized information, innovative property and economic competencies.[7] Computerized information includes computer software and databases. Innovative property refers to the innovative activity built on a scientific base of knowledge as well as to innovation and new product/process R&D more broadly defined. Economic competencies indicate spending on strategic planning, worker training, redesigning or reconfiguring existing products in existing markets, investment to retain or gain market share and investment in brand names.

The Systems of National Accounts currently incorporates in the asset boundary only an array of in-

5 Baldwin and Yan (2014) test whether the integration of Canadian manufacturing firms in a GVC improves their productivity and find that the effects vary by industrial sector, internalization process, and import-source/export-destination country in a way that suggests the most substantial gains are derived from technological improvements.

6 INTAN-invest is a research collaboration dedicated to improving the measurement and analysis of intangible assets (www.intannvest.net).

7 For a detailed description of the methodology, see Corrado *et al.* (2018). These indicators have been used in many studies especially for assessing their contribution to GDP and productivity growth (see e.g. Corrado et al. 2009, 2013, 2016, 2017).

tangible assets, namely R&D, mineral exploration, computer software and databases, entertainment, literary and artistic originals, under the category "intellectual property products." The remaining intangibles identified by Corrado *et al.* (2005) as investments, are treated as intermediate expenditures in official statistics. The INTAN Invest initiative provides estimates for both National Account and Non- National Account intangible investment.

A relevant characteristic of the INTAN-Invest measures of intangibles is that they are consistent with National Account principles and are entirely based on official statistics. In this article, we select from the INTAN database information for the following set of intangible assets: R&D, design, advertising and market research (brand), training and organizational capital.[8] The main original data source to build indicators for these intangibles is Eurostat. In particular, investment in advertising and market research, design and organizational capital are calculated adopting an expenditure approach and resorting to expenditure data by industry from the Use Tables, compiled according to the new classification system (NACE Rev2/CPA 2008). Additional information about data sources and estimation methods can be found in Corrado *et al.* (2018).

**Measures of GVC participation**

The measure of backward participation used in our analysis is obtained from the World Input Output Database (WIOD). The indicator is based on the work of Koopman *et al.* (2010, 2014) extending the work of Hummels *et al.* (2001) and Johnson and Noguera (2012). Hummels *et al.* (2001) compute an index of vertical specialization accounting for the use of imported inputs in producing goods that are then exported. However, this indicator does not take into account that a country exports intermediates that are used to produce final goods absorbed at home. By using input-output data for source and destination countries simultaneously, Johnson and Noguera (2012) overcome this limitation and compute the ratio of value added to gross exports as a measure of the intensity of production sharing.

Finally, Koopman *et al.* (2010, 2014) provide a full decomposition of value added including returned domestic value added (domestic value

8 The database used in this paper resorts to R&D expenditure from BERD and not to R&D National Account data to be coherent with the EUKLEMS (2012) figures that were not yet adjusted to the new European System of National Accounts (ESA 2010). Moreover, we do not use INTAN data on software since we include total Information and Communication Technologies (ICT) capital taken from EUKLEMS.

added that comes back incorporated in foreign inputs produced with domestic inputs) and the indirect exports to third countries. They propose two measures of participation. These are the backward and the forward participation indicators, which are respectively the importing and exporting elements of GVCs (see Figure A1). The figure illustrates how gross exports can be decomposed into many different constituent elements. At their most basic, gross exports are composed of domestic and foreign value added which can themselves be further decomposed using Input-Output tables. For example, the domestic value added that is embodied in exports can serve to produce final goods and services (element (1) in figure A1) or it can be used to produce intermediates which are then used domestically (2) or exported (3+4). Forward participation refers to the domestic value added in foreign exports (3+4) while backward participation refers to the foreign value added in domestic exports (5+6).

In this article we focus on backward participation which is closer to traditional indicators of offshoring activity (such as the share of imported inputs in producing goods that are then exported). A variant of this indicator decomposes value added, similarly across countries and sectors, but according to final demand (Timmer *et al.*, 2013; Los *et al.*, 2015). This tracks not just the value added traded in the production of exports, but also that used to satisfy domestic and international final demand.[9] Both measures (one based on exports and one on final demand) involve similar calculation techniques, but the former is solely concerned with exporting activities whereas the latter considers the origin of value added in GDP. The difference is relevant because domestic final demand and gross export vectors are significantly different.

Since both measures have their pros and cons, we report the main econometric estimates using both the indicator of backward linkages based on exports and the other based on final demand. In particular, we focus on foreign value added in domestic exports over total exports (backward participation) for comparisons with other studies (this is the measure of participation mostly used by the OECD (OECD, 2013b)) but we report

9 To provide an example of the difference in the two indicators, imagine that the total demand for BMW cars is 100 of which 60 are sales to German customers while 40 are exports. The cars are assembled outside Germany using a variety of components such as car body parts, interior and exterior components, some of which are made in Germany, but others abroad. Out of the total value of each car two thirds is domestic (German) value added and one third is foreign value added. Using the export indicator the foreign value added in domestic exports of German cars would be (1/3)*40 while using the final demand indicator it would be (1/3)*100 (counting also the cars that are consumed by German customers).

also estimates based on foreign value added in domestic final demand over total final demand (backward participation based on final demand) to test the robustness of our findings. Much work on GVCs to date uses the backward participation indicator and identifies one of the most salient features to be the rise in the share of foreign value added used to produce exports (see for example OECD (2013), Taglioni and Wrinkler (2016), Baldwin and Lopez-Gonzalez (2015), and Kowalski *et al.* (2015)).

## The database

The database employed in this article merges data on tangible capital inputs, ICT capital as well as standard growth accounting variables such as output and labour input from EUKLEMS[10] with data on intangibles from INTAN-Invest. Data cover the period 1998-2013 for nine European countries (Austria (AT), Germany (DE), Denmark (DK), Spain (ES), Finland (FI), Italy (IT), Netherlands (NL), Sweden (SE), United Kingdom (UK)) and 18 industries NACE REV 2.

## Descriptive analysis

Chart 1 shows the rate of growth of our main variables of interest: labour productivity, backward participation (export-based measure) and intangible capital over the period 1998-2013. Manufacturing is in Panel A while business services in Panel B.

In manufacturing all countries have experienced on average positive rates of growth of labour productivity, intangible capital and backward participation. Austria, Denmark, Spain and Finland show the fastest intangible capital accumulation and, with the exception of Spain, higher than average labour productivity growth. Differences in backward participation across countries are less marked, with the Netherlands being the fastest (almost 4 per cent) and Sweden the lowest (below 1 per cent).

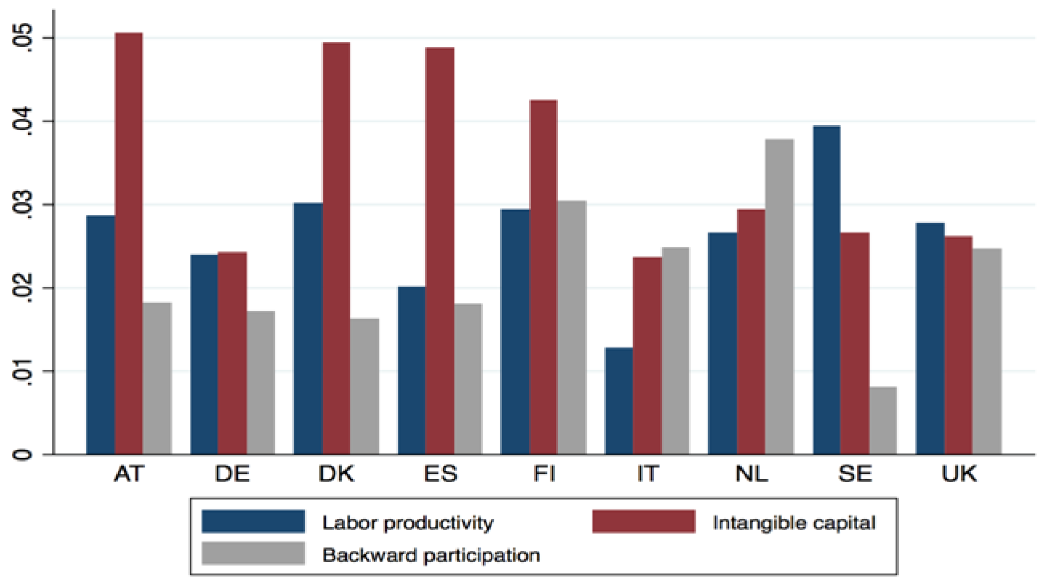
In business services, there is more variation across countries, particularly for backward participation. Two countries, Spain and Sweden, have negative rates of growth in foreign value added in domestic exports, while participation has been very high in Finland. Labour productivity growth upsurged in Sweden and the UK while slowed down in Germany, Italy and Finland. Finally, intangible capital accumulation is relatively faster in Spain, Austria and the Netherlands while it is almost stable in Finland and Italy.

Chart 2 focuses on differences in the intensity of intangibles (intangible capital per hour worked) across

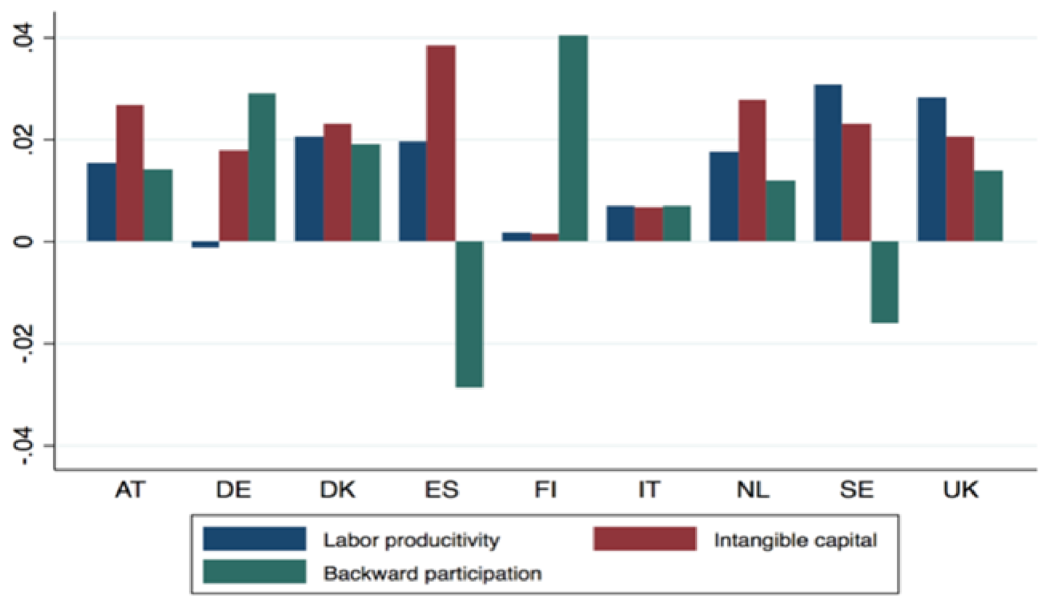
10 http://www.euklems.net. See O'Mahony and Timmer (2009) for details.

**Chart 1: Productivity, Backward Participation and Intangible Capital (Logarithmic Rates of Growth, Average Values 1998-2013)**

**Manufacturing**




**Business services**




Source: Author's calculation on EUKLEMS, WIOD and INTAN Invest data. Labour productivity is measured as real value added per hours worked.

countries distinguishing between different assets. Data suggest that Nordic countries (Denmark, Finland and Sweden) are the more intangible intensive economies, while the Mediterranean economies (Italy and Spain) are relatively low intensive. Non-R&D assets are quantitatively more relevant than R&D in all sample countries, suggesting the importance of exploring their contribution to the productivity growth differentials between countries. Moreover, although there appears to be some complementarity between R&D and non-R&D intangibles, there are also important differences. For example, UK and the Netherlands have very high intensities of non-R&D intangibles but rank below the average in terms of R&D intensity. Finally, among the non-R&D assets, organizational capital is quantitatively the most relevant asset particularly in the Netherlands, Sweden and the UK, followed by design, training and brand. Italy and Spain economies are confirmed to lag behind.

The first step of our analysis is to investigate if and to what extent intangible capital accumulation and backward participation are related to labour productivity growth. Thus, Chart 3 shows the relationship between labour productivity growth, per hour worked total intangible capital (growth and level) and backward participation (level) in manufacturing and services in the sample economies. The correlation is significantly positive in all cases and, as expected particularly strong between labour productivity growth and intangible capital per hour.

Moreover, there is a positive relationship between backward participation and labour productivity growth, but it is less marked. Our hypothesis is that this correlation depends on the extent to which countries and industries invest in intangible capital.

Finally, it is worth notice that nor GVC participation nor intangible investments were considerably and persistently affected by the financial crisis. Existing evidence shows that besides the immediate slowdown experienced during the crisis years (2008-2009) participation and intangible capital accumulation recovered quickly even if at different pace across countries (Corrado *et al.*, 2018; ECB, 2017).

## Empirical Strategy

### Econometric approach

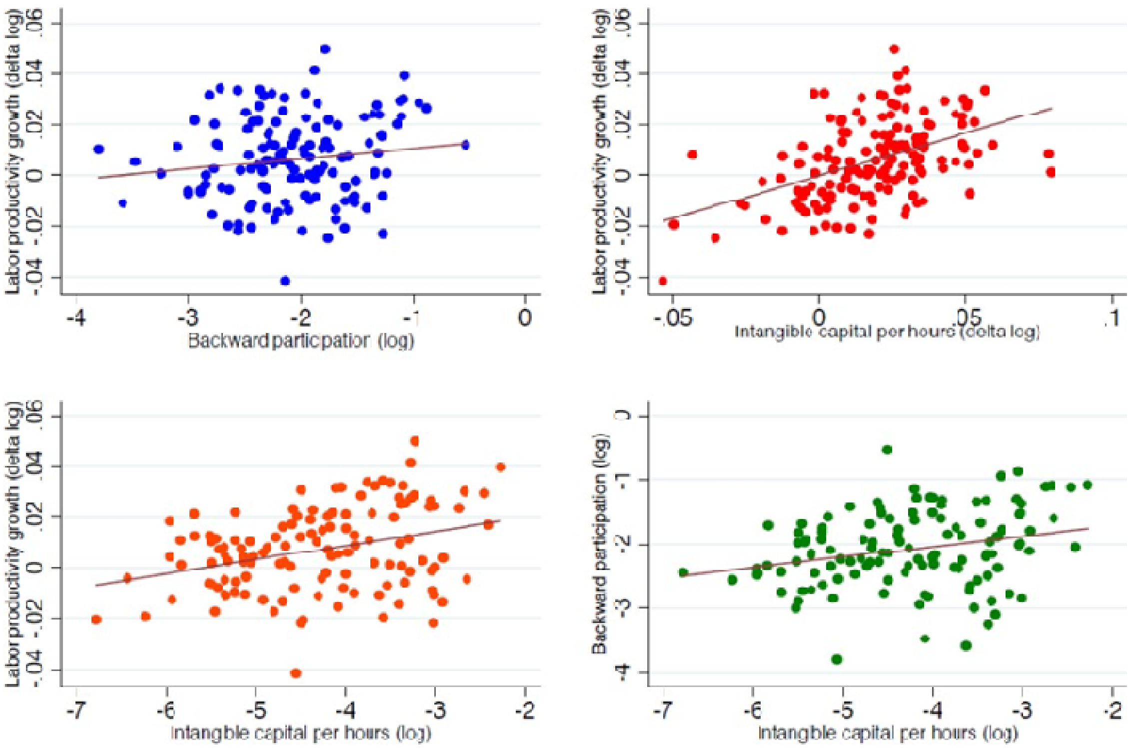
We explore the relationship between GVC participation, intangible capital and productivity growth estimating a production function including intangibles and augmented with a measure of backward participation.

First, we test the direct linkage

**Chart 2: Intangibles Intensities: Capital Stocks per Hour Worked, Average Values 1998-2013**


Source: Author's calculations on INTAN Invest data. Capital stock is chain linked values of national currencies in per hour terms.

**Chart 3: Labour Productivity, Intangible Capital and Backward Participation**




Source: Author's calculation on EUKLEMS, WIOD and INTAN Invest data between participation and productivity growth and then evaluate the extent to which the productivity returns from participation are conditional to intangible capital intensity across countries-industries. We adopt a difference-in-difference empirical approach following Rajan and Zingales (1998) who estimated the impact of financial development on economic growth in a model with country-industry interactions. Thus, our empirical specification is as follows:

$$\Delta \ln (Y/H)_{i,c,t} = \alpha_1 \Delta \ln (K^J/H)_{i,c,t} + \alpha_2 \Delta \ln (K^I/H)_{i,c,t} + \alpha_3 \ln (P_{gvc})_{i,c,t-2} + \alpha_4 \ln (K^I/H))_{i,c} + \alpha_5 \ln (P_{gvc})_{i,c,t-2} * \ln (K^I/H)_{i,c} + \lambda_i + \lambda_t + \eta_{i,c,t} \quad (1)$$

where variables vary by country c, industry i and time t; Y denotes value added adjusted to include intangible capital (as in Corrado, Hulten, and Sichel 2005, 2009), H is total hours worked, $K^J$ is for $J =$ ICT and Non-ICT capital, $K^I$ is for I=total intangible, brand, training, design, R&D and organizational capital, $P_{gvc}$ is backward participation and $ln(K^I/H)_{i,c}$ denotes country-industry's average (log) intangible intensity, and $\Lambda_i$, $\Lambda_t$ are industry and time dummies. The interaction variable is symmetric with respect to the interacted terms as it does not say anything about the causality between $ln(K^I/H)$ and $ln(P_{gvc})$ (Brambor *et al.*, 2006). Thus, we simply assume that intangible capital is our conditional variable affecting the influence of backward participation on productivity growth.

Notice that the term we use to capture the differential impact of participation on productivity growth in intangible intensive sectors is the time average of intangible intensity of all industries and countries interacted with the level of GVC participation in industry i country c, at time t-2. The adoption of the average intangible intensity in the interaction implies some restriction as it bounds the elasticity of labour productivity as intangible intensity rises.

If our proxy for intangible intensity in equation (1) is correct, we should find $\alpha_5 > 0$, indicating that each country industry experiences relatively higher productivity growth when participation in GVC is complemented by higher intangible capital intensity. This is because controlling intangible- intensive parts of the chain allows experiencing a relatively larger productivity improvement from network participation as output expands.[11] We include also the industry dummies to control for the possible correlation between specific industry characteristics and our measure of intangible intensity. Ultimately, the estimation of equation (1) can be affected by structural identification problems related to measurement error, multicollinearity, and endogeneity of factor inputs. Thus, we also test our results with IV and GMM estimation (Ackerberg *et al.*, 2015).

## Empirical Results

Table 1 shows estimates of equation 1. All regression models contain industry and time fixed effects and are estimated by GLS. Column 1 estimates equation (1) with no participation and no interaction terms as our benchmark specification. The standard inputs and intangible capital have positive and statistically significant coefficients coherent with previous empirical literature (Corrado *et al.*, 2017). Column 2 includes the lagged GVC participation index, i.e. the export-based indicator of backward participation, to test the assumption that participating in global production generates positive productivity returns and that this takes time. Estimation results support this assumption showing positive and significant correlation across all the specifications. This is in line with the theoretical predictions of Baldwin and Robert-Nicoud (2014) and with the empirical evidence reported in Kummritz (2016).

Columns 3 to 5 check for the complementary effect of intangible capital and participation on productivity growth looking at the level effect of the interaction between intangible capital per hour and lagged backward participation. The conditional effect of intangible intensity on participation is affected by the inclusion of software in the aggregate level of intangible capital (column 3). Then excluding software (column 4) and also R&D (column 5) from total intangibles we uncover a positive and significant $\alpha_5$ thus supporting the assumption that higher intangible intensity strengthens the positive effect of participation on productivity growth.

To judge the economic significance of our findings we look at the contribution of participation to labour productivity growth using column 2 in Table 1. The contribution from participation accounts for 0.14 percentage points per year of a growth rate of productivity equal to 0.5 per cent

11 In principle, there might be different representations of the production function (Cobb Douglas (CD) or CES) allowing for different degrees of variation in output elasticities. As our hypothesis of a significant interaction term implies that output elasticities vary, we assume a CES that is a more general function than CD allowing for variation in elasticities due to e.g. biases in technical progress, different factor prices etc.

**Table 1: Production Function Augmented with Participation and Interacted Variables**

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | Production function | Production function augmented with t-2 backp (level) | Production fcn augmented with t-2 backp(level) interacted with level *intg_isf* | Production fcn augmented with t-2 backp(level) interacted with level *intg_xsf* (t-2) | Production fcn augmented with t-2 backp(level) interacted with level *intg_xrdsf* (t-2) |
| $\Delta ln(K^I/H)$ | 0.204*** | 0.154*** | 0.162*** | | |
| | (0.017) | (0.019) | (0.020) | | |
| $\Delta ln(K^{IxSF}/H)$ | | | | 0.197*** | |
| | | | | (0.022) | |
| $\Delta ln(K^{IxSFR\&D}/H)$ | | | | | 0.207*** |
| | | | | | (0.021) |
| $\Delta ln(K^{ICT}/H)$ | 0.032*** | 0.049*** | 0.043*** | | |
| | (0.008) | (0.009) | (0.010) | | |
| $\Delta ln(K^{ICT\_iSF}/H)$ | | | | 0.040*** | 0.040*** |
| | | | | (0.013) | (0.014) |
| $\Delta ln(K^{NonICT}/H)$ | 0.176*** | 0.175*** | 0.166*** | 0.175*** | 0.192*** |
| | (0.020) | (0.024) | (0.025) | (0.025) | (0.024) |
| $\Delta ln(LH)$ | 0.088*** | 0.109*** | 0.104*** | 0.101*** | 0.085** |
| | (0.031) | (0.037) | (0.039) | (0.036) | (0.036) |
| $ln(K^{IxSF}/H) * ln(BackP)_{t-2}$ | | | | 0.003* | |
| | | | | (0.001) | |
| $ln(K^I/H) * ln(BackP)_{t-2}$ | | | 0.002 | | |
| | | | (0.001) | | |
| $ln(K^{IxR\&D}/H) * ln(BackP)_{t-2}$ | | | | | 0.003* |
| | | | | | (0.001) |
| $ln(BackP)_{t-2}$ | | 0.005** | 0.014** | 0.021*** | 0.022*** |
| | | (0.002) | (0.007) | (0.007) | (0.008) |
| $ln(K^I/H)$ | | | 0.005 | | |
| | | | (0.004) | | |
| $ln(K^{IxSF}/H)$ | | | | 0.007** | |
| | | | | (0.004) | |
| $ln(K^{IxSFR\&D}/H)$ | | | | | 0.006 |
| | | | | | (0.004) |
| Observations | 1,958 | 1,507 | 1,495 | 1,531 | 1,495 |
| Number of ctrysec | 142 | 126 | 125 | 128 | 125 |

Note: All regressions contain country, industry and time fixed effects. To control for endogeneity of capital inputs we all specifications have been tested with GMM. Results are reported in the appendix.
Legend key: $K^I$ is for I=total intangible, brand (br), training (tr), design (de), R&D and Organizational capital (OgC) and , $K^{IxSF}$ is intangible capital excluding software, $K^{IxSF\&R\&D}$ refers to $K^I$ excluding software and R&D, $K^ICT$ is ICT capital while $K^{ICTxSF}$ is ICT excluding software. *Backp* is backward participation and *LH* refers to labour composition.

per year. That is a relatively large contribution.

Table 2 shows the estimates of equation (1) testing the interaction of average intangible intensity and lagged backward participation looking at both aggregate and individual intangible asset effects.

The interactive terms are positive and statistically significant for total intangibles (columns 1) and stronger if we exclude R&D (column 2) confirming a complementary relationship with lagged backward participation. Moreover, among intangibles, organizational capital has the strongest effect on productivity and interacts positively with GVC participation. This highlights the importance to go beyond R&D to capture the full effect of intangibles on productivity. The result is also consistent with the pos-

**Table 2: Production Function Augmented with Participation and Interacted Variables**

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | Production fcn with lagged gvc level and average intang intensity interactions all sample | | | | | | |
| $\Delta ln(K^I/H)$ | 0.169*** | | 0.167*** | 0.184*** | 0.170*** | 0.184*** | 0.183*** |
| | (0.020) | | (0.020) | (0.020) | (0.020) | (0.020) | (0.021) |
| $\Delta ln(K^{ICT}/H)$ | 0.042*** | 0.046*** | 0.043*** | 0.046*** | 0.045*** | 0.046*** | 0.046*** |
| | (0.009) | (0.009) | (0.009) | (0.009) | (0.009) | (0.009) | (0.009) |
| $ln(K^I/H)_{avg}$ | 0.011*** | | | | | | |
| | (0.004) | | | | | | |
| $ln(BackP)_{t-2}$ | 0.025*** | 0.031*** | 0.013** | 0.024*** | 0.020*** | -0.004 | 0.017** |
| | (0.007) | (0.008) | (0.006) | (0.008) | (0.007) | (0.009) | (0.007) |
| $ln(K^I/H)_{avg}*$ | 0.004*** | | | | | | |
| $ln(BackP)_{t-2}$ | (0.002) | | | | | | |
| $\Delta ln(K^{IxR\&D}/H)$ | | 0.177*** | | | | | |
| | | (0.019) | | | | | |
| $ln(K^{IxR\&D}/H)avg$ | | 0.011*** | | | | | |
| | | (0.004) | | | | | |
| $ln(K^{IxR\&D}/H)avg*$ | | 0.005*** | | | | | |
| $ln(BackP)_{t-2}$ | | (0.002) | | | | | |
| $ln(KR\&D/H)avg$ | | | 0.003 | | | | |
| | | | (0.003) | | | | |
| $ln(K^{R\&D}/H)avg*$ | | | 0.001 | | | | |
| $ln(BackP)_{t-2}$ | | | (0.001) | | | | |
| $ln(K^{OgC}/H)avg$ | | | | 0.009*** | | | |
| | | | | (0.003) | | | |
| $ln(K^{OgC}/H)avg*$ | | | | 0.003** | | | |
| $ln(BackP)_{t-2}$ | | | | (0.001) | | | |
| $ln(K^{Tr}/H)avg$ | | | | | 0.002 | | |
| | | | | | (0.003) | | |
| $ln(K^{Tr}/H)avg*$ | | | | | 0.002* | | |
| $ln(BackP)_{t-2}$ | | | | | (0.001) | | |
| $ln(K^{Br}/H)avg$ | | | | | | -0.002 | |
| | | | | | | (0.003) | |
| $ln(K^{Br}/H)avg*$ | | | | | | -0.001 | |
| $ln(BackP)_{t-2}$ | | | | | | (0.001) | |
| $ln(K^{De}/H)avg$ | | | | | | | 0.005** |
| | | | | | | | (0.002) |
| $ln(K^{De}/H)avg*$ | | | | | | | 0.002* |
| $ln(BackP)_{t-2}$ | | | | | | | (0.001) |
| Observations | 1,519 | 1,663 | 1,519 | 1,687 | 1,547 | 1,687 | 1,525 |
| Number of ctrysec | 127 | 139 | 127 | 141 | 141 | 141 | 139 |

Note: All regressions contain country, industry and time fixed effects and controls for $K^{NonICT}$ and Labor composition.

Legend key: $K^I$ is for I=Total intangible, brand (br), training (tr), design (de), R&D and Organizational capital (OgC) and, $K^{IxSF}$ is intangible capital excluding software, $K^{IxSF\&R\&D}$ refers to $K^I$ excluding software and R&D, $K^{ICT}$ is ICT capital while $K^{ICTxSF}$ is ICT excluding software. *Backp* is backward participation and *LH* refers to labour composition.

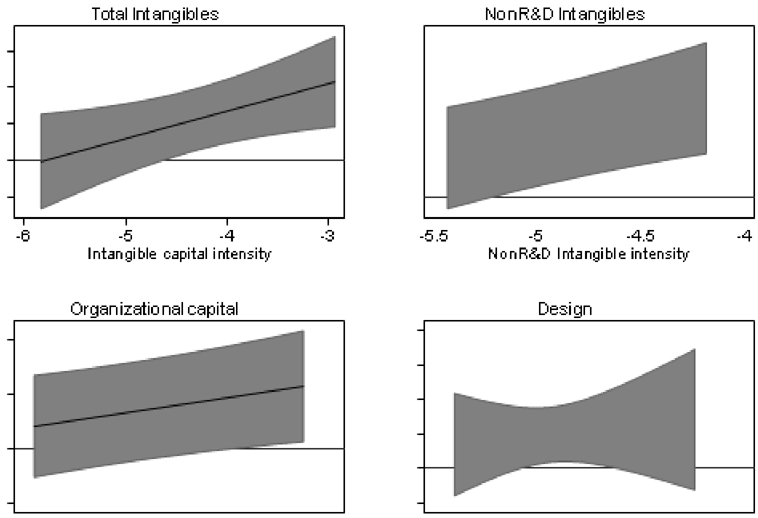
itive impact of managerial practices on firm productivity and profitability and on country total factor productivity (Bloom and Van Reenen, 2007; Bloom *et al.*, 2016). Overall these results support the assumption that labour productivity growth in above average intangible intensive countries-industries is faster in countries-industries participating relatively more to GVC production.

Chart 4 shows the marginal effects of backward participation between the $5^{th}$ and the $95^{th}$ percentile of the distribution of intangible intensities with the shaded area representing the 95 per cent confidence interval where the effects on productivity are statistically significant. In the four cases, the marginal effect increases as the degree of intangible intensity increases. To get some idea of the numbers involved, the top right panel shows the marginal effect of participation over the distribution of non-R&D intangible intensity. When this is at the $60^{th}$ percentile the elasticity is 0.008 whereas at the $95^{th}$ percentile it is 0.01.

As robustness checks, in Table 3, we report the results obtained using the backward participation indicator based on final demand (foreign value added in domestic final demand/ total final demand). We focus on the estimates testing the interaction of average intangible intensity and lagged backward participation looking at both aggregate intangible assets (column 1), intangible assets excluding R&D (column 2) and organizational capital (column 3). The results based on the final demand indicator of backward participation are very similar to those based on the export indicator. We also checked the robustness of our results with GMM and IV and report the main findings in Table A1 in the Appendix. The results of GMM estimates confirm the positive impact of backward participation on productivity and the fact that this is enhanced by investment in intangible capital.

Overall the empirical findings are consistent with our main hypotheses. Intangible capital positively affects productivity growth through two channels: a primary effect via capital deepening and secondary effect via complementary relationship with backward participation. When distinguishing among intangible assets, non-R&D intangibles emerge as the main drivers of growth, particularly organizational capital showing a strong synergy with GVC participation. R&D instead plays a relatively minor role in this respect. This is consistent with the view that more tacit forms of knowledge may be more difficult to replicate so that industries and countries investing more in these forms of knowledge may be in a better

**Chart 4: Marginal effect of backward participation on productivity growth**




Source: Authors' calculations.

position to appropriate the benefits of being engaged in global value chains.

Moreover, the results on the role of organizational capital confirm the relevance of governance for extracting maximum rents from GVC participation (Gereffi *et al.*, 2005).

## Conclusion

Our analysis is a first attempt at bridging two streams of literature with the goal of testing whether intangible capital contributes to foster countries' capabilities to appropriate value added along the supply chain. To explore this linkage, we use a cross-country econometric approach and test the productivity gains of GVC participation and the mediating effect of intangible capital on productivity returns from GVC participation. Our sample covers nine EU countries, 18 industries in 2000-2013.

We have three main key findings. First, using our country-industry-time data, we find a positive and statistically significant impact of backward participation on productivity growth. Second, we uncover a complementary linkage between intangible capital intensity and GVC participation suggesting that productivity returns to backward participation are stronger in intangible intensive countries-industries. Finally, estimation results show that non-R&D intangibles, and particularly organizational capital, exerts a significant conditional effect on GVC involvement enhancing the productivity benefits from participation.

Overall, our findings are broadly consistent (and complementary) to the growing literature documenting the strategic role of intangible capi-

**Table 3: Testing for Interactions Between Average Intangible Intensity and Backward Participation Based on Final Demand**

| | (1) | (2) | (3) |
|---|---|---|---|
| | Interaction between average intangible capital and backward participation | Interaction between average non R&D intangible capital and backward participation | Interaction between average Organizational capital and backward participation |
| $\Delta ln(K^{I}/H)$ | 0.139*** | | 0.150*** |
| | (0.020) | | (0.020) |
| $\Delta ln(K^{ICT}/H)$ | 0.045*** | 0.047*** | 0.052*** |
| | (0.011) | (0.011) | (0.010) |
| $\Delta ln(K^{NonICT}/H)$ | 0.176*** | 0.178*** | 0.170*** |
| | (0.027) | (0.026) | (0.026) |
| $\Delta ln(LH)$ | 0.097** | 0.089** | 0.097** |
| | (0.040) | (0.040) | (0.040) |
| $ln(K^{I}/H)_{avg}$ | 0.010*** | | |
| | (0.003) | | |
| $ln(BackPDem)_{t-2}$ | 0.009*** | 0.018*** | 0.009** |
| | (0.003) | (0.004) | (0.004) |
| $ln(K^{I}/H)_{avg}*$ | 0.002*** | | |
| $ln(BackPDem)_{t-2}$ | (0.001) | | |
| $\Delta ln(K^{IxR\&D}/H)$ | | 0.144*** | |
| | | (0.021) | |
| $\Delta ln(K^{R\&D}/H)$ | | -0.006 | |
| | | (0.010) | |
| $ln(K^{IxR\&D}/H)_{avg}$ | | 0.014*** | |
| | | (0.003) | |
| $ln(K^{IxR\&D}/H)_{avg}*$ | | 0.004*** | |
| $ln(BackPDem)_{t-2}$ | | (0.001) | |
| $ln(K^{OgC}/H)_{avg}$ | | | 0.008*** |
| | | | (0.002) |
| $ln(K^{OgC}/H)_{avg}*$ | | | 0.002*** |
| $ln(BackPDem)_{t-2}$ | | | (0.001) |
| Observations | 1,291 | 1,290 | 1,411 |
| Number of ctrysec | 108 | 108 | 118 |

Note: All regressions contain country, industry and time fixed effects and controls for $K^{NonICT}$ and Labor composition.
Legend key: $K^{I}$ is for I=Total intangible, brand (br), training (tr), design (de), R&D and Organizational capital (OgC) and, $K^{IxSF}$ is intangible capital excluding software, $K^{IxSF\&R\&D}$ refers to $K^{I}$ excluding software and R&D, $K^{ICT}$ is ICT capital while $K^{ICTxSF}$ is ICT excluding software. *Backp* is backward participation and *LH* refers to labour composition.

tal as driver of productivity growth (Corrado *et al.*, 2009, 2013, 2018) and GVC upgrading (OECD, 2013 and Criscuolo *et al.*, 2017).

The first set of results illustrated in this article suggest that further analysis focusing on complementarities between different modes of participation (backward and forward), individual intangible asset and skills would be strategic to better understand the novel drivers of international competitiveness and the productivity returns from GVC participation.

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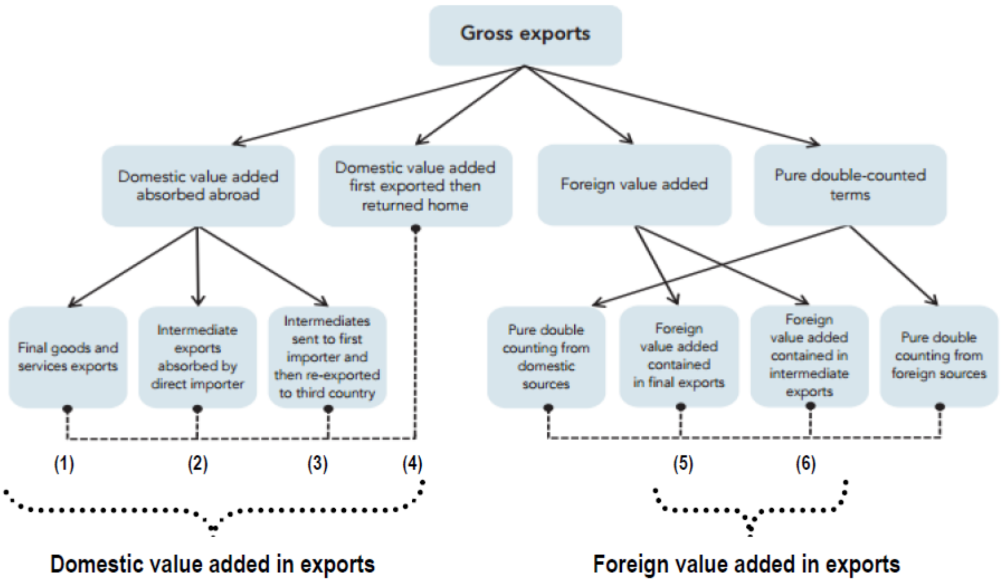
# Appendix

**Figure A1: Gross Trade Accounting Framework**




**Source: Adapted from WBG-IDE-OECD-UIBE-WTO (2017)**

**Table A1: GMM and IV estimates of Benchmark Specifications and Interaction Models**

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | Benchmark Specifications<br>Table 1, Col. 1 to 3<br>GMM | | | Interaction Models<br>Table 2, Col. 1 and 2 | IV | Table 3 Col. 1 |
| $\Delta ln(K^I/H)$ | 0.248***<br>(0.051) | 0.193***<br>(0.051) | 0.134***<br>(0.045) | 0.237***<br>(0.083) | | 0.284***<br>(0.085) |
| $DlnKH_intan_xrd$ | | | | | 0.204***<br>(0.071) | |
| $ln(K^{I\_SW}/H)$ | | | 0.058***<br>(0.011) | | | |
| $ln(K^I/H)_{avg}$ | | | | 0.014**<br>(0.006) | | 0.012***<br>(0.004) |
| $ln(K^{IxR\&D}/H)_{avg}$ | | | | | 0.016***<br>(0.006) | |
| $ln(BackP)_{t-2}$ | | 0.022***<br>(0.007) | 0.064***<br>(0.021) | 0.025**<br>(0.013) | 0.030**<br>(0.013) | |
| $ln(K^{IxR\&D}/H)_{avg}*$ $ln(BackP)_{t-2}$ | | | | | 0.006**<br>(0.002) | |
| $ln(K^I/H)_{avg}$ $ln(BackP)_{t-2}$ | | | | 0.004*<br>(0.003) | | |
| $ln(K^{I\_SW}/H)_{avg}$ $ln(BackP)_{t-2}$ | | | 0.013***<br>(0.005) | | | |
| $ln(QH)_{t-1}$ | 0.979***<br>(0.008) | 0.964***<br>(0.009) | 0.925***<br>(0.009) | | | |
| $ln(BackPDem)_{t-2}$ | | | | | | 0.008*<br>(0.005) |
| $ln(K^I/H)_{avg}$ $ln(BackPDem)_{t-2}$ | | | | | | 0.002**<br>(0.001) |
| Observations | 1,747 | 1,426 | 1,294 | 1,304 | 1,400 | 1,220 |

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.
Table A1 shows the GMM and Instrumental variable estimates of the main reference specifications illustrated in Tables 1 to 3. Estimates in columns 1 to 3 are GMM estimation results based on the Arellano-Bover/Blundell-Bond system estimator that is well suited for panels with small T as ours. Dependent variable in columns 1 to 3 is lnQHt, that is labour productivity level at time t. Dependent variable in cols 4 to 6 is the $DlnQH_t$. All specifications contain controls for ICT, NON-ICT and L quality as well as for time and industry fixed effects. Cols 1 to 3 refer to standard GMM estimates while cols 4 to 6 to Instrumental Variables.

# Structural Change and Productivity in the Market Economy of Mainland Norway: 1997-2014

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Abstract

Based on a newly compiled Norwegian KLEMS database, this article investigates structural change and productivity in the market economy of mainland Norway for the 1997-2014 period. The findings largely confirm the general trends identified by many other studies. However, detailed sector analyses reveal substantial differences within both goods production and services sectors. In addition, an increased share of skilled labour in value added is found for the total market economy over the entire period, as well as for almost all the sectors, at least for the latter period (2008-2014). For the total market economy, the shares in value added of both software and R&D capital increased, while those of hardware decreased, for the whole period. With a few exceptions, this finding also holds for most of the sectors, at least for the latter period (2008-2014). Finally, test results indicate that the complementarity hypothesis between ICT capital and skilled labour is not supported, but that between Intellectual Property Products (IPP), and esp. R&D capital, and highly skilled labour is supported, implying that intangible assets combined with human capital had been playing an increasingly important role in recent economic growth in Norway.

For the last century, there has been a substantial structural change taking place in the Norwegian economy. For example, at the beginning of the 1900s, the primary sector, defined as agriculture, forestry, and fishery, accounted for roughly half of the total employment. A shift of labour from primary into secondary and tertiary sectors then took place, with the share of secondary sector peaking in the 1970s. Since then, the tertiary sector, generally referred to as the services sector, has been growing rapidly. However, labour productivity growth in services sector was found lower than in either primary or secondary sector (e.g. Skoglund, 2013).

The stylized facts observed in a small country like Norway are in line

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with the empirical regularities found in many other western countries (e.g. Kuznets, 1971; Maddison, 1980). In particular, all studies shared a common view as regards the services sector, namely due to limited scope for innovation and technical change, productivity growth in this sector is much lower than in both primary and secondary sectors (e.g. Baumol, 1967).

Based on detailed industry level data, however, recent studies have found that although a continuing shift of output and employment can be observed from the secondary to services sector, the conventional view of a stagnant services sector is no longer valid. Productivity growth within this sector reveals very considerable differences, with a number of services industries achieving even higher productivity growth than some traditional goods-producing industries (e.g. Triplett and Bosworth, 2006; Jorgenson *et al.*, 2005; Timmer *et al.*, 2010).

Recent evidence also suggest that, along with the economic growth, technical change seems to have favoured certain production inputs and affected the production structures in a rather asymmetric way. Specifically, the last decades have been characterized by a growing importance of skilled labour and information and communication technology (ICT) assets in production (e.g. Jorgenson *et al.* 2005). One appealing explanation in the literature to this phenomenon is that there exists complementarity between increased use of skilled labour and ICT capital (e.g. O'Mahony *et al.*, 2008; Timmer *et al.*, 2010).

The purpose of this article is twofold. By using a newly compiled Norwegian KLEMS database, first I examine whether the above-mentioned stylized observations still hold for the market economy of mainland Norway during the period 1997-2014. The market economy of mainland Norway is a concept routinely used in official statistics at Statistics Norway; it does not include the offshore oil and gas extraction and the maritime sector, as well as all non-market activities.[2] Since the primary sector has become rather small in Norway, the main focus in this article will be on the structural change in the secondary and services sectors. In particular, I will look at the increasing share of services in output and employment at the expense of the secondary sector and at the comparative productivity growth in these two sectors.

Second, I will investigate changes in the structure of production technologies that occurred in the mar-

2 The definition of the market economy of mainland Norway will be discussed in more detail in Section 1.

ket economy of mainland Norway for 1997-2014, with special focus on the changes in the production input composition of skilled labour and knowledge-based capital in general, and the ICT, R&D assets in particular. Using Norwegian industry-level data, the hypothesis of the existence of complementarity between skilled labour and the ICT assets will be tested. This complementarity hypothesis was once employed to explain the prevalence of knowledge intensification featuring many countries' recent economic growth (see e.g. Berman *et al.* 1998).

The article is organized as follows. A brief description of the Norwegian KLEMS database is given in Section 1. Section 2 is devoted to changes in sectoral output and employment shares. In Section 3 the trend in labour and multi-factor productivity is discussed. Section 4 studies patterns in the use of the skilled labour and the knowledge-based capital. Moreover, the hypothesis of complementarity between the use of ICT assets and skilled labour is tested by using Norwegian data. Section 5 concludes the article.

## The Norwegian KLEMS Database

The current Norwegian KLEMS database is based principally on official statistics, such as annual national accounts data, including annual Supply and Use tables. The database provides detailed production input measures including capital (K), labour (L), energy (E), materials (M) and services (S), as well as the output measure, at the disaggregated industry level, for the market economy of mainland Norway over the period 1997-2014 (Liu, 2017).

For each industry, labour inputs are further decomposed into hours worked and changes of labour composition, and capital inputs are grouped into broad asset categories classified by the System of National Accounts (SNA) (United Nations, 2009; Eurostat, 2013). These further classifications make it possible for the decomposition of productivity growth into various detailed components.

The variables in the database are organized by means of the modern growth accounting methodology (Jorgenson and Griliches, 1967; Diewert, 1976; Caves *et al.*, 1982; Jorgenson *et al.*, 1987, 2005). Being well-founded in the neo-classical production theory, the modern growth accounting offers a clear conceptual framework, within which the interactions among different variables in the growth accounts can be analyzed in an internally consistent way. As such, the framework of the modern growth accounting has become an international standard now (Schreyer, 2001, 2009).

The Norwegian KLEMS database is meant to be used primarily for analyzing productivity trend over time in the Norwegian economy. Nonetheless, the database can serve for undertaking research in many other areas, such as in skill development, capital formation, technological progress and R&D activities, as well as in economic growth more generally.

For the purpose of this article, by drawing upon the Norwegian KLEMS database, useful statistical indicators will be derived as regards the changes of output and employment, labour and multi-factor productivity, and input composition among different sectors that occurred in the market economy of mainland Norway for the period 1997-2014.

The market economy of mainland Norway is defined by excluding from the total Norwegian economy all non-market activities, and the offshore oil and gas extraction and maritime sector. The former consists of central and local government activities, such as education, health, defense, and public administration, and activities of the NPISHs;[3] and the latter comprises the offshore industry extracting oil and gas (KNR2306), the pipeline transport of oil and gas (KNR2348), and the maritime transport (KNR2349). Due to exposure to the volatile international oil and gas market, the Norwegian offshore oil and gas extraction and maritime sector has experienced substantial swings, and thus necessitates a separate treatment from the economy of mainland Norway.

Finally, the industries that provide owner-occupied housing services (KNR2368), as well as private renting (KNR2369), are also excluded from the total Norwegian economy. In the end, the market economy of mainland Norway comprises in total 57 industries, the names and the corresponding codes of which are listed in Table 1.[4]

Traditionally, the main distinction in sectoral studies is among primary, secondary, and tertiary (services) sectors. However, since the importance of primary sector has rapidly declined while services sector has become by far the largest sector in Norway, the traditional taxonomy is not sufficient any more for the purpose. Therefore, a more detailed view of the services sector is essential. Moreover, to study the development of the ICT sector which has played an important role in

3 Although significant progress has been made, difficulties for measuring output of these non-market activities remain (Atkinson, 2005; Schreyer, 2010).

4 KNRxxxx as listed in Table 1 are industry codes applied at Statistics Norway where the standard of industry classification is based on NACE Rev.2.

recent economic growth, a special focus on this sector is also worthwhile.

Given the above concerns, the market economy of mainland Norway is subdivided further into the following exhaustive and mutually exclusive six sectors: ICT production (ELECOM); manufacturing excluding ICT production (MEXELEC); other goods production (with traditional primary sector included) (OTHERG);[5] distribution services (DISTR); finance and business services (FINBU); personal services (PERS).

In Table 1 the detailed description and the corresponding abbreviations of the six sectors are listed. Meanwhile, the precise composition of each sector in terms of the industry codes is also presented. Note that the sector definition/classification applied here is in accordance with that in the EU KLEMS database (O'Mahony and Timmer, 2009; Timmer *et al.*, 2010), which is of potential use for comparative analysis.

## Changes in output and employment

A country's economic growth has been usually accompanied with large-scale mobilization of economic resources across different sectors. For instance, the shift of economic resources (output and employment) from primary into secondary sector featured prominently in the earlier literature on economic growth (e.g. Kuznets, 1971; Maddison, 1980), and is still an important characteristic of growth in developing countries (Chenery *et al.*, 1986; Temple, 2005).

Currently, however, the shift from primary into secondary sector has lost its prominence in advanced economies because of the former's tiny share in the total economy. For example, in 2014, the primary sector employed about 4 per cent of the total labour force and accounted for less than 2 per cent of total value added in the market economy of mainland Norway. On the other hand, the shift from secondary into services sector has dominated the process of structural change since the 1970s, and therefore, is the main focus in this article.

Chart 1 shows the ratio of value added and hours worked in (aggregate) services sector (the sum of three services sectors, i.e. distribution, finance and business, and personal services) to those in (aggregate) goods production sector (the sum of two goods production sectors, i.e. manufacturing, and other goods production) over the period from 1997 to

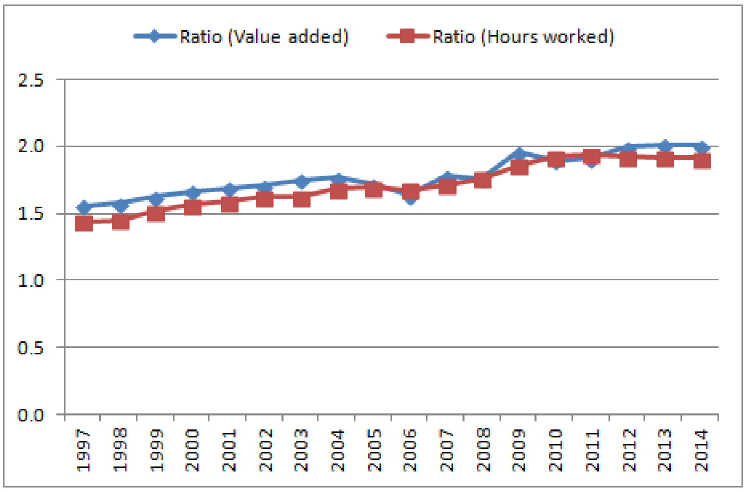
5 Note that other goods production sector (OTHERG) includes electricity (KNR2336), which is in fact a services industry. The average value added share of this industry in other goods production sector is about 8 per cent over the period 1997-2014.

**Table 1: Industries/Sectors in the Market Economy of Mainland Norway**

| Industries | | Sectors | |
|---|---|---|---|
| Code | Description | Abbreviation | Description |
| KNR2326 | Computer and electronics | ELECOM | ICT Production (including Electrical machinery manufacturing and post and communication services) |
| KNR2327 | Electrical equipment | | |
| KNR2353 | Post and distribution | | |
| KNR2361 | Telecommunication | | |
| KNR2362 | Information services | | |
| KNR2310 | Food products, beverages and tobacco | MEXELEC | Manufacturing (excluding Electrical machinery) |
| KNR2312 | Fish farming | | |
| KNR2313 | Textiles, wearing apparel, leather | | |
| KNR2315 | Manufacture of wood and wood products | | |
| KNR2316 | Wood processing | | |
| KNR2317 | Graphic production | | |
| KNR2318 | Production of coal and refined petroleum | | |
| KNR2319 | Chemical raw goods | | |
| KNR2320 | Chemical products | | |
| KNR2321 | Production of pharmaceutical products | | |
| KNR2322 | Rubber and plastic products | | |
| KNR2323 | Other chemical and mineral products | | |
| KNR2324 | Metal raw goods | | |
| KNR2325 | Metal products | | |
| KNR2328 | Machinery and equipment | | |
| KNR2329 | Production of transport equipment | | |
| KNR2330 | Building of ships | | |
| KNR2331 | Building of oil platforms and modules | | |
| KNR2332 | Other industry production | | |
| KNR2333 | Repair/installation of machinery/equipment | | |
| KNR2301 | Agriculture, Hunting | OTHERG | Other production (including Agriculture, mining, utilities and construction) |
| KNR2302 | Forestry | | |
| KNR2303 | Fishing | | |
| KNR2304 | Aquaculture | | |
| KNR2305 | Mining and quarrying | | |
| KNR2335 | Production of electricity | | |
| KNR2336 | Transport and sale of electricity | | |
| KNR2337 | Other energy, district heating and gas | | |
| KNR2341 | Building development | | |
| KNR2342 | Construction | | |
| KNR2344 | Wholesale/retail trade, repair of motor v. | DISTR | Distribution(including Trade and transportation) |
| KNR2346 | Passenger transport | | |
| KNR2347 | Goods transport | | |
| KNR2350 | Domestic maritime transport | | |
| KNR2351 | Air transport | | |
| KNR2352 | Services connected to transport | | |
| KNR2307 | Service activities incidental to oil and gas | FINBU | Finance and business services (excluding housing services) |
| KNR2358 | Publishing business | | |
| KNR2364 | Financial services | | |
| KNR2367 | Managing real estate | | |
| KNR2370 | Architecture/legal/accounting/consulting | | |
| KNR2372 | Research and Development | | |
| KNR2373 | Marketing/veterinary and other services | | |
| KNR2377 | Leasing, travel and other business services | | |
| KNR2338 | Water supply, sewerage, waste | PERS | Personal services (including Hotels, restaurants and community, social and personal services) |
| KNR2356 | Hotel and restaurant | | |
| KNR2385 | Education/training | | |
| KNR2386 | Health services | | |
| KNR2387 | Social welfare services | | |
| KNR2390 | Cultural/sports/leisure activities | | |
| KNR2394 | Membership and other private activities | | |
| KNR2397 | Paid household works | | |

Statistics Norway and EU KLEMS database (www.euklems.net)

**Chart 1: Ratio of Services Over Goods Production in Mainland Norway, 1997-2014**




Note: Value added in current prices.
Source: Calculations are based on Norwegian KLEMS database, July 2017.

2014.

Note that the ICT production sector is not included in the (aggregate) goods production sector for comparison, because it incorporates some part of services industries, such as information services. However, if this sector is included in a broad sense, the calculated two ratios reported in Chart 1 will be slightly lower. Nevertheless, the trend over time is almost the same as shown in Chart 1.

Compared with goods production, the importance of market services had gradually but steadily increased over the period 1997-2014. This is in accordance with the empirical regularities that have been found in many other studies, i.e. the increase in the shares of services came at the expense of traditional goods production (e.g. Kuznets, 1971; Maddison, 1980; Jorgenson and Timmer, 2009). At the same time, Chart 1 makes rather clear that services had become a very sizable sector in its entirety. In 2014, the output (in terms of value added) of this (aggregate) market services sector was double (and the employment (in terms of hours worked) almost double) that of the (aggregate) goods production sector.

The growing importance of market services is the result of many interacting factors (Schettkat and Yokarini, 2006). For instance, higher per capita income leads to higher demand for services in general. There is also an increasing marketization of traditional household production activities, such as dining outside the home, paying cleaning and care assistance from the market. Moreover, many manufacturing firms are outsourcing aspects of business services, such as accounting, canteen, trade and transport activities, etc.

Table 2 presents the shares of sector value added and hours worked as a percentage of the total in the market economy of mainland Norway for the six sectors in 1997 and 2014. Despite the main trends as reflected by the total market economy of mainland Norway in Chart 1, the more detailed sector figures in 2 reveals striking differences that appeared both within the goods production sectors and among the three services sectors.

Within the goods production sectors, both shares of sector value added, and hours worked in manufacturing sector had decreased from 1997 to 2014. While the share of hours worked in other goods production sector had reduced, its value added share had actually increased, though with a small margin (from 17.1 in 1997 to 18.1 per cent in 2014). This implies that the ratio of labour productivity in other goods production sector to that of at least one other sector had increased over the period 1997-2014.[6]

Among the three services sectors, the shares of both sector value added and hours worked in distribution services sector had decreased; on the contrary, those in finance and business services sector had increased. In fact, the increases in this specific sector were the largest among all sectors in the total market economy of mainland Norway.

As for personal services sector, although its share of hours worked had increased substantially, its value-added share had actually decreased over the whole period 1997-2014, indicating a reduced labour productivity ratio of this sector to at least one other sector over the same period.

The ICT production sector is singled out from the total market economy of mainland Norway because of its exceptional performance in driving productivity growth in recent years.[7] As shown in Table 2, the shares of both sector value added and hours worked in this sector were small compared to those for other sectors, and these shares had shrunk to some extent from 1997 to 2014.

## Changes in Productivity

### Labour Productivity

One of the empirical regularities once documented by the literature (e.g. Kuznets, 1971; Maddison, 1980; Skoglund, 2013) is the slow growth of labour productivity in services industry compared to manufacturing in-

6 However, this does not necessarily mean that the absolute level of labour productivity in Other goods production sector had increased, because the absolute level in each sector is determined not only by the ratio of shares of sector value added to hours worked, but also by the labour productivity level of the total market economy of mainland Norway.

7 As will be shown later, although the production of ICT goods and services makes up only a small part of total value added (Table 2), its productivity growth was the highest among all the six sectors.

**Table 2: Share of Value Added and Hours Worked by Sector in Mainland Norway, 1997 and 2014 (%)**

| | Value Added | | Hours Worked | |
|---|---|---|---|---|
| | 1997 | 2014 | 1997 | 2014 |
| Total market economy of mainland Norway | 100 | 100 | 100 | 100 |
| ICT production (ELECOM) | 7.8 | 6.9 | 6.1 | 5.6 |
| Goods | 36.1 | 31 | 38.5 | 32.4 |
| Manufacturing (MEXELEC) | 19.0 | 12.9 | 18.6 | 13.8 |
| Other goods (OTHERG) | 17.1 | 18.1 | 20.0 | 18.6 |
| Services | 56.2 | 62.2 | 55.4 | 62.0 |
| Distribution (DISTR) | 24.8 | 20.2 | 28.0 | 25.5 |
| Finance and business (FINBU) | 22.4 | 33.6 | 16.6 | 23.3 |
| Personal (PERS) | 9.0 | 8.4 | 10.9 | 13.3 |

Note: Value added in current prices.
Source: Calculations are based on Norwegian KLEMS database, July 2017.

dustry. Traditionally, manufacturing activities have been regarded as the locus of innovation and technological change and thus the essentially central source of economic growth. This was also considered as the key to post-World War II growth in Europe through realization of economies of scale, capital intensification and incremental innovation (Crafts and Toniolo, 1996).

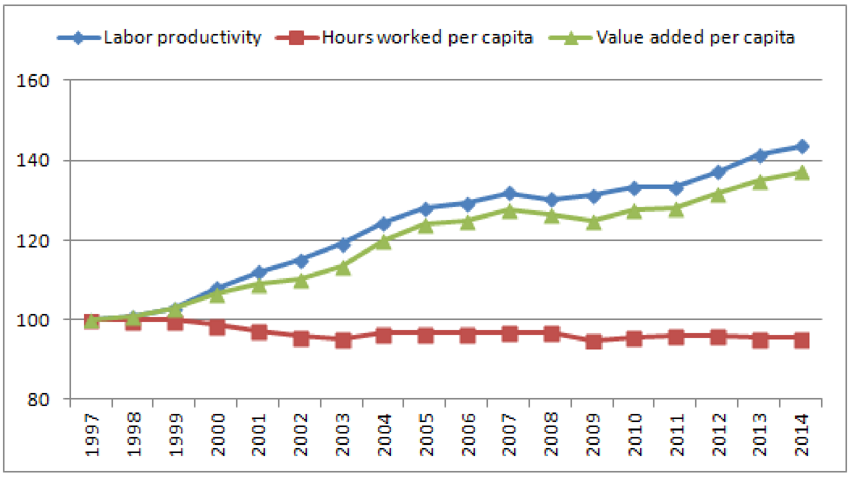
More recently, rapid technological change in ICT production (such as computer and semi-conductor manufacturing) seemingly reinforced the predominance of innovation in the broad manufacturing sector (including ICT production). By contrast, productivity growth in services was usually assumed to be low or even zero.

Baumol's cost disease theory suggests that productivity improvements in services are less likely than in goods-producing industries because most services are labour-intensive, making it difficult to substitute capital for labour in service industries (Baumol, 1967). However, a seminal study by Triplett and Bosworth (2006) shows that after 1995 fifteen out of twenty-two two-digit services industries in the United States had experienced acceleration in labour productivity growth that at least equaled the economy-wide average.

In this article I will look for similar patterns in Norway and study sectoral trends in productivity both for the entire period 1997-2014, and for two sub-periods (1997-2006, and 2006-2014).[8] The Norwegian KLEMS database provides the opportunity for examining the trends in both labour and multi-factor productivity (MFP). The MFP provides a measure of the

8 The year 2006 is chosen as sub-period demarcation for two reasons. First, official statistics at Statistics Norway show that both labour and multi-factor productivity (MFP) growth in the market economy of mainland Norway had decreased significantly since 2006. Second, 2006 is a natural mid-year of the entire period 1997-2014.

**Chart 2: Trends of Labour Productivity, Hours Worked per Capita, and Value Added per Capita in the Total Market Economy of Mainland Norway (1997=100)**




Note: Value added in volume.
Source: Calculations are based on Norwegian KLEMS database, July 2017.

efficiency of labour and other inputs combined and is often used as an indicator of technological change.

As shown in Chart 2, over the entire period 1997-2014, the fact that hours worked per capita had been gradually decreasing, together with an enhanced value added per capita, lead to increased labour productivity in the market economy of mainland Norway. In 2014, the labour productivity measured by value added per hour worked was above 140% of the level in 1997. But the picture painted by the total market economy of mainland Norway may hide some significant divergences among the sectors that make up it. Indeed, as shown in Table 3 and Chart 3, sectors are highly diverse in terms of their labour productivity performance, although in general the overall average annual labour productivity growth in (aggregate) goods production sector was larger than that in (aggregate) services sector over the entire period (2.1 vs. 1.5 per cent in 1997-2014).

Table 3 provides average annual growth rates for the period 1997-2014, as well as two sub-periods of 1997-2006 and 2006-2014. Chart 3 presents the corresponding trends of labour productivity for the six sectors with 1997 indexed to 100, where the annual average growth rate for the whole period (1997-2014) is applied.

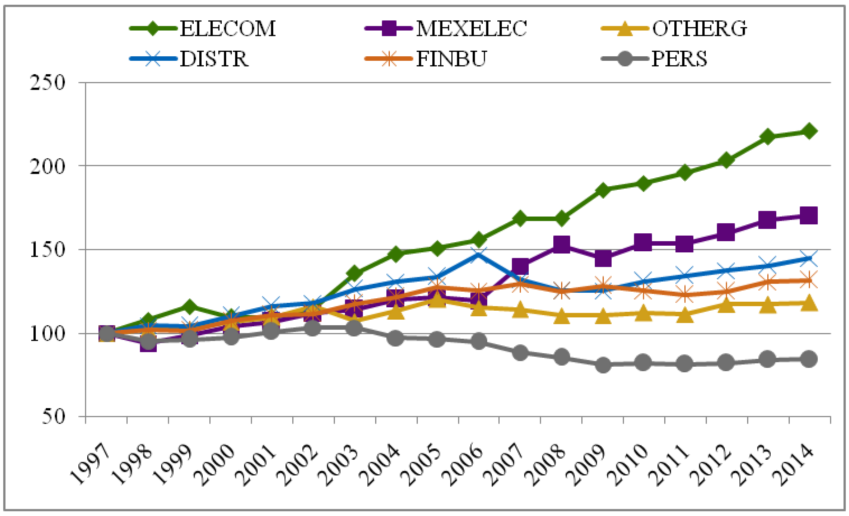
By far the fastest growth in labour productivity is found in the ICT production sector, with annual average growth rates of 4.9 per cent over the whole period, leading to its productivity level in 2014 more than twice than in 1997. During the same period, the second fastest growth sector is manufacturing, compared with which, all the three services sectors had lower productivity growth. Moreover, the productivity growth in personal ser-

**Table 3: Labour Productivity Growth in Total Market Economy of Mainland Norway, Value Added Based (%)**

| | 1997-2014 | 1997-2006 | 2006-2014 |
|---|---|---|---|
| Total market economy of mainland Norway | 2.15 | 2.89 | 1.33 |
| ICT production (ELECOM) | 4.90 | 5.21 | 4.51 |
| Goods | 2.11 | 1.86 | 2.41 |
| Manufacturing (MEXELEC) | 3.28 | 2.04 | 5.02 |
| Other goods (OTHERG) | 1.02 | 1.66 | 0.34 |
| Services | 1.50 | 2.2 | 0.09 |
| Distribution (DISTR) | 2.30 | 4.35 | -0.21 |
| Finance and business (FINBU) | 1.60 | 2.59 | 0.70 |
| Personal (PERS) | -0.92 | -0.52 | -1.41 |

Note: Average annual compound growth rates.
Source: Calculations are based on Norwegian KLEMS database, July 2017.

**Chart 3: Labour Productivity by Sector of the Total Market Economy of Mainland Norway, Value Added Based (1997=100)**




Source: Calculations are based on Norwegian KLEMS database, July 2017.

vices sector was even negative.

When considering the two sub-periods (1997-2006 and 2006-2014) as shown in Table 3, the overall labour productivity performance for (aggregate) goods production sector was actually weaker than (aggregate) services sector in the first sub-period (1.9 vs. 2.8 per cent). However, during the second sub-period, its performance was much stronger (2.4 vs. 0.1 per cent), thanks in part to the good performance by the manufacturing sector, and in part to the bad performance by the services sectors in general, and by distribution services sector in particular.

Indeed, except for the manufacturing sector, average labour productivity growth for all the other sectors had decreased from the first sub-period (1997-2006) to the second

(2006-2014). The labour productivity growth for distribution sector had even become negative. As a result, even if the labour productivity growth for manufacturing sector more than doubled (from 2.0 to 5.0 per cent), the labour productivity growth for the total market economy of mainland Norway had more than halved from the first sub-period 1997-2006 (2.9 per cent) to the second 2006-2014 (1.3 per cent).

## Multi-factor productivity

As mentioned, technical change is usually measured as the growth in multi-factor productivity (MFP). Table 4 provides average annual MFP growth rates for the period 1997-2014, as well as two sub-periods of 1997-2006 and 2006-2014. There is also a large variation in the average rates of MFP growth among the sectors, although, again, the overall average annual MFP growth in the (aggregate) goods production sector was larger than that in the (aggregate) services sector over the entire period (1.9 vs. 0.7 per cent).

For the entire period 1997-2014, the sector ranking is broadly the same as that for labour productivity growth. The only exception is the sector ranking order between finance and business services, and other goods production sectors. The annual average growth rate for finance and business sector was lower in terms of MFP (0.3 vs. 1.2 per cent), while higher in terms of labour productivity in Table 3 (1.6 vs. 1.0 per cent), than that for other goods production sector.

The main reason is as follows. As shown in equation (1), the estimate of (value added-based) MFP growth in sector $j$ ($\Delta\ln A_j^Z$) is empirically calculated as a residual, in other words, as average (value added-based) labour productivity growth ($\Delta\ln z_j$) deducted by contribution from changes of labour composition ($\bar{v}_{L,j}^Z \Delta\ln LC_j$) and that from capital intensity ($\bar{v}_{K,j}^Z \Delta\ln k_j$) in sector $j$ (Liu, 2017).

$$\begin{aligned}\Delta\ln A_j^Z &= \Delta\ln z_j - \\ \bar{v}_{L,j}^Z \Delta\ln LC_j &- \bar{v}_{K,j}^Z \Delta\ln k_j\end{aligned} \quad (1)$$

While the contribution to average labour productivity growth from changes of labour composition ($\bar{v}_{L,j}^Z \Delta\ln LC_j$) was negative and of a large absolute value for other goods production sector, it was positive for finance and business services sector. Moreover, although the contribution to average labour productivity growth from capital intensity ($\bar{v}_{K,j}^Z \Delta\ln k_j$) was positive for both finance and business services and other goods production sectors, it was far larger for the former than for the latter. As a result, one ends up with a much lower estimate of MFP growth

**Table 4: Multi-Factor Productivity Growth in Total Market Economy of Mainland Norway, Value Added Based (%)**

| | 1997-2014 | 1997-2006 | 2006-2014 |
|---|---|---|---|
| Total market economy of mainland Norway | 1.35 | 1.55 | 1.13 |
| ICT production (ELECOM) | 4.06 | 3.81 | 4.38 |
| Goods | 1.85 | 1.10 | 2.76 |
| Manufacturing (MEXELEC) | 2.58 | 1.01 | 4.78 |
| Other goods (OTHERG) | 1.17 | 1.19 | 1.16 |
| Services | 0.72 | 1.50 | -0.12 |
| Distribution (DISTR) | 2.15 | 3.54 | 0.44 |
| Finance and business (FINBU) | 0.27 | 0.76 | -0.18 |
| Personal (PERS) | -1.53 | -1.71 | -1.30 |

Notes: Average annual compound growth rates.
Source: Calculations are based on Norwegian KLEMS database, July 2017.

($\Delta \ln A_j^Z$) for finance and business services sector than for other goods production sector (Liu, 2017).

Chart 4 gives the trends of MFP level for the six sectors, and all the curves are indexed to 100 in 1997, by using the annual average growth rate of MFP for the whole period (1997-2014). As shown, being consistent with the discussion outlined above, the ranking of MFP level is similar with that of labour productivity, except that the sector order of other goods production and finance and business services sectors is different.

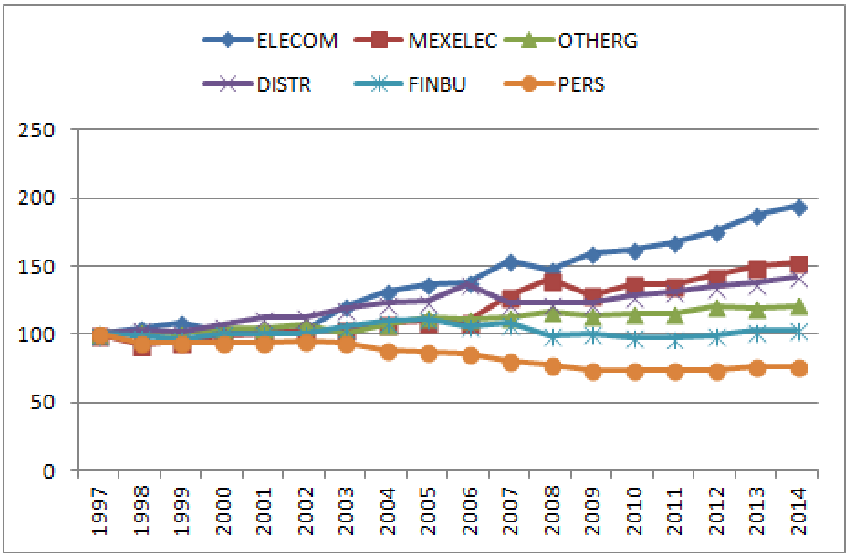
Further comparison between Charts 3 and 4 also reveals that except for the other goods production sector, labour productivity level index is larger than the corresponding MFP level index for all the other sectors, because the average growth of labour productivity ($\Delta \ln z_j$) is larger than that of the corresponding estimated MFP. The latter observation is due to that the summed contributions from the change of labour composition ($\bar{v}_{L,j}^Z \Delta \ln LC_j$) and capital intensity ($\bar{v}_{K,j}^Z \Delta \ln k_j$) are positive for these sectors, while negative for the other goods production sector, over the observed period 1997-2014 (Liu, 2017).[9]

Considering the two sub-periods (1997-2006, and 2006-2014) as shown in Table 4, similar with the revealed pattern by labour productivity growth, the overall MFP performance for the (aggregate) goods production sector was weaker in the first subperiod (1.1 vs. 1.5 per cent), while much stronger during the second subperiod (2.8 vs. -0.1 per cent), than the (aggregate) services sector. This is again owing in part to the good performance by manufacturing sector, and in part to the bad performance by the services sectors, and in particular, by distribution services sector.

On the other hand, over the two sub-periods, the detailed change pat-

9 Also see equation (1).

**Chart 4: Multi-Factor Productivity by Sector of the Total Market Economy of Mainland Norway, Value Added Based (1997=100)**




Source: Calculations are based on Norwegian KLEMS database, July 2017.

terns of MFP growth among the sectors are different from those of labour productivity growth. For instance, there was only one sector (manufacturing) having improved labour productivity growth; while there were three sectors, i.e. ICT production, manufacturing, and personal services, having increased their MFP growth. In addition, the MFP growth of finance and business services sector, which was positive in the first sub-period (0.8 per cent), became negative in the second sub-period (-0.2 per cent).

To sum up, the analysis has up to now painted a diversified picture of sectoral development in the market economy of mainland Norway over the period 1997-2014. Although both the shares in value added and in hours worked decreased, there was continuing productivity growth in the ICT production and manufacturing sectors. And even stronger productivity growth was observed for the second sub-period (2006-2014) for the manufacturing sector. However, despite an increase of its share in value added, other goods production sector had revealed low productivity growth, and its average growth had decreased from the first sub-period to the second.

Both shares of value added and hours worked of finance and business services sector had increased sharply over 1997-2014. In 2014, this sector accounted for about a third of value added and a quarter of hours worked of the market economy of mainland Norway. But this sector experienced relatively low productivity growth. Nonetheless, as shown by Oulton (2016), the aggregate MFP growth can rise when resources (value added) shift towards those sectors supplying intermediate services, even if these supplying sectors themselves have low MFP growth (provided it is positive). In other words, as a large intermediate services provider, finance and business services had contributed positively to the overall MFP growth of the market economy of mainland Norway, both for the entire period and for the first sub-period.

Within finance and business services sector, the financial services industry (KNR2364) is the largest one, accounting for in average about 26 per cent of the sector's value added over the period 1997-2014. However, the current estimation method for the output from this industry, i.e. FISIM (Financial Intermediation Services Indirectly Measured), is rather different from those applied for other industries in national accounts compilation system (United Nations, 2009; Eurostat, 2013). Therefore, any results associated with the financial and business services sector should be interpreted with due caution.

The personal services sector seems to be a typically stagnant sector with low or even no productivity improvements, but with increasing shares in employment, which is consistent with the prediction made by Baumol (1967), and in more recent analyses for the USA by Baumol *et al.* (1985) and Nordhaus (2008).

As for distribution services sector, both its shares in value added and in hours worked had declined, but this sector had higher productivity growth even than the other goods production sector over the entire period. From the first sub-period to the second, however, this sector suffered a large decline in productivity growth, and its average labour productivity growth became negative.

## Changes in input composition

Structural change not only entails the changes in output, employment, and labour and multi-factor productivity, but also involves changes in the mix of inputs used in the production process. For instance, one study has found that compared to the United States and other Anglo-Saxon countries, there was a stronger substitution process of capital for labour in continental Europe, and the reason was partly due to higher wage-rental ratios in Europe (Blanchard, 1997).

In the past decades, attention has been focused on the increased use of inputs that are well suited to the generation, processing and diffusion of knowledge and information, namely, skilled labour and ICT equipment. An appealing explanation to this economic phenomenon is the existence of complementarity between increased use of ICT and skilled labour (e.g. O'Mahony *et al.*, 2008). For the

USA, Jorgenson *et al.* (2005) document large increases in the use of both skilled labour and ICT capital across the economy, which seems to be consistent with this complementarity hypothesis.

In the previous sections, it has been demonstrated that the patterns of structural change revealed solely by either total economy or two (aggregate) sectors may be misleading. Therefore, in this section I will track the use of skilled labour and the knowledge-based capital in general, and the ICT and R&D capital in particular, with focus being placed on the six sectors that make up the market economy of mainland Norway.

### Measures of input intensity

Indicators for input intensity in this article are value measures, rather than the more frequently used quantity ones (such as the share of workers with high education in total employment or the number of computers per employee). The value measures are also applied by the EU KLEMS project (where they are referred to as cost measures) (Timmer *et al.*, 2010).

In this article, skilled labour is represented by those workers with high education attained. For simplicity, all the other workers with other than high educational attainment are regarded as unskilled labour (UL).[10] High education consists of two levels: High Ed-short is defined as Tertiary education, lower degree; High Ed-long is defined as Tertiary education, higher degree. Simply put, High Ed-short refers largely to Bachelors while High Ed-long mainly to Masters and/or Doctors.

The capital assets are classified first into two broad asset categories: the knowledge-based capital, and all other assets (other), with the former consisting of ICT and R&D capital. The dichotomous distinction between the knowledge-based capital and all others (other) merits some discussion here. In fact, such a simple categorization does not mean that only the ICT and R&D capital are knowledge-based, while others have no knowledge embodied at all, which is clearly wrong. The purpose of this categorization is to focus on the ICT and related assets, because these assets have been frequently employed for explaining the prevalence of knowledge intensification featuring many countries' recent economic growth (e.g. Berman *et al.*, 1998).

The ICT capital is further divided into two subgroups: IT-hardware and IT-software. IT-hardware con-

10 The definition of skilled vs. unskilled labour applied in this article is only a relative concept. For detailed classifications on the Norwegian educational attainment levels, see Liu (2017).

sists of office and computing equipment, and communications equipment. IT-software is supposed to be treated separately from databases (United Nations, 2009; Eurostat, 2013). However, in the Norwegian KLEMS database, databases are not distinguished from software, and therefore, IT-software applied here includes databases.

R&D capital refers to the asset developed through Research and Development experimental activities. Expenditures on R&D had traditionally been treated as intermediate consumption, although there had long been argued that these expenditures should be considered as capital investments, and therefore incorporated into the asset boundary within the SNA.

In the latest SNA (United Nations, 2009; Eurostat, 2013), R&D was for the first time incorporated into the asset boundary and treated as one type of capital under the category of Intellectual Property Products (IPP).[11] Later, implementation of capitalizing R&D expenditures in national accounts has been carried out by many countries, including Norway (see Sørensen, 2016), which offers the opportunity for better analyzing the relationship between the use of skilled labor and the knowledge-based capital more comprehensively than before.

Input intensity measures based on the value approach as in this article start from the standard national accounting identity that value added equals the cost, namely, the compensation for labour and capital in total.

Let $P$ and $Q$ denote prices and quantities respectively, indexed (by superscript) for value added and various inputs components. Then:

$$\begin{aligned}P^{VA}Q^{VA} = P^{UL}Q^{UL}+\\ P^{HighEd-short}Q^{HighEd-short}+\\ P^{HighEd-long}Q^{HighEd-long}+\\ P^{IT-hardware}Q^{IT-hardware}+\\ P^{IT-software}Q^{IT-software}+\\ P^{R\&D}Q^{R\&D}+P^{Other}Q^{Other}\end{aligned} \tag{2}$$

In equation (2), the price applied to value added ($P^{VA}$) is basic prices which are evaluated from the producer's point of view and thus exclude all taxes from the value of output but include product subsidies. The concept of basic prices is defined and recommended in the SNA (United Na-

11 Intellectual Property Products (IPP) includes among others *computer software and databases* which had already been recommended to be incorporated into the asset boundary by the *System of National Accounts 1993* (United Nations, 1993).

tions, 2009; Eurostat, 2013).[12]

Using equation (2), the input intensity for each input component is defined as its compensation of services divided by total value added. For instance, the input intensity for unskilled labor is calculated as $P^{UL}Q^{UL}$ divided by total value added $P^{VA}Q^{VA}$.

As a share of value added, an increase of an input intensity indicates a growing importance of the input in production. Note that this rise can be attributed either to an increase in the price of the input, or to an increase in the quantity used, or to both simultaneously, relative to the other inputs. On the contrary, indicators based on quantities alone usually ignore price changes. Moreover, the value measures of input intensity as defined in this article take account of substitution effects not only among different labour types but also between labour and other inputs, such as various capital inputs.

The empirical implementation of indicators for labour input intensity is relatively straightforward as the hours worked by various types of labour and their relative labour compensation can be directly drawn from the Norwegian KLEMS database.[13]

Measuring the capital input intensity of production is less straightforward as quantities and prices of capital services are not directly observable. The measure of the relative importance of different capital asset is based on the concept of capital services introduced by Jorgenson and Griliches (1967). According to this approach, capital input is measured through its delivery of capital services in a specific period (e.g. a year). Being consistent with the entire framework of the modern growth accounting, the capital input intensity as measured in this article is considered to be better than those calculated, e.g. as the ratio of R&D investment to GDP, the share of firms undertaking R&D within an industry (Brasch, 2015; Foyn, 2017).

In the Appendix, the estimated input intensity measures for three selected years (1997, 2008, and 2014) are presented by different labor inputs in Table A1, and by various knowledge-based capital inputs in Ta-

12 As implicitly reflected by equation (2), other taxes (net of subsidies) on production have been allocated to either labour or capital inputs. These taxes (net of subsidies) could include a variety of taxes levied on ownership and use of land, use of fixed assets, total wage bill, licenses, etc. However, without detailed knowledge about the various tax types, taxes on production are practically allocated to capital compensation as they mainly fall on this factor input.

13 Note that labour compensation computed in the Norwegian KLEMS database includes employer's social contributions, in addition to wages/salaries. As for labour compensation of the self-employed, an imputation is made by assuming that the compensation per hour of the self-employed is equal to the compensation per hour worked of employees.

ble A2, both for the total market economy of mainland Norway, as well as for the six sectors.

### Skilled Labour

Chart 5 provides the time trend of input intensity for total labor, High Ed-short, and High Ed-long in the market economy of mainland Norway over the period 1997-2014. The valued added share for total labor dropped gradually from 70 per cent in 1997 to 67 per cent in 2008 and continued to shrink to slightly lower than 67 per cent in 2014 (Table A1 in the Appendix). This observation reflects a long-run trend of substituting labour by capital as described by Blanchard (1997). However, the value added share of labour services by both High Ed-short and High Ed-long had been growing during 1997-2014. In 1997, the shares of High Ed-short and High Ed-long were 12.9 and 5.3 per cent, while they became 15.0 and 8.1 per cent in 2014, respectively (see Table A1 in Appendix).

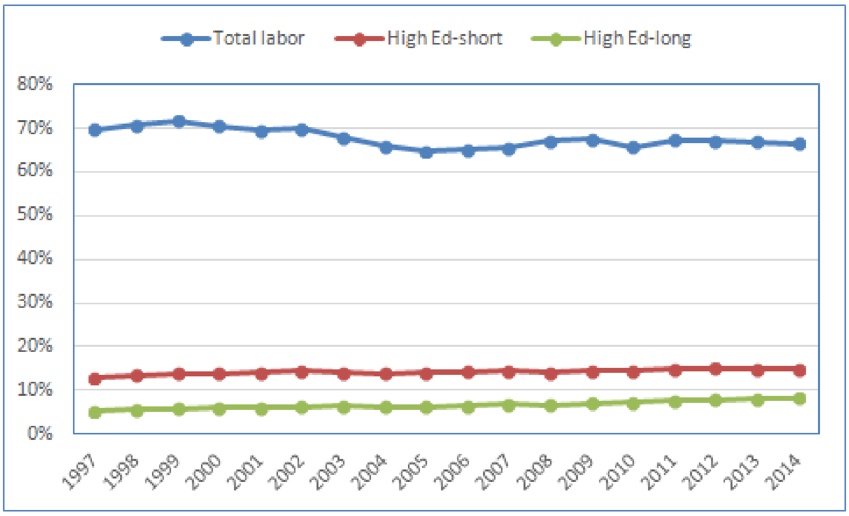
In Chart 6, the time trend of labour input intensity is presented in Panel (a) for High Ed-short and in Panel (b) for High Ed-long workers for the six sectors. Note that only estimated labour input intensity for the period 2008-2014 are presented in Chart 6, because labour input data cross-classified by age, gender, education, and industry before 2008 is of relatively lower quality (Liu, 2017).

In general, labour compensation share with either High Ed-short or High Ed-long education in sector value added was higher in 2014 than in 2008 for almost all the sectors. The only exception is finance and business services sector for which the labour compensation share of workers with High Ed-short in 2014 was slightly lower than in 2008 (see Table A1 in Appendix).

As visualized in Chart 6, three sectors (i.e. ICT production, finance and business services, and personal services) are highly skilled labour-intensive sectors, compared with the other three ones (i.e. manufacturing, other goods production, and distribution services sectors). As for the sector rankings, finance and business services and manufacturing have relatively higher (than personal services and distribution services, respectively) rankings of labour services share in Panel (b) (for High Ed-long), compared with those in Panel (a) (for High Ed-short).

The reason why labour services share of High Ed-short in sector value added for personal services sector is higher than that for financial and business services sector is not because the average labour compensation in the former sector is larger than in the latter one. In fact, the average share of High Ed-short in sector labour com-

**Chart 5: Labour Services Share in Value Added Total Market Economy of Mainland Norway, by Skill Level, 1997-2014 (%)**




Notes: Labour includes employees and self-employed.
Source: Calculations are based on Norwegian KLEMS database, July 2017.

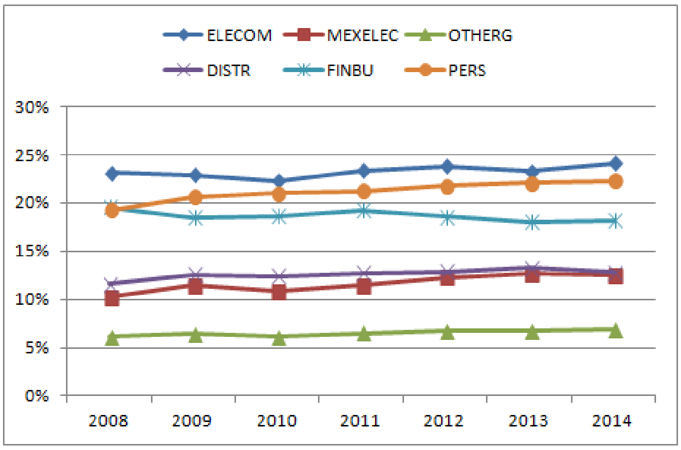
pensation is 25.8 per cent for personal services sector, and 32.2 per cent for financial and business services sector over the period 2008-2014. However, as a typical labour-intensive sector, the average share of labour compensation in sector value added for personal services sector is 81.9 per cent, while that for financial and business services sector is 58.0 per cent over the same period. Consequently,the average labour services share of High Ed-short in sector value added for personal services sector is 21.2 per cent, which is higher than 18.6 per cent for financial and business services sector (Liu, 2017).

Finally, by combining High Ed-short and High Ed-long together, labour services share of workers with high education in general (i.e. High Ed (short + long)) is shown in Panel (c) in Chart 6. Briefly speaking, the ranking of the three highly skilled labour-intensive sectors (i.e. ICT production, finance and business services, and personal services) as shown in Panel (c) is the same as that in Panel (a) (for High Ed-short only), simply because the share of High Ed-short (Panel (a)) is considerably larger than the corresponding share of High Ed-long (Panel (b)) for each sector, as well as in every year.

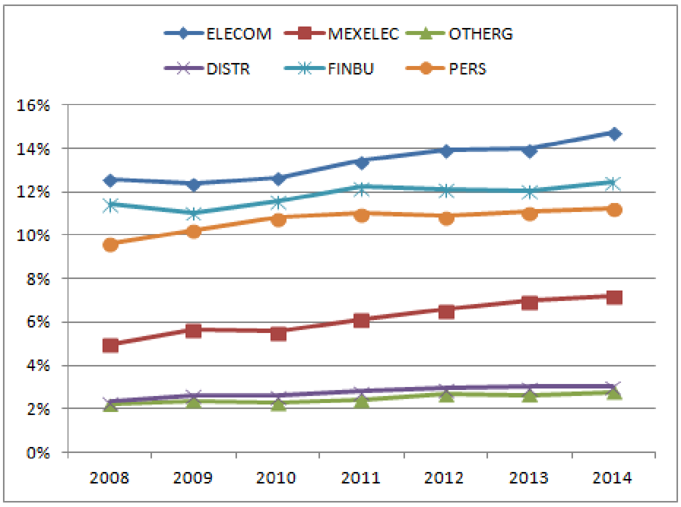
On the other hand, the ranking order revealed by Panel (c) for the other three sectors (i.e. manufacturing, distribution services, and other goods production) looks the same as that by Panel (b) (for High Ed-long only). The reason is that the labour services share in value added of distribution

**Chart 6: Compensation of High Education Share in Sector Value Added for Total Market Economy of Mainland Norway, 2008-2014**

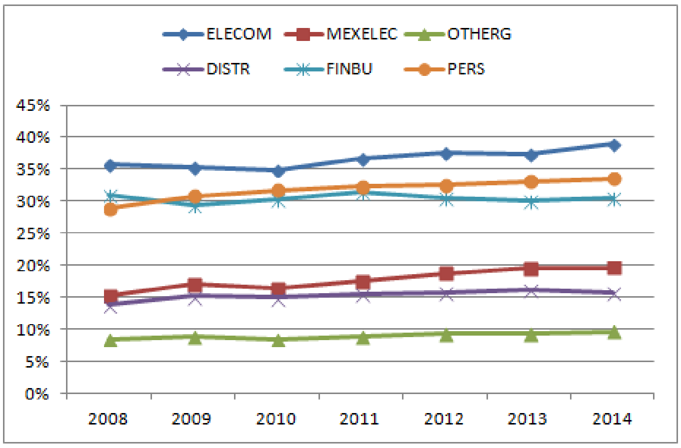
**(a) High Ed-short**




**(b) High Ed-long**




**(c) High Ed (Short + Long)**




Notes: Labour includes employees and self-employed. Source: Calculations are based on Norwegian KLEMS database, July 2017.

services sector is so low for High Ed-long that it effectively drags down the sum of the labour services share of both High Ed-short and High Ed-long for this sector below that for manufacturing sector as shown in Panel (c) of Chart 6.

### Knowledge-Based Capital

The time trend of capital services share in value added for the total market economy of mainland Norway over the period 1997-2014 is presented in Chart 7 for three knowledge-based capital: IT-hardware, IT-software, and R&D.

In general, the time trend for the total market economy of mainland Norway was declining for IT-hardware, while increasing for both IT-software and R&D, especially during the latter period. The falling share of IT-hardware could be largely related to the nature of the ongoing technological change in the digital economy, which has shifted from investing in ICT hardware to outsourcing ICT services, such as purchasing IT services from cloud computing.

#### ICT Capital

The time trend of different capital services share in sector value added for IT-hardware, IT-software, and for ICT capital (hardware + software), for each of the six sectors is displayed respectively in Panels (a), (b), and (c) of Chart 8.

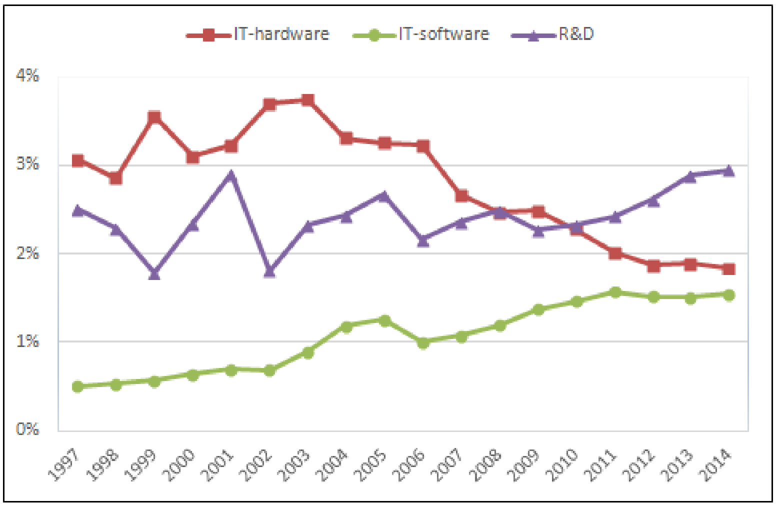
As shown in Panel (a), in terms of the IT-hardware services share in sector value added, for the ICT production sector experienced a heavy decline over the entire period. In 2014, at 9.7 per cent, the share was almost half of that in 1997 (17.5 per cent) (Table A2 in Appendix). In spite of that, the IT-hardware share for this sector is far larger than those for any of the other sectors.

Broadly speaking, after having peaked around mid-2000, the shares for finance and business services, distribution services, personal services, and manufacturing sectors, declined rapidly, although the share for manufacturing sector resumed upturn near the end of the period. As for the other goods production sector, its share had been gradually increasing over the whole period 1997-2014.

As displayed in Panel (b), over the entire period, the capital services share of IT-software had increased for all the sectors, and for the total market economy as well. However, in the latter period 2008-2014, the share for the ICT production sector declined, and that for personal services sector had remained more or less unchanged.

Panel (c) shows that the ICT production and finance and business services are ICT capital intensive sectors, simply because these two sectors are more intensive in terms of both IT-

**Chart 7: Capital Services Share in Value Added of Total Market Economy of Mainland Norway, 1997-2014**




Source: Calculations are based on Norwegian KLEMS database, July 2017.

hardware and IT-software capital inputs in sector value added. In general, the capital services share of IT-hardware is higher in magnitude than that of IT-software for each sector and in every year. Therefore, the general trend reflected in Panel (a) for IT-hardware will dominate that reflected in Panel (b) for IT-software, especially for the latter period 2008-2014.

### R&D Capital

R&D capital services share in value added for the six sectors is displayed in Chart 9, which shows that three sectors (i.e. ICT production, manufacturing, and finance and business services) are more R&D intensive, compared with the other sectors. The general trend of R&D capital services shares for the manufacturing and finance and business services sectors had been increasing, especially over the latter period of 2008-2014.

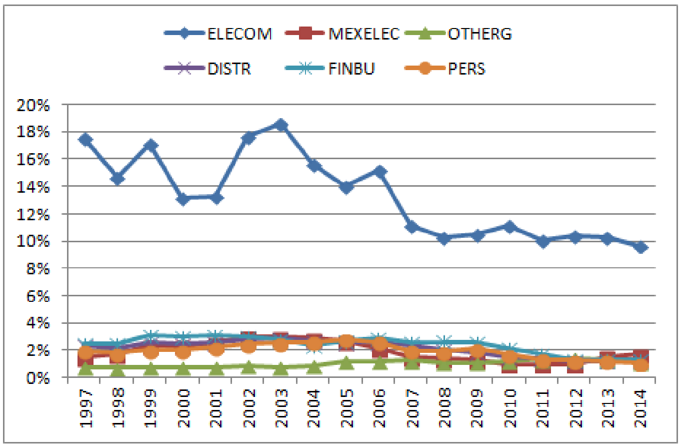
As for the ICT production sector, despite ups and downs, its share increased in 2014 (8.8 per cent), if compared with that in 1997 (8.5 per cent); while declined slightly, if compared with that in 2008 (8.9 per cent). On the other hand, the time trend of R&D capital services shares for the other goods production, distribution services, and personal services sectors had been gradually but steadily increasing, over the entire period of 1997-2014 (also see Table A2 in the Appendix).

### Intensification of Knowledge Inputs

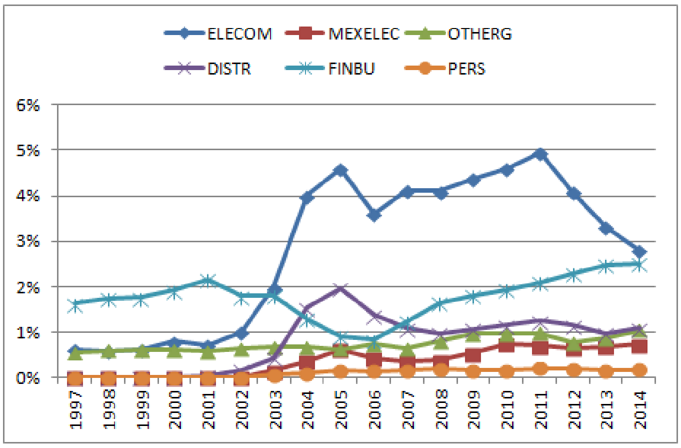
Knowledge inputs used by production process include not only the skilled labour with accumulated knowledge as part of human capital developed, but also the knowledge based non-human capital, with knowledge either physically embodied

**Chart 8: ICT Capital Services Share in Sector Value Added for Total Market Economy of Mainland Norway, 1997-2014**

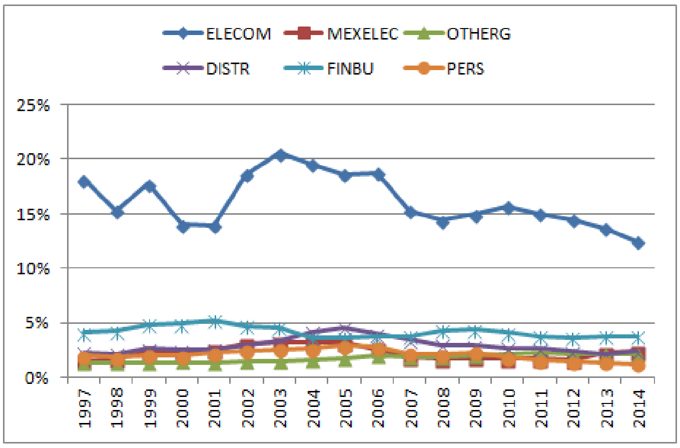
**(a) IT-Hardware**




**(b) IT-Software**

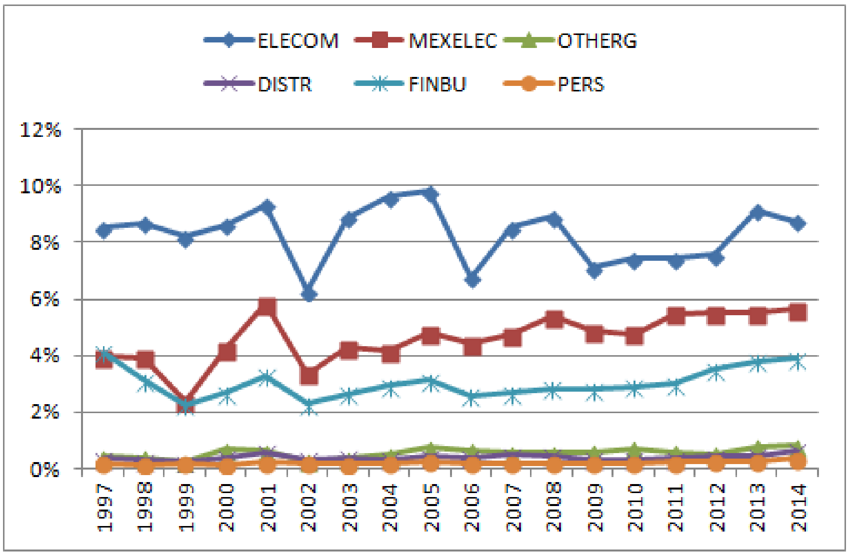



**(c) ICT (Hardware + Software)**




Notes: Calculations are based on Norwegian KLEMS database, July 2017.

**Chart 9: R&D Share in Sector Value Added Total for Market Economy of Mainland Norway, 1997-2014**




Source: Calculations are based on Norwegian KLEMS database, July 2017.

in new or quality-enhanced capital assets, such as IT-hardware, or in intangible forms such as R&D capital.

Modern economic growth has been featured with the intensification of knowledge inputs across the world and over time. In particular, the past decades have witnessed the increased use of skilled labour and ICT capital in both the United States and European countries (Jorgenson *et al.*, 2005; Timmer *et al.*, 2010). One appealing explanation to this economic phenomenon is that complementarity may exist between the two knowledge inputs, namely, skilled labour and ICT capital.

If this complementary hypothesis holds, there should be a positive correlation between the input intensity of skilled labour and that of ICT capital over time. Moreover, from a bottom-up perspective, this positive correlation is expected to hold not only for the total economy, but also for the different sectors that make up it.

In the previous sections it has been demonstrated that the input intensity of skilled labour had been increasing for the total market economy of mainland Norway over the entire observed period (1997-2014); and for almost all the sectors, at least over the latter period (2008-2014). However, the input intensity of the knowledge-based capital revealed a diversified picture both across different capital assets, and among the different sectors.

To test the complementarity hypothesis by means of the Norwegian data, the sample correlation coefficients are calculated between different types of skilled labour and various knowledge-based capital as defined in this article, making use of the estimated time trend of input intensity as presented both for labour services share and for capital services share in value added in the previous sections.

The calculated results are presented in Table 5. Note that we have grouped IT-software and R&D together and define it as the Intellectual Property Products (IPP), given that the IPP capital does include among others IT-software and R&D, as categorized in the latest SNA (United Nations, 2009; Eurostat, 2013). In addition, the sample period is chosen as 2008-2014, because the quality of labour services data cross-classified by age, gender, education and industry is higher for this sub-period (2008-2014), compared to that before 2008 (Liu, 2017).

The first row of Table 5 shows that for the total market economy of mainland Norway, the sample correlation coefficient between the (total) knowledge-based capital (i.e. ICT (hardware + software) and R&D) and High Ed (short + long), High Ed-short, and High Ed-long, is 0.34, 0.23, and 0.41, respectively. Similarly, the sample correlation coefficient between ICT (hardware + software) capital, and High Ed (short + long), High Ed-short, and High Ed-long, is −0.79, −0.71, and −0.83, respectively.

As the results indicate, the hypothesis that there exists a complementarity relationship between the use of skilled labour and ICT capital is not supported by the Norwegian data, because many of the calculated correlation coefficients are negative between ICT (hardware + software) capital and different types of skilled labour, as shown by the last three columns in the right upper panel of Table 5.

On the other hand, a complementarity relationship is found suggestive between one type of highly skilled labour (i.e. High Ed-long) and the IPP capital (i.e. IT-software + R&D), which is reflected by the third column (in bold) in the left lower panel of Table 5. Moreover, the existence of a complementarity relationship between the use of one highly skilled labour (i.e. High Ed-long) and R&D capital is considered to be strongly suggestive, as the last column in the right lower panel of Table 5 is the only one in which all the calculated correlation coefficients are positive numbers (in bold) in Table 5.

It may be concluded that it is intangibles assets including IPP (i.e. IT-software + R&D), and particularly, it is R&D capital, rather than the ICT capital in its entirety (i.e. IT-hardware together with IT-software), combined with the employment of highly skilled labour (High Ed-long), that had been gaining growing importance during the recent economic

**Table 5: Correlation Coefficients Between Use of Skilled Labour and of Knowledge-Based Capital**

| | Knowledge-based capital (ICT (hardware+software) and R&D) | | | ICT capital (hardware+software) | | |
|---|---|---|---|---|---|---|
| | High Ed (short+long) | High Ed-short | High Ed-long | High Ed (short+long) | High Ed-Short | High Ed-long |
| Total market economy | 0.34 | 0.23 | 0.41 | -0.79 | -0.71 | -0.83 |
| ICT production (ELECOM) | -0.69 | -0.72 | -0.63 | -0.85 | -0.83 | -0.8 |
| Goods | | | | | | |
| Manufacturing (MEXELEC) | 0.74 | 0.68 | 0.78 | 0.66 | 0.61 | 0.70 |
| Other goods (OTHERG) | 0.47 | 0.45 | 0.48 | 0.34 | 0.33 | 0.34 |
| Services | | | | | | |
| Distribution (DISTR) | -0.90 | -0.91 | -0.83 | -0.90 | -0.86 | -0.92 |
| Finance and business (FINBU) | -0.43 | -0.73 | 0.27 | -0.34 | 0.41 | -0.90 |
| Personal (PERS) | -0.86 | -0.84 | -0.87 | -0.86 | -0.84 | -0.85 |

| | IPP Capital (IT-software and R&D) | | | R&D capital | | |
|---|---|---|---|---|---|---|
| | High Ed (short+long) | High Ed-Short | High Ed-long | High Ed (short+long) | High Ed-Short | High Ed-long |
| Total market economy | 0.91 | 0.82 | **0.95** | 0.73 | 0.62 | **0.79** |
| ICT production (ELECOM) | -0.26 | -0.24 | **-0.26** | 0.46 | 0.41 | **0.46** |
| Goods | | | | | | |
| Manufacturing (MEXELEC) | 0.76 | 0.70 | **0.81** | 0.60 | 0.55 | **0.64** |
| Other goods (OTHERG) | 0.32 | 0.31 | **0.31** | 0.39 | 0.37 | **0.40** |
| Services | | | | | | |
| Distribution (DISTR) | 0.38 | 0.27 | **0.57** | 0.25 | 0.12 | **0.50** |
| Finance and business (FINBU) | -0.04 | -0.75 | **0.79** | -0.06 | -0.74 | **0.75** |
| Personal (PERS) | 0.61 | 0.63 | **0.56** | 0.65 | 0.68 | **0.56** |

Source: Calculations are based on Norwegian KLEMS database, July 2017.

growth that had occurred in the market economy of mainland Norway.

## Conclusion

Drawing upon a newly constructed Norwegian KLEMS database, this article has studied the structural change and productivity in the market economy of mainland Norway over the period of 1997-2014. At the most general level an increasing share is found in output and employment of services at the expense of goods production, and services had become the largest sector in terms of both output and employment in the total market economy of mainland Norway.

In addition, over the entire period 1997-2014, productivity growth in (aggregate) goods production sector was higher than in (aggregate) services sector. All these findings largely confirm the trends that have been identified by many other studies (e.g. Kuznets, 1971; Maddison, 1980; Skoglund, 2013; Timmer *et al.*, 2010). However, when considering the changes between two selected sub-periods (1997-2006, and 2006-2014), productivity performance in the (aggregate) goods production sector was weaker in the first sub-period, while much stronger in the second, than in the (aggregate) services sector.

Moreover, more detailed sector analyses reveal very substantial differences both within the (aggregate) goods production sector and among the (aggregate) services sector, leaving the traditional distinction between goods and services outdated. In particular, the characterization of services as stagnant in terms of productivity growth and input structure is no longer valid.

With a decreasing share in both output and employment, a continuing productivity growth is found in the ICT production and manufacturing sectors. And even stronger productivity growth is observed for the second sub-period (2006-2014) for the manufacturing sector. In terms of intensification of knowledge inputs, the ICT production sector was the highest, while the manufacturing sector was among the highest in terms of R&D capital input intensity.

Despite an increase of its share in output, the other goods production sector revealed a trend of low productivity growth, and its average growth even decreased between sub-periods. Even with a steady increase over the latter period (2008-2014), the input intensity in both skilled labour and knowledge-based capital in this sector had been among the lowest.

The finance and business services sector had become highly intensive in both skilled labour and knowledge-based capital and experienced an increased share in employment while very weak productivity growth for the entire period. Nonetheless, as a large intermediate services provider, this sector had contributed positively to the overall MFP growth over the entire period as well as the first sub-period.

Personal services had revealed negative productivity growth and an increased share in employment over the period 1997-2014. This sector seems to epitomize a stagnant sector as described by Baumol (1967). On the other hand, this sector was highly skilled labour intensive, although its knowledge-based capital input intensity was among the lowest.

As for the distribution services sector, over the entire period, both the shares in output and employment had declined, but this sector had productivity growth even higher than the other goods production sector. It is true that this sector was a major engine of productivity growth alongside the ICT production and manufacturing sectors, for the first sub-period (1997-2006). In the second sub-period (2006-2014), however, this sector abruptly lost the momentum, leading to labour productivity growth becoming negative.

An increased share of skilled labour in value added is found for the total market economy of mainland Norway over the entire period 1997-2014, as well as for almost all the sectors, at least for the latter period (2008-2014). For the total market economy, the shares in value added of both IT-software and R&D capital increased, while those of IT-hardware decreased, for the entire period 1997-2014. With a few exceptions, this finding also holds for most of the sectors, at least for the latter period (2008-2014).

Finally, tests results indicate that the complementarity hypothesis between the use of ICT capital and skilled labour is not supported by the Norwegian data. But the existence of complementarity between the use of IPP capital and highly skilled labour is suggestive. Furthermore, the complementarity relationship between R&D capital and highly skilled labour is strongly suggestive based on the Norwegian data, which implies that intangible assets, combined with human capital, had been playing an increasingly important role in recent economic growth in the market economy of mainland Norway.

The findings may have a number of implications for both theoretical and empirical works in the future. For instance, since reliance conventionally on an aggregate representation of either goods production or services sector in its entirety does not make sense any more, greater attention should be paid to individual sector or even to detailed industries, with the view of better understanding the drivers of economic growth.

The new evidence of the existence of complementary relationship between the use of highly skilled labour and IPP capital in general, and R&D capital in particular (instead of ICT capital in its entirety as found in earlier studies) also calls for further investigation into the linkages among intangible capital investment, education and technological change that had been taking place in recent years in the market economy of mainland Norway.

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# Appendix

**Table A1: Labour Compensation a Percentage of Value Added in the Total Market Economy of Mainland Norway, by Type of Education (%)**

| | High Ed-short | | | High Ed-long | | | High Ed (short + long) | | | Total Labour | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1997 | 2008 | 2014 | 1997 | 2008 | 2014 | 1997 | 2008 | 2014 | 1997 | 2008 | 2014 |
| Total market economy | 12.9 | 14.1 | 15.0 | 5.3 | 6.6 | 8.1 | 18.2 | 20.7 | 23.1 | 69.8 | 67.0 | 66.5 |
| ICT production (ELECOM) | 11.7 | 23.1 | 24.1 | 4.7 | 12.6 | 14.7 | 16.4 | 35.7 | 38.9 | 63.9 | 69.2 | 69.4 |
| Goods | | | | | | | | | | | | |
| Manufacturing (MEXELEC) | 13.7 | 10.3 | 12.5 | 6.0 | 5.0 | 7.2 | 19.7 | 15.2 | 19.7 | 72.5 | 66.9 | 71.7 |
| Other goods (OTHERG) | 11.8 | 6.2 | 6.9 | 5.7 | 2.2 | 2.8 | 17.5 | 8.4 | 9.7 | 64.8 | 60.2 | 60.4 |
| Services | | | | | | | | | | | | |
| Distribution (DISTR) | 14.5 | 11.6 | 12.8 | 5.7 | 2.3 | 3.0 | 20.2 | 13.9 | 15.8 | 77.5 | 75.7 | 77.2 |
| Finance and business (FINBU) | 11.6 | 19.6 | 18.1 | 4.4 | 11.5 | 12.4 | 16.0 | 31.0 | 30.5 | 63.4 | 60.8 | 56.9 |
| Personal (PERS) | 13.6 | 19.2 | 22.3 | 4.4 | 9.6 | 11.2 | 18.0 | 28.9 | 33.6 | 73.1 | 79.9 | 82.4 |

Notes: Labour includes employees and self-employed.

Source: Calculations are based on Norwegian KLEMS database, July 2017.

**Table A2: Capital Compensation of Knowledge-Based Capital as a Percentage of Value Added in the Total Market Economy of Mainland Norway (%)**

| | IT-Hardware | | | It-Software | | | ICT (hardware + software | | | R&D | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1997 | 2008 | 2014 | 1997 | 2008 | 2014 | 1997 | 2008 | 2014 | 1997 | 2008 | 2014 |
| Total market economy | 3.1 | 2.5 | 1.9 | 0.5 | 1.2 | 1.6 | 3.6 | 3.7 | 3.4 | 2.5 | 2.5 | 3.0 |
| ICT production (ELECOM) | 17.5 | 10.3 | 9.7 | 0.6 | 4.1 | 2.8 | 18.1 | 14.4 | 12.5 | 8.5 | 8.9 | 8.8 |
| Goods | | | | | | | | | | | | |
| Manufacturing (MEXELEC) | 1.5 | 1.4 | 1.7 | 0.0 | 0.4 | 0.7 | 1.5 | 1.7 | 2.4 | 4.0 | 5.4 | 5.6 |
| Other goods (OTHERG) | 0.8 | 1.1 | 1.1 | 0.6 | 0.8 | 1.1 | 1.3 | 1.9 | 2.2 | 0.4 | 0.6 | 0.8 |
| Services | | | | | | | | | | | | |
| Distribution (DISTR) | 2.3 | 2.0 | 1.3 | 0.0 | 1.0 | 1.1 | 2.3 | 3.0 | 2.4 | 0.4 | 0.5 | 0.7 |
| Finance and business (FINBU) | 2.5 | 2.6 | 1.2 | 1.6 | 1.7 | 2.5 | 4.1 | 4.3 | 3.8 | 4.1 | 2.8 | 3.9 |
| Personal (PERS) | 2.0 | 1.9 | 1.1 | 0.0 | 0.2 | 0.2 | 2.0 | 2.1 | 1.3 | 0.2 | 0.2 | 0.4 |

Source: Calculations are based on Norwegian KLEMS database, July 2017.

# The UK and Western Productivity Puzzle: Does Arthur Lewis Hold the Key?

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Abstract

A new explanation for the UK and developed world productivity puzzle is proposed which grafts the Lewis (1954) model onto a standard Solow growth model. What is called here the neo-Lewis model is identical to the Solow model in good times. But in bad times foreign demand for a country's exports is constrained below potential supply. This makes labour productivity growth depend negatively on the growth of labour input and positively on the growth of export demand.The predictions of the neo-Lewis model are tested on data for 23 countries (20 EU and 3 non-EU) and find support. It is also argued that the neo-Lewis model can explain the fall in TFP growth, in the UK and elsewhere, after 2007. This proposition also finds support when tested on a larger sample of 52 countries.

Labour productivity has barely grown in the UK since the last boom ended at the beginning of 2008. The decade or more of productivity stagnation since then is even more surprising given that before the crisis the UK's productivity growth was one of the highest amongst the advanced economies. The Office for Budget Responsibility (2017) has recently estimated that up to 2017 the decline in labour productivity growth relative to the pre-crisis trend has already caused a loss of about 21 per cent in GDP

1 Nicholas Oulton is an Associate at the Centre for Macroeconomics and a Fellow of the National Institute of Economic and Social Research (NIESR) and the Economic Statistics Centre of Excellence (ESCOE). An early version of this paper was presented at a seminar in the Department of Economics, University of Queensland, in October 2017. I am grateful to participants, particularly to Alicia Rambaldi, for useful comments. A subsequent version was presented at a Centre for Macroeconomics (LSE) seminar in March 2018 and at the World KLEMS conference at Harvard in June 2018. The present version has benefited from comments by Bill Martin, Andrew Gurney, Steve Millard, Rebecca Riley, Bob Rowthorn, Martin Weale, Silvana Tenreyro, Jonathan Haskel, Francesco Caselli, Charlie Bean, two anonymous referees and Andrew Sharpe. I am particularly grateful to Bill Martin for a lengthy comment on the previous version (Martin, 2018) as a result of which the paper has been extensively revised and now includes a section on TFP. Email: n.oulton@lse.ac.uk.

per hour. By contrast the OECD recently projected that after Brexit the UK's GDP per head will be 3 per cent lower by 2030 than it would have been if the UK remained in the EU (OECD 2016, central scenario). The productivity puzzle is therefore the greatest challenge facing UK economic policy, and far larger than Brexit.

On the other hand, the performance of the UK labour market has been excellent. True, as the Great Recession began unemployment rose rapidly above its pre-crisis level but it has since declined and at 4.0 per cent in 2018Q4 is now lower than at the peak of the boom. Employment too took a hit during the recession itself, which saw a fall in GDP of over 6 per cent from the peak to the trough, but it has subsequently (2009-2015) grown as fast as during the boom. In summary, an excellent labour market performance has accompanied an unprecedentedly poor productivity performance. This is the twofold puzzle of the UK economy since the Great Recession.

The UK productivity puzzle has been much discussed and much reviewed (Oulton 2016a; Haldane 2017; Tenreyro 2018), but without any consensus so far being reached. Here I propose a new explanation based on insights gained from the work of Arthur Lewis. Briefly, the argument is as follows. After the recession began, many countries, particularly in Europe, suffered from a deficiency in foreign demand for their exports. This situation has persisted into the recovery period, after GDP stopped actually falling, The slower growth of exports led to slower growth of GDP. The effect of this on labour productivity depended on the nature of labour market institutions.

In the UK, for example, labour input has continued to rise at the same rate after the crisis as it had done before. This was possible because of the flexible labour market which allowed workers to price themselves into jobs. With the same growth of labour input but slower growth of GDP post-crisis, the growth rate of labour productivity necessarily fell. Both before and after the crisis the bulk of the increase in labour input was due to immigration. In continental Europe by contrast labour markets are less flexible. So the growth of labour input was constrained; in fact labour input declined in most countries. Consequently the slowdown in labour productivity was less pronounced in continental Europe than in the UK.[2]

This explanation puts the blame for

2 See Online Appendix B for discussion of the differences between UK and European labour markets (available at: http://www.csls.ca/ipm/36/Oulton_appendix.pdf).

the slowdown squarely on the Great Recession. However the accepted view now seems to be that continuing low productivity growth has little or nothing to do with the recession. It is instead explained by a decline in the growth rate of TFP which predated the crisis. This decline is partly exogenous, due to the fading effects of the ICT revolution. But it is also partly endogenous, due to weaknesses in the competitive process, which again predate the recession (Bergaud *et al.*, 2014; Fernald, 2015; Cette *et al.*, 2016; Antolin-Diaz *et al.*, 2017). This has been compounded in some countries by failure to adopt the type of structural reforms long advocated by the OECD. These authors have given good reasons for expecting TFP growth to be lower in future than it was in the United States in the glory days of the ICT revolution. And there does seem to be evidence that the competitive process has been weakening; for example, laggard firms seem to have increasing difficulty in catching up to the leading ones (see e.g. Andrews *et al.*, 2015, and Cette *et al.*, 2018).

But this is not the whole story. The collapse in TFP growth, particularly in Europe, is too large to be explained by these forces and moreover the timing is suspicious. Instead, it is argued that the Great Recession itself did significant damage to TFP growth through a number of channels. There is industry-based evidence for increasing returns: an industry's TFP growth rate is higher when the economy is expanding more rapidly (Hall, 1988; Caballero and Lyons, 1990; Bartelsman *et al.*, 1994; and Oulton, 1996). So raising the growth rate of GDP would also raise the growth rate of TFP and consequently of labour productivity.

The plan of the article is as follows. The first section reviews the UK's performance since 2000, compared with other EU and non-EU countries (Australia, Canada, and the United States) over the same period. The second section considers whether the standard growth model due to Solow (1956) can explain the data. This is a reasonable question to ask of the model, at least for the UK, since it assumes full employment which is what we now have. I conclude that the Solow model cannot explain the UK experience since 2007. The third section sets out the Lewis (1954) model of growth with unlimited supplies of labour in a dualistic economy. Section 4 construct what I call the neo-Lewis model in which the spirit of the original model is (I hope) preserved. It turns out that the neo-Lewis model is just the same as the Solow model, except in a "bad regime" when export demand is below potential export supply. In section

5 the neo-Lewis model is confronted with the facts as revealed in the latest (September 2017) release of the EU KLEMS dataset. Then in section 6 the orthodox view of the labour productivity slowdown in the U.K. and elsewhere, namely a slowdown in TFP growth which started before the recession, is critically examined. It is argued that the pre-crisis slowdown is too small to account for the collapse in TFP growth which has occurred since 2007. Instead, I make the case that the bulk of the slowdown, particularly outside the United States, is due to the recession itself. The mechanism is increasing returns, working in reverse. Section 7 concludes.

## The UK Productivity Puzzle

### The UK Economy: the Twofold Puzzle

#### GDP and Labour Productivity

GDP in the UK peaked in 2008Q1 and then fell for 5 consecutive quarters. The cumulative fall in output from peak to trough in 2009Q2 was 6.1 per cent. From 2009Q3 GDP began to grow again and growth has been positive in nearly every quarter up to the end of 2018. But in 2017Q3 GDP was only 9.7 per cent higher than at the previous peak nearly ten years earlier, in other words the growth rate of GDP since 2008Q1 was only 0.98 per cent per year.[3]

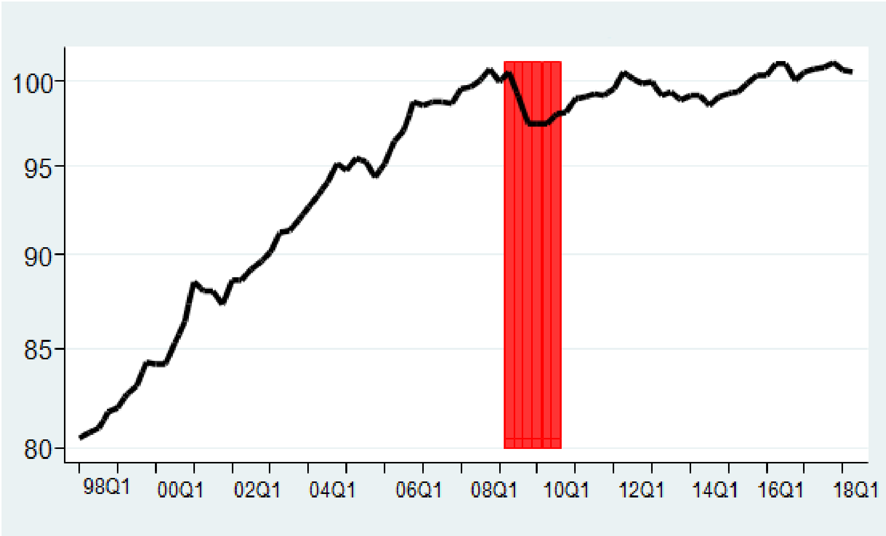
The course of labour productivity since 1997Q1 is shown in Chart 1. Productivity was growing strongly up till 2008Q1. It fell sharply during the Great Recession which was not surprising given the large fall in GDP and experience in previous recessions. What has come as a great surprise is that though productivity growth has been generally positive since the trough it has been so slow that the productivity level in 2017Q2 was still below the previous peak in 2007Q4. So since the peak nearly ten years earlier productivity growth has been virtually zero, even though the recession proper only lasted for 5 quarters. This is the productivity puzzle.

#### The Labour Market

Unemployment was 5.2 per cent at the end of the boom in 2007Q4. It then rose sharply to peak at 8.4 per cent in 2011Q4. But since then it has fallen steadily to stand at 4.3 per cent in 2017Q3 (Chart 2); in 2018Q4 it stood at 4.0 per cent. This fall in unemployment during the recovery from the Great Recession coincided with a rapid rise in employment which rose

3 Source: Office for National Statistics, https://www.ons.gov.uk/economy/grossdomesticproductgdp/timeseries/abmi/pn2, accessed on 10/12/2017. Seasonally adjusted, CVM, £m. Variable cdid: ABMI.

**Chart 1: GDP per Hour in the UK, 1997Q1-2017Q2 (Index, 2008Q1 = 100)**




Note: Red bar marks Great Recession.
Source: Office for National Statistics

at 0.95 per cent per year from 2000 to 2007. Employment growth slowed slightly during and after the recession, but still grew at 0.85 per cent per year from 2007 to 2016 (Chart 3 and Table 1). Between 2000 and 2016 an additional 4.2 million people entered employment.

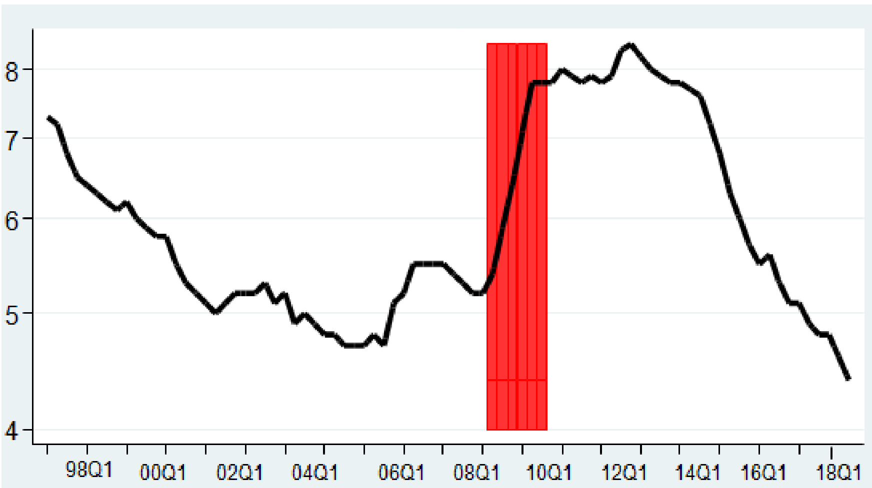
How is it possible for the UK, with a birth rate below replacement level as is typical in Europe, to increase employment at such a rapid rate? The answer of course is immigration. From 2000 to 2007 employment amongst the UK-born grew at only 0.32 per cent per year slowing to 0.18 per cent afterwards. By contrast employment of the foreign-born grew at 6.67 per cent per year during the boom and at a still impressive 4.85 per cent per year in the subsequent period (Table 1). If we break down the foreign-born into those born in the EU27 and those born elsewhere we see that since 2007 there has been no slowdown in the growth of those born in the EU but a halving of the growth rate of those born outside the EU. Amongst the EU-born there has been a large change in composition: those born in the accession countries (the A10) now account for 58 per cent of the EU stock. But despite the rapid growth of migrants from the EU, migrants from the rest of the world still constitute 58 per cent of the foreign-born. In all, the foreign-born accounted for 17 per cent of UK employment in 2016, up from 8 per cent in 2000. And the foreign-born accounted for around three quarters (76.6 per cent) of the increase in employment in

**Table 1: UK Employment by Country of Birth, Millions**

| | Total | UK-born | Foreign-born | of which: EU27 | non-EU |
|---|---|---|---|---|---|
| 1997 | 26.523 | 24.547 | 1.975 | 0.651 | 1.324 |
| 1998 | 26.794 | 24.712 | 2.080 | 0.700 | 1.380 |
| 1999 | 27.167 | 25.050 | 2.116 | 0.697 | 1.419 |
| 2000 | 27.483 | 25.272 | 2.210 | 0.710 | 1.500 |
| 2001 | 27.711 | 25.397 | 2.311 | 0.725 | 1.586 |
| 2002 | 27.944 | 25.484 | 2.457 | 0.738 | 1.719 |
| 2003 | 28.223 | 25.656 | 2.565 | 0.752 | 1.813 |
| 2004 | 28.533 | 25.825 | 2.707 | 0.784 | 1.923 |
| 2005 | 28.853 | 25.940 | 2.911 | 0.884 | 2.027 |
| 2006 | 29.140 | 25.899 | 3.238 | 1.017 | 2.221 |
| 2007 | 29.379 | 25.846 | 3.525 | 1.174 | 2.351 |
| 2008 | 29.628 | 25.843 | 3.780 | 1.288 | 2.492 |
| 2009 | 29.154 | 25.358 | 3.788 | 1.288 | 2.501 |
| 2010 | 29.227 | 25.336 | 3.886 | 1.354 | 2.532 |
| 2011 | 29.375 | 25.218 | 4.147 | 1.498 | 2.649 |
| 2012 | 29.695 | 25.419 | 4.268 | 1.570 | 2.698 |
| 2013 | 30.042 | 25.591 | 4.437 | 1.652 | 2.785 |
| 2014 | 30.752 | 25.992 | 4.749 | 1.834 | 2.915 |
| 2015 | 31.281 | 26.214 | 5.050 | 2.061 | 2.989 |
| 2016 | 31.725 | 26.266 | 5.453 | 2.303 | 3.150 |
| 2017 (Jan-June) | 31.931 | 26.267 | 5.660 | 2.366 | 3.294 |
| Growth rates, % pa | | | | | |
| 2000-2007 | 0.95 | 0.32 | 6.67 | 7.18 | 6.42 |
| 2007-2016 | 0.85 | 0.18 | 4.85 | 7.49 | 3.25 |

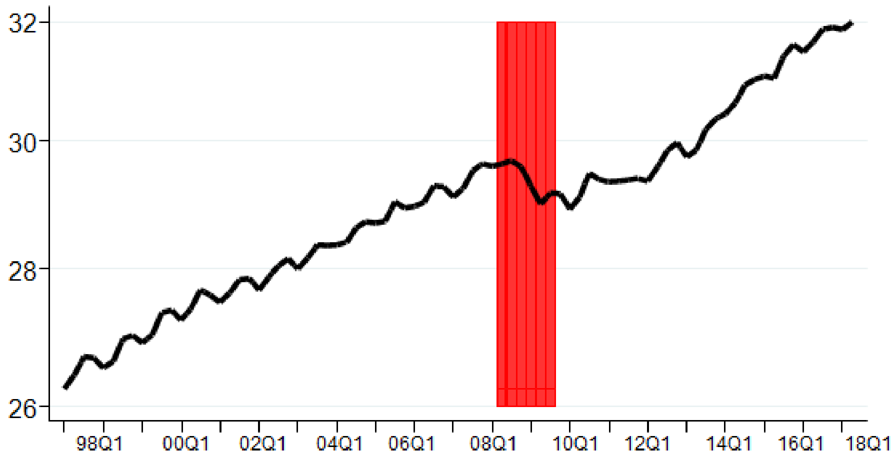
Source: ONS, "Employment by country of birth and nationality", August 2017 [emp06aug2017.xlsx]
Note: Annual averages of quarterly levels.

**Chart 2: Unemployment Rate in the UK, 1997Q1-2017Q2 (per cent)**




Note: Red bar marks Great Recession
Source: Office for National Statistics, "Labour Productivity: Apr to June 2017: Historical Estimates"[lprodhist.xlsx]

**Chart 3: Employment in the UK, 1997Q1-2017Q2 (millions)**




Note: Red bar marks Great Recession
Source: Office for National Statistics

the UK between 2000 and 2016, with this contribution split about equally between the EU27-born and the non-EU born (Table 1).[4]

Alongside employment, total hours worked also increased rapidly both before and after 2007. From 2000 to 2007 hours rose at 0.72 per cent per year and from 2007 to 2016 at 0.87 per cent per year. So not only did total hours rise more rapidly after the boom ended, but hours worked per worker also increased slightly.[5] In other words, it was not the case that the increase in employment was balanced by a fall in average hours worked by the typical worker.

## International Comparisons

### The Data

Most of the data used in this section come from the latest release of the EU KLEMS dataset (September 2017; available at www.euklems.net). These data go up to 2015 while in previous releases the data ended in 2007. For most countries the data go back to 1995 but most data are from 2000 as this was a cyclical peak in the United States (the end of the dot-com bubble) and a "growth pause" in other countries like the UK. The

4 These statistics are from the ONS, "Employment by country of birth and nationality", August 2017 ( a spreadsheet entitled emp06aug2017.xlsx) and are for country of birth. The ONS also publishes a breakdown of employment by nationality which shows substantially lower figures for foreigners. But this is because many of the foreign-born become British citizens. For present purposes, country of birth is the relevant measure.

5 Office for National Statistics, Labour Force Survey, downloaded on 10/12/2107 from https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/timeseries/ybus/lms. Variable cdid: YBUS.

great advantage of the EU KLEMS dataset is that labour productivity, hours worked, investment, capital services, human capital, and TFP are measured on a consistent basis across countries. In particular capital services (as well as capital stocks) are provided. Capital services is the appropriate measure for productivity analysis (OECD 2009) though unfortunately it is not a mandatory part of the System of National Accounts and so not provided routinely by national statistical agencies.[6]

A total of 29 countries are included in the latest release including (despite the name of the dataset) the US. In previous releases Australia, Canada and Japan were also included but are omitted from the September 2017 release. I have added Australia and Canada to the data used here since these have constructed their own productivity accounts using very similar principles to EU KLEMS.[7] However for these two countries the unit of analysis is the market or business sector while for the rest it is the whole economy. Japan is still omitted since recent productivity accounts for this country would not be found. I have also excluded six countries due to their very small size: Cyprus, Estonia, Latvia, Lithuania, Luxembourg and Malta. Most data are missing for Croatia.

In summary, for the countries included here, and for the whole period 2000-2015, twenty-four have data on GDP, 23 on labour productivity and hours worked, 15 have data on capital intensity and 14 on TFP.

### Results

Table 2 shows the pattern of growth before and after the crisis. GDP growth declined in all 24 countries after 2007 by on average 2.69 percentage points. Greece, Finland, Italy, Portugal and Slovenia had negative growth in GDP post-crisis, i.e. in 2015 their level of GDP was still below the 2007 level. GDP growth in the UK was above the mean post-crisis: better than in France, and a bit less than in Germany and the United States.

Before the crisis, the growth of hours in the UK was below the cross-country mean though faster than

6 The EUKLEMS capital services measure is constructed out of asset stocks in the national accounts of the countries who provided these data. EU KLEMS constructs capital services as a rental-price-weighted aggregate over these stocks. As the website notes, there is a possible inconsistency here as each country uses its own assumptions about depreciation to estimate stocks while EU KLEMS uses a common set of depreciation rates (very similar to the rates used by the U.S. BEA) to estimate rental prices.

7 Data for Canada are from Statistics Canada, downloaded on 17/11/2017 from http://www.statcan.gc.ca/eng/start, a spreadsheet named cansim-3830021.xls. For Australia they are from Australian Bureau of Statistics, downloaded on 17/11/2017 from http://www.abs.gov.au/AusStats/ABS@.nsf/MF/5260.0.55.002, a spreadsheet named 52600550022016.xls.

in France, Germany, Italy and the United States. After the crisis hours declined in all countries except Denmark, Germany, Romania and Sweden. In the UK hours grew slightly faster after 2007 than before. Hours grew at a faster rate in the UK post-crisis than in any other country except Canada and Sweden.

Before the crisis labour productivity was growing more rapidly in the UK than in most of the advanced countries, faster than in Canada, France, Denmark, Germany, Ireland, Italy, the Netherlands and the United States, though slower than in Australia, Finland and Sweden. Some emerging markets like Bulgaria, Czech Republic, Romania, Slovakia, Slovenia and even Greece did better in 2000-2007 which likely reflects the realization of their catch-up potential. After the crisis labour productivity growth fell in 18 out of 22 countries, on average by 1.34 percentage points. In the UK growth was slower than in any other country except Finland and Greece where growth was negative. In these two countries GDP growth was also negative.

The growth of capital intensity fell in 9 out of 15 countries after the crisis. In the UK it grew at only 0.22 per cent pa after 2007. This compares with 1.04 per cent pa in Germany, 1.27 per cent in France and 0.96 per cent in the United States.

In summary, there is no striking difference between the UK and these other countries in GDP growth post-crisis. What is striking about the UK though is labour productivity growth (close to zero) and the growth of hours (comparatively rapid). The UK also saw the largest decline in the growth of capital intensity of any country in the dataset.

One other feature stands out in Table 2. After 2007 TFP growth fell in 12 out of 14 countries. In the UK the growth rate fell by 1.3 percentage points. The only exceptions to this pattern were Canada and Italy where TFP growth has been negative since 2000. TFP levels actually fell in 13 countries. In TFP the United States performed best after 2007 but even here the growth rate declined by 0.54 percentage points; the level of TFP in the United States was only a bit over 1 per cent higher in 2015 than it had been in 2007.

## Can the Solow Model Explain the Puzzle?

Let us consider whether the textbook model of economic growth due to Solow (1956), still the workhorse model in many applications, can help to explain what has been happening in the UK in the boom, the Great Recession and the subsequent recovery. This section sets out the theory and

**Table 2: Growth Rates of GDP, Hours, and Labour Productivity in 24 Countries, 2000-2007 and 2007-2015 (% per year)**

| | | GDP (Y) | | Hours (L) | | Labour Productivity (y) | |
|---|---|---|---|---|---|---|---|
| Country | Code | 2000-2007 | 2007-2015 | 2000-2007 | 2007-2015 | 2000-2007 | 2007-2015 |
| Austria | AT | 2.31 | 0.57 | 0.37 | -0.12 | 1.94 | 0.7 |
| Australia | AU | 3.71 | 2.51 | 1.79 | 0.6 | 1.92 | 1.91 |
| Belgium | BE | 2.11 | 0.82 | 0.73 | 0.43 | 1.38 | 0.39 |
| Bulgaria | BG | 5.73 | 1.56 | 2.13 | -1.06 | 3.61 | 2.62 |
| Canada | CA | 2.47 | 1.28 | 1.81 | 0.81 | 0.66 | 0.47 |
| Czech Rep. | CZ | 4.38 | 0.59 | -0.19 | 0.01 | 4.58 | 0.61 |
| Germany | DE | 1.57 | 0.79 | -0.13 | 0.31 | 1.70 | 0.48 |
| Denmark | DK | 1.31 | 0.37 | 0.47 | -0.54 | 0.84 | 0.91 |
| Greece | EL | 3.74 | -3.65 | 1.54 | -2.67 | 2.20 | -0.97 |
| Spain | ES | 3.37 | -0.41 | 3.07 | -1.79 | 0.30 | 1.38 |
| Finland | FI | 2.97 | -0.84 | 0.82 | -0.42 | 2.15 | -0.42 |
| France | FR | 1.82 | 0.55 | 0.55 | 0.01 | 1.27 | 0.54 |
| Hungary | HU | 3.51 | 0.46 | . | . | . | . |
| Ireland* | IE | 4.72 | 0.04 | 2.83 | -2.48 | 1.89 | 2.52 |
| Italy | IT | 1.13 | -0.96 | 1.09 | -1.08 | 0.04 | 0.12 |
| Netherlands | NL | 1.96 | 0.57 | 0.63 | 0.00 | 1.34 | 0.57 |
| Poland** | PL | 5.40 | 3.14 | 2.62 | 0.48 | 2.78 | 2.66 |
| Portugal | PT | 1.38 | -0.49 | -0.07 | -1.47 | 1.45 | 0.98 |
| Romania | RO | 6.03 | 1.64 | -1.81 | -1.61 | 7.84 | 3.25 |
| Sweden | SE | 2.94 | 1.25 | 0.46 | 0.76 | 2.49 | 0.49 |
| Slovenia | SI | 4.43 | -0.04 | 0.46 | -0.20 | 3.97 | 0.16 |
| Slovakia | SK | 6.03 | 2.09 | 0.84 | 0.25 | 5.19 | 1.84 |
| United Kingdom | UK | 2.61 | 0.78 | 0.69 | 0.70 | 1.91 | 0.08 |
| United States | US | 2.08 | 0.85 | 0.37 | 0.23 | 1.70 | 0.63 |
| | | | | | | | |
| Mean (unweighted) | | 3.14 | 0.56 | 0.83 | -0.38 | 2.29 | 0.95 |
| Min | | 1.13 | -3.65 | -1.81 | -2.67 | 0.04 | -0.97 |
| Max | | 6.03 | 3.14 | 3.07 | 0.81 | 7.84 | 3.25 |

Source: For all countries except Canada and Australia: EU KLEMS, September 2017 release (www.euklems.net). Data for Canada are from Statistics Canada, downloaded on 17/11/2017 from http://www.statcan.gc.ca/eng/start, a spreadsheet named cansim-3830021.xls. Australian data are from Australian Bureau of Statistics, downloaded on 17/11/2017 from http://www.abs.gov.au/AusStats/ABS@.nsf/MF/5260.0.55.002, a spreadsheet named 52600550022016.xls.
Note: For Canada and Australia, figures are for the market sector. For all other countries, figures are for the whole economy.
∗ Ireland: 2007-2014, not 2007-2015, since Irish GDP in 2015 was distorted by tax manipulation by multinationals.
∗∗ Poland: 2003-2007, not 2000-2007, due to missing values in 2000, 2001 and 2002.

**Table 3: Growth Rates of Capital Intensity, TFP, and Real Foreign Demand in 24 Countries, 2000-2007 and 2007-2015 (% per year)**

| | | Capital intensity (k) | | TFP (A) | | Real Foreign Demand (Z) | |
|---|---|---|---|---|---|---|---|
| Country | Code | 2000-2007 | 2007-2015 | 2000-2007 | 2007-2015 | 2000-2007 | 2007-2015 |
| Austria | AT | 2.12 | 1.54 | 0.89 | -0.02 | 3.34 | 0.50 |
| Australia | AU | 3.55 | 3.76 | 0.21 | -0.01 | 5.34 | 2.63 |
| Belgium | BE | 2.03 | 0.69 | 0.47 | -0.1 | 2.63 | 0.44 |
| Bulgaria | BG | . | . | . | . | 3.92 | -0.45 |
| Canada | CA | 2.12 | 1.46 | -0.23 | -0.13 | 2.17 | 0.17 |
| Czech Rep. | CZ | 4.10 | 4.32 | 2.20 | -1.67 | . | . |
| Germany | DE | 2.45 | 1.04 | 0.87 | -0.07 | 3.40 | 0.49 |
| Denmark | DK | 1.58 | 2.43 | 0.01 | -0.39 | 2.86 | 0.53 |
| Greece | EL | . | . | . | . | 5.00 | 0.92 |
| Spain | ES | 1.44 | 2.91 | -0.39 | -0.44 | 2.37 | 0.27 |
| Finland | FI | 0.84 | 0.94 | 1.66 | -0.94 | 3.35 | 0.40 |
| France | FR | 2.30 | 1.27 | 0.23 | -0.35 | 2.94 | 0.29 |
| Hungary | HU | . | . | . | . | 3.83 | 0.38 |
| Ireland* | IE | . | . | . | . | 2.22 | 0.19 |
| Italy | IT | 1.46 | 1.66 | -0.70 | -0.51 | 3.28 | 0.43 |
| Netherlands | NL | 0.82 | 0.80 | . | 0.1 | 2.66 | 0.46 |
| Poland** | PL | . | . | . | . | 3.57 | 0.20 |
| Portugal | PT | . | . | . | . | 3.02 | -0.29 |
| Romania | RO | . | . | . | . | 3.52 | -0.03 |
| Sweden | SE | 2.85 | 1.80 | -0.14 | -0.73 | 3.22 | 0.36 |
| Slovenia | SI | . | . | . | . | 3.61 | 0.21 |
| Slovakia | SK | . | 3.36 | . | 0.07 | 3.79 | 0.40 |
| United Kingdom | UK | 1.86 | 0.22 | 1.01 | -0.3 | 2.78 | 0.59 |
| United States | US | 2.30 | 0.96 | 0.69 | 0.15 | 3.08 | 1.25 |
| Mean (unweighted) | | 2.12 | 1.82 | 0.48 | -0.33 | 3.38 | 0.44 |
| Min | | 0.82 | 0.22 | -0.70 | -1.67 | 2.17 | -0.45 |
| Max | | 4.10 | 4.32 | 2.20 | 0.15 | 5.47 | 2.63 |

Source: For all countries except Canada and Australia: EU KLEMS, September 2017 release (www.euklems.net). Data for Canada are from Statistics Canada, downloaded on 17/11/2017 from http://www.statcan.gc.ca/eng/start, a spreadsheet named cansim-3830021.xls. Australian data are from Australian Bureau of Statistics, downloaded on 17/11/2017 from http://www.abs.gov.au/AusStats/ABS@.nsf/MF/5260.0.55.002, a spreadsheet named 52600550022016.xls. Foreign demand: Export-Weighted Imports (EWI) from NIESR's NiGEM database.

Note: For Canada and Australia, figures are for the market sector. For all other countries, figures are for the whole economy. Real foreign demand (Z) for each country is measured by the export-weighted imports (EWI) of its trading partners in US dollars, deflated by the US GDP deflator (see text).

∗ Ireland: 2007-2014, not 2007-2015, since Irish GDP in 2015 was distorted by tax manipulation by multinationals.

∗∗ Poland: 2003-2007, not 2000-2007, due to missing values in 2000, 2001 and 2002.

then discusses its application to the UK.

## Theory

The aggregate production function, assumed to be constant returns to scale and for simplicity to take the Cobb-Douglas form, is

$$Y = AK^{\alpha}L^{1-\alpha}$$

$$0 < \alpha < 1$$

or

$$y = Ak^{\alpha} \quad (1)$$

where $y := Y/L$ and $k := K/L$. Here $Y$ is output (GDP), $A$ is the level of TFP, $L$ is labour (hours), assumed to be growing at the rate $n$, $K$ is capital, $y$ is output per unit of labour (productivity), $k$ is the capital-labour ratio (capital intensity) and the parameter $\alpha$ can be identified with the share of capital; the symbol ":=" means "is defined to be". Capital accumulates in accordance with the following law:

$$\dot{K} = sY - \delta K \quad (2)$$

Here $s$ $(= I/Y)$ is the investment ratio and $\delta$ is the depreciation rate, both assumed constant. Using (1) we can rewrite this as

$$\widehat{k} = sAk^{\alpha-1} - \delta - \widehat{L} \quad (3)$$

where a hat ($\wedge$) denote a growth rate. e.g. $\widehat{y} = \dot{y}/y$. The growth rate labour of productivity is

$$\widehat{y} = \widehat{A} + \alpha\widehat{k} \quad (4)$$

Equations (3) and (4) constitute the short run dynamics of the model. We can use them to solve for the paths of $y$ and $k$, given the initial level of $k$ and the path of L.

As Solow showed, the model possesses a steady state where the long run growth rate of GDP is:

$$\widehat{Y}^{*} = \frac{\widehat{A}}{1-\alpha} + n \quad (5)$$

Here $n$ is the growth rate of labour, assumed to be constant in the steady state, and a star ($*$) denotes the steady state. The steady state growth rate of GDP per hour (productivity), denoted by $g$, which is also the steady state growth rate of capital intensity ($k$), is therefore

$$g := \widehat{y^{*}} = \widehat{k^{*}} = \frac{\widehat{A}}{1-\alpha} \quad (6)$$

Note that the growth rate of hours ($n$) has no effect on the long run growth rate of productivity or of capital intensity.

## Application to the UK

Suppose now we consider an economy in a long run steady state as described by equation (6) which is now subject to a labour supply shock, an unexpected one-off rise in the labour supply with no change in any of the parameters. This is a standard exercise in the manipulation of the Solow growth model where we seek to characterise the transition path from one equilibrium to another. The increase in the labour supply lowers the capital-labour ratio. So the marginal product of labour falls as does the real wage; the latter change is necessary to maintain full employment. The steady state growth rate and level of productivity are unchanged. So after the (instantaneous) fall in the capital-labour ratio the capital stock must grow more rapidly than before for a while, in order to restore the capital-labour ratio to its long run level; there is an incentive to do this because the marginal product of capital has risen. Labour productivity and the real wage must also grow more rapidly for a while. This process, an investment boom does not sound much like what has been happening in the UK since 2007. We therefore turn now to an alternative model of growth developed by Arthur Lewis.

## The Lewis Model of Development in a Dual Economy

In 1954, Arthur Lewis published a seminal article on economic development in a dual economy (Lewis, 1954)[8]. His vision was based on the colonial economies of his own day in which a small modern, capitalist sector is embedded in a larger economy which uses pre-modern technology, the subsistence sector. The capitalist sector uses modern technology and has high average labour productivity while in the subsistence sector average productivity is low. The subsistence sector can be identified with agriculture though Lewis argued it could be extended to include petty traders and the servants of the well-to-do. He argued that in the subsistence sector the marginal product of labour is zero so there is surplus labour. People in the subsistence sector can be attracted to work in the capitalist sector by paying a wage which gives a (probably small) premium over the subsistence level of income; the latter is determined either by the average productivity of labour in the subsistence sector or by convention. This process can continue and the capitalist sector can expand till the surplus labour is exhausted.

We can formalize the Lewis model by assuming that in the capitalist sector a production function of the Solow type applies: see equation (1). Technical progress is assumed to be zero in the subsistence sector. The real wage ($w$) in the capitalist sector is a constant, determined by the subsistence

8 See Gollin (2014) for a modern assessment.

level of income plus some premium necessary to cover the costs of migration out of the subsistence sector. Capitalists set the real wage equal to the marginal product of labour:

$$w = (1-\alpha)AK^{\alpha}L^{-\alpha} = (1-\alpha)Ak^{\alpha} \tag{7}$$

Migration from the subsistence sector keeps the real wage constant:

$$\widehat{w} = \widehat{A} + \alpha\widehat{k} = 0 \tag{8}$$

which implies that

$$\begin{gathered} \widehat{k} = -\widehat{A}/\alpha \leq 0 \\ \text{if } \widehat{A} \geq 0 \end{gathered} \tag{9}$$

(Lewis (1954) generally takes $\widehat{A} = 0$ though he certainly envisaged the possibility of technical progress). Consequently in the capitalist sector

$$\widehat{y} = \widehat{A} + \alpha\widehat{k} = \widehat{A} - \widehat{A} = 0 \tag{10}$$

i.e. labour productivity growth is zero: any technical progress is offset by falling capital intensity.

In the Lewis model, as long as unlimited supplies of labour last, growth in the capitalist sector is driven by demand for the products of this sector. Lewis is not very explicit about this, but one interpretation is that the capitalist sector is producing for export, e.g. the products of mines, plantations, or labour-intensive manufacturing, as in the export-processing zones later established by many developing countries, for which domestic demand is insignificant. So the model can be completed by adding an equation for demand and a market-clearing condition:

$$\begin{gathered} Y^d = g(Z) = \gamma Z^{\theta} \\ \gamma > 0, \theta > 0 \end{gathered} \tag{11}$$

where $\mathrm{Y^d}$ is foreign demand for the country's exports and Z is world demand. I have picked a simple functional form which will be useful below. The market-clearing condition is

$$Y = Y^d \tag{12}$$

Then the long run growth rate of output in the capitalist sector, as long as labour supplies last, is given by $\theta\widehat{Z}$ and this equals the growth rate of the capitalist labour force:

$$\widehat{Y} = \widehat{A} + \alpha\widehat{k} + \widehat{L} = \widehat{L} = \theta\widehat{Z} \tag{13}$$

using (11).

The Lewis model, unlike the Solow model, does not make truly long run predictions about growth, since the surplus labour which drives the model will eventually be exhausted. After that point Lewis expected growth to be determined by what he called the "neo-classical" model, by which he likely meant something like the Solow model though the latter was not to be published until two years after his own. If the Solow model applies after surplus labour is exhausted, then technical progress has to be the driver of growth in the long run.

If despite this caveat we compare the predictions of the two models we can note the following contrasts:

- In the Lewis model, growth is the opposite of "inclusive." Due to the expansion of the capitalist sector GDP and profits rise but the workers receive no benefit: their real wages are constant. In the Solow model, the rising tide lifts all boats.
- This difference in the conclusions is driven by the different assumptions about labour. In the Solow model, growth of the labour force is exogenous, in the Lewis model, it is endogenous (at least in the capitalist sector) and driven entirely by the demand of employers which in turn is driven by foreign demand.

## The Neo-Lewis Model

How can the Lewis model, whatever its merits as a model of growth in a dual economy, have any application to a developed economy like the UK? The answer is that we can consider the whole UK economy like the capitalist sector of the Lewis model. The "subsistence" sector is now the rest of the world. The UK economy can draw on the rest of the world to augment its own home-grown labour.

The Lewis model, at least in my interpretation, has two essential elements. First, demand for exports is driven by demand in the rest of the world; second, labour input is endogenous and driven by the demands of employers. In what follows, which is called the neo-Lewis model, the first element is maintained but it is then necessary to explain how export demand determines demand for the remainder of UK output. The second element is dropped since it seems unrealistic to claim that labour input is determined entirely by employers. It is true that UK employers nowadays actively recruit overseas but immigration has its own dynamic, driven by conditions in the sending countries as well as differences in the receptivity of the possible destination countries (more on this below).

### The Model

The economy produces a single good which can be consumed, invested or exported. A different consumer good can be imported. The size and growth rate of the labour force are exogenous. Goods and labour markets always clear (full employment). I make the small economy assumption that the terms of trade and foreign demand for domestic output are exogenous.

#### Production, Investment and Capital

The production and capital accumulation side of the model are the same as in the Solow model; see equations (1)-(6). As before the domestic production function is:

$$Y = Ak^{\alpha}L \tag{14}$$

whence

$$\widehat{Y} = \widehat{A} + \alpha\widehat{k} + \widehat{L} \tag{15}$$

#### Investment and Capital Accumulation

I make the Solovian (and Keynesian) assumption that investment is proportional to output:

$$I = sY \quad 0 < s < 1 \tag{16}$$

From this and equations (2) and (14) we get the capital accumulation equation:

$$\widehat{k} = sAk^{\alpha-1} - \delta - \widehat{L} \tag{17}$$

This equation always holds but as shall be seen the assumption that $s$ is a constant may have to be dropped.

#### Household demand

Let $C$ be consumption, measured in units of domestic output, let $D$ be consumers' expenditure on domestic output, let $M$ be the quantity of imports purchased by consumers, and let $p$ be the relative price of imports in terms of domestic output: $p := P_M/P$ where $P$ is the domestic price and $P_M$ the import price. Then

$$C = D + pM \tag{18}$$

The national income identity is:

$$\begin{aligned} GDP(E) &= C + I + X - pM \\ &= D + I + X = Y \\ &= GDP(O) \end{aligned} \tag{19}$$

and using (16)

$$D + X = (1 - s)Y \tag{20}$$

Consumers maximise utility $U$ which depends on domestic goods and imports

$$\begin{gathered} U = D^{\omega}M^{1-\omega} \\ 0 < \omega < 1 \end{gathered} \tag{21}$$

subject to the budget constraint:

$$D + pM = C \tag{22}$$

The first order conditions of this problem yield

$$\frac{D}{M} = \frac{\omega}{1-\omega}p \tag{23}$$

Hence, differentiating with respect to time,

$$\widehat{D} = \widehat{M} + \widehat{p} \tag{24}$$

#### Balance of trade

The balance of trade, in units of domestic output, is $X - pM$. I assume that there is some mechanism, ultimately the intertemporal budget constraint, which prevents the balance moving from its equilibrium value given by:

$$X = \phi pM \qquad \phi > 0 \tag{25}$$

Some countries (e.g. Germany, the Netherlands) seem to be able to run a positive balance of trade indefinitely ($\phi$ >1) while others (e.g. the United States, Australia) have a negative balance for decades ($\phi$ <1). So no assumption as to the size of $\phi$ is made except that it is positive. The parameter $\phi$ presumably depends on demography and other factors such as preferences which are left in the background.

Differentiating (25) with respect to time,

$$\widehat{X} = \widehat{M} + \widehat{p} \tag{26}$$

From (24) and (26)

$$\widehat{D} = \widehat{X} \tag{27}$$

That is, domestic demand for domestic output grows in line with exports.

#### Foreign demand for exports

Foreign demand for exports is

$$X^d = \gamma Z^\theta \qquad \gamma > 0, \theta > 0 \tag{28}$$

Hence

$$\widehat{X}^D = \theta \widehat{Z} \tag{29}$$

Now we reach the key assumption. The supply of exports, X, cannot exceed demand but may not equal it either:

$$X \leq X^d \tag{30}$$

In good conditions the weak inequality (30) does not bind as an equality ($X < X^d$), in other words the home country can export as much as it likes. But after a sufficiently large shock to foreign demand the inequality may bind ($X = X^d$) — the country's exports are constrained by foreign demand.[9] So now we have two regimes to analyse, a good one and a bad one.

#### The two regimes

*(a) good regime:* $X < X^d$

Weak inequality (30) is not binding as an equality so the solution is the same as that of the Solow model: the short run dynamics are given by equations (15) and (17).

9 The idea that growth might be limited by foreign demand is also found in Kaldor (1966), Houthakker and Magee (1969) and Thirlwall (1979), though in the latter the idea is applied to developing countries

*(b) bad regime:* $X = X^d$

Equation (30) binds as an equality, so from (27) and (29)

$$\widehat{D} = \widehat{X} = \theta\widehat{Z} \quad (31)$$

Implicit in the bad regime is that the economy cannot grow as fast as in the good regime. In the good regime the economy is assumed to be in a steady state where

$$\widehat{I} = \widehat{K} = \widehat{Y} = g + n \quad (32)$$

Now in the bad regime by assumption we have

$$\theta\widehat{Z} < g + n \quad (33)$$

It is straightforward to show that this implies that in the bad regime

$$\widehat{Y} < g + n \quad (34)$$

*Proposition:*[10] Assume that in the good regime the economy was in a steady state in which output ($Y$), investment ($I$) and capital ($K$) were growing at the same rate, i.e. labour productivity ($y$) and capital intensity ($k$) were growing at rate $g$. Then in the bad regime, with a constant investment ratio, and given the same growth of labour supply in the two regimes, labour productivity and capital intensity grow more slowly than in the good regime. That is,

$$\widehat{Y} = \theta\widehat{Z} < g + n \quad (35)$$

and

$$\widehat{K} < g + n \quad (36)$$

Suppose that the investment ratio is lower in the bad regime than in the good one (which is what we find in the data). Then there must have been a period in which the investment ratio ($I/Y$) was falling, i.e. when $I$ was growing less rapidly than $Y$. So at the onset of the bad regime investment and capital grow even less rapidly for a period while the bad regime "beds in."

In summary, in the bad regime foreign demand drives the growth of output. Investment and capital intensity then respond to ensure that the exogenously-given labour force is fully employed. So from (34) labour productivity growth in the bad regime is

$$\widehat{y} = \theta\widehat{Z} - \widehat{L} \quad (37)$$

Using (36) and solving for $\widehat{k}$ from (15):

$$\widehat{k} = \frac{1}{\alpha}[\theta\widehat{Z} - \widehat{A} - \widehat{L}] \quad (38)$$

So an increase in the growth rate of

10 For proof, see online appendix A (http://www.csls.ca/ipm/36/Oulton_appendix.pdf).

foreign demand raises the growth rate of capital intensity while an increase in the growth rate of labour supply lowers it, as does an increase in the TFP growth rate. The second and third of these predictions are exactly the opposite of the Solow model's: in the latter TFP growth and capital deepening are positively related and capital deepening is independent of labour supply growth, at least in the steady state.

## Testing the Neo-Lewis Model

To test the neo-Lewis model empirically, equation (36) is assumed to apply in both periods, before and after the crisis, i.e. 2000-2007 and 2007-2015, denoted by superscript B and A respectively, but with a shift factor which is expected to be larger before the crisis. So for the $i$-th country

$$\begin{aligned} \widehat{y}_{\mathrm{i}}^{\mathrm{B}} &= \mu_{\mathrm{i}}^{\mathrm{B}} + \pi_Z \widehat{Z}_{\mathrm{i}}^{\mathrm{B}} + \pi_L \widehat{L}_{\mathrm{i}}^{\mathrm{B}} + \epsilon_{\mathrm{i}}^{\mathrm{B}} \\ \widehat{y}_{\mathrm{i}}^{\mathrm{A}} &= \mu_{\mathrm{i}}^{\mathrm{A}} + \pi_Z \widehat{Z}_{\mathrm{i}}^{\mathrm{A}} + \pi_L \widehat{L}_{\mathrm{i}}^{\mathrm{A}} + \epsilon_{\mathrm{i}}^{\mathrm{A}} \end{aligned} \tag{39}$$

Here $\epsilon_{\mathrm{i}}^{\mathrm{B}}$ and $\epsilon_{\mathrm{i}}^{\mathrm{A}}$ are error terms and we expect $\mu_{\mathrm{i}}^{\mathrm{B}} > \mu_{\mathrm{i}}^{\mathrm{A}}$,$\pi_Z > 0$, and $\pi_L < 0$. Then taking differences (growth after minus growth before) we obtain the equation to be used for testing the hypothesis:

$$\begin{aligned} \Delta\widehat{y}_i &= (\mu_{\mathrm{i}}^{\mathrm{A}} - \mu_{\mathrm{i}}^{\mathrm{B}}) \\ &+\pi_z \Delta\widehat{Z}_i + \pi_L \Delta\widehat{L}_i + (\epsilon_{\mathrm{i}}^{\mathrm{A}} - \epsilon_{\mathrm{i}}^{\mathrm{B}}) \end{aligned} \tag{40}$$

An analogous equation for testing predictions about capital intensity can be based on equation (37).

Now we need an empirical proxy for world demand, Z. This is measured for each country by the export-weighted imports (EWI) of its trading partners, which indicates the potential for a country to expand its exports. For the i-th country the EWI is defined as

$$EWI_i = \frac{\sum_j X_{ij} M_j}{\sum_j X_{ij}} \tag{41}$$

where the $X_{ij}$ are country $i$'s exports to country $j$ and $M_j$ is total imports of country $j$. So if country $i$ tends to export to countries whose imports are growing rapidly then $EWI_i$ will be growing more rapidly than if its exports are concentrated on slow-growing countries. (This will be the case even if the country's exports to rapidly growing economies are for some reason not growing as fast as those countries' total imports). This variable is initially nominal and measured in US dollars.[11] It is converted to real values with the US GDP deflator. The growth rate of real EWI before and after the crisis appears in

11 This variable is part of the database of the National Institute Global Econometric Model (NiGEM). I am grateful to Garry Young and Yanitsa Kazalova for making it available to me.

Table 4: **Tests of the Neo-Lewis Model: Dependent Variables are the Change in the Growth of Labour Productivity ($\Delta\hat{y}$) and the Change in the Growth of Capital Intensity ($\Delta\hat{k}$)**

| | change in labour productivity growth ($\Delta y$) | | | | change in capital intensity growth ($\Delta k$) | | | |
|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| $\Delta\widehat{k}$ | | 1.146** | 1.270*** | 0.868* | | -0.05032 | -0.398 | -0.402 |
| | | (0.474) | (0.395) | (0.471) | | (0.669) | (0.255) | (0.276) |
| $\Delta\widehat{L}$ | -0.369* | | -0.433*** | -0.507*** | -0.586*** | | -0.606*** | -0.618*** |
| | (0.2) | | (0.135) | (0.146) | (0.0834) | | (0.0766) | (0.0903) |
| $\widehat{Y}^B$ | | | | .0.343* | | | | -0.075 |
| | | | | (0.168) | | | | (0.27) |
| Constant | -1.745*** | 1.995 | 1.751 | 1.602 | -0.983*** | -0.577 | -1.985** | -1.833 |
| | (0.377) | (1.231) | (1.024) | (1.15) | (0.167) | (1.782) | (0.737) | (1.088) |
| Observations | 22 | 22 | 22 | 22 | 14 | 14 | 14 | 14 |
| R-squared | 0.168 | 0.285 | 0.513 | 0.603 | 0.686 | 0 | 0.713 | 0.716 |

Source: Data from Table 2.
Note: *** p<0.01, ** p<0.05, * p<0.1. OLS estimates; robust standard errors in parentheses.

Table 2. There has been a substantial decline in all countries. The cross-country average is a fall of 2.85 percentage points, with a considerable range around this average (standard deviation: 0.69).

The results of estimating equation (39) are in Table 4. Consider first column (3) where the change in labour productivity growth is the left-hand-side variable. Both the independent variables, export demand and hours, are highly significant (at the 1 per cent level) and have the correct sign.[12] Given that this is a difference between two cross sections, the level of explanatory power is quite high (R-squared = 0.513). However the neo-Lewis model predicts that the coefficient on hours should be -1 while the estimated coefficient is smaller in absolute value, -0.433. The upper panel of Chart 4 shows the added variable plots for this regression from which it is clear that no single country is driving the results. The specification in column (3) in effect assumes that the same constant applies to all countries which could lead to biased estimates.

One way to deal with this is fixed effects but there are not enough observations for this. So instead the growth rate of GDP over 2000-2007 ($\widehat{Y}^B$) is added in column (4) to proxy for country-specific effects. The coefficient on this variable is negative and significant at the 10 per cent level, indicating that countries which did well before the crisis did worse after it. The coefficient on export demand is now smaller and less significant but hours remains highly signifi-

12 The coefficient on the growth of foreign demand ($\Delta\widehat{Z}$) might be thought quite large, even when the growth of GDP in 2000-2007 is included. (as in column 4). But note that this coefficient measures not the short run effect on aggregate demand when exports rise but the long run effect on GDP of a rise in foreign demand, the parameter $\theta$. There is a multiplier effect here since in the model's bad regime domestic demand is determined by foreign demand: See equation (25).

cant and somewhat larger in absolute value. The lower panel of Chart 4 shows the added variable plots for this regression. Even more than the upper panel, this shows that the results are not being distorted by outliers.

Columns (5)-(8) in Table 4 have the same specification as columns (1)-(4) except that the dependent variable is now the change in the growth rate of capital intensity. The hours variable is highly significant again but export demand is not. However there are only 14 countries now.

So the facts are broadly consistent with the neo-Lewis model put forward here, although the model has not captured all the important features of the data since the coefficient on hours is not equal to minus one. Even setting this aside, there is of course no guarantee that the model is true: any set of facts is consistent with an unlimited number of theories. The problem is that the sort of facts discussed here will only be observed on very rare occasions, most recently the Great Recession. The only previous event in the twentieth century comparable to this in scale was the Great Depression of the 1930s. Hence it is difficult for conventional econometric techniques to achieve empirically rigorous results.

## Is It All About TFP?

### Did the TFP slowdown precede the Great Recession?

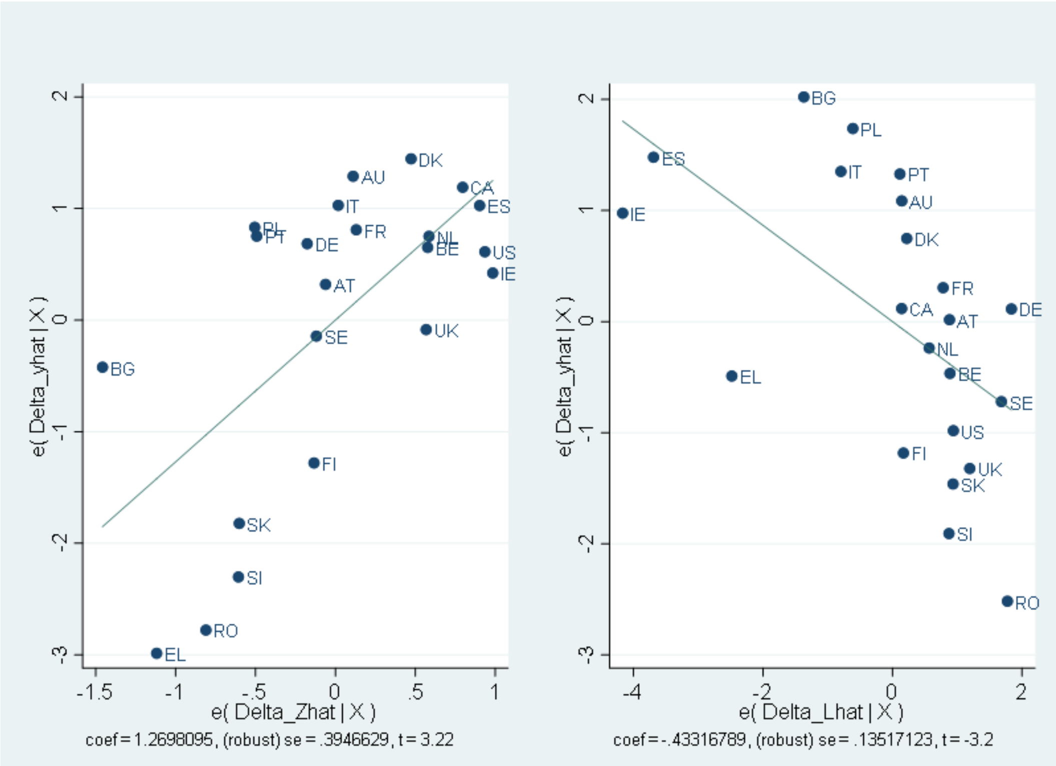
TFP growth has fallen dramatically since the crisis as we have seen (Table 2). In the UK's case, the slowdown in TFP accounts for 71 per cent of the slowdown in labour productivity growth, in a growth accounting sense (Table 2). And this finding survives untouched when a longer list of intangible assets is included under capital (Goodrich *et al.*, 2018). So is not the TFP slowdown the main story, eclipsing the role of any slowdown in the growth of capital intensity? Furthermore, it is often asserted that the slowdown in TFP growth preceded the financial crisis, suggesting that a micro-based explanation should be sought and implying that the policy remedy is "structural reforms" (Andrews *et al.*, 2015; Bergaud *et al.*, 2014; Fernald, 2015; Cette *et al.*, 2016).[13]

However, if one just considers the period up till 2007, it is very difficult to find evidence of a TFP slowdown in most countries. Chart 5, re-

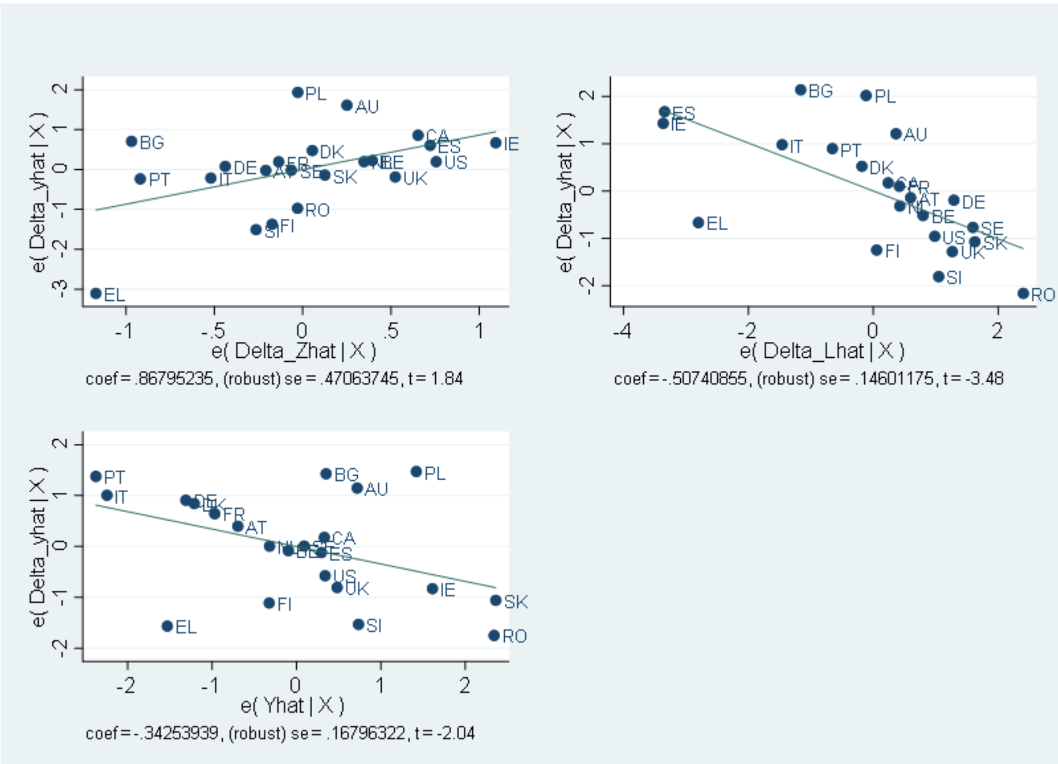
13 Micro studies have thrown light on the evolution of productivity. For example, using French firm-level data Cette et al. (2018) exhibit a number of adverse trends which could impact TFP growth. But the timing is problematic for explaining the post-2007 collapse. For example, they find that the speed of convergence of laggard firms to leading firms actually rose in the period 2007-2012, though it fell sharply in 2014 (their latest year).

**Chart 4: Added Variable Plots (Dependent Variable: Change in Growth of Labour Productivity)**

**(a) For Column (3) of Table 4**




**(b) For Column (4) of Table 4**




See Table 2 for country codes.

**Chart 5: TFP Growth in the Market Sector in 18 Countries to 2007**


Source: Oulton (2016b), derived using EU KLEMS (the March 2011 update of the November 2009 release).

produced from Oulton (2016b), shows TFP growth in the market sector in 18 countries; data are from the earlier release of the EUKLEMS database which fortuitously stops in 2007.[14] Two simple measures of the trend are shown: the mean over the data period for each country (dashed line) and a Hodrick-Prescott (HP) trend (red line). In most cases the country's actual TFP growth rate is at or near its mean level at the end of the period; exceptions are Australia and Ireland. In addition, in most cases the HP trend is flat or rising in the years leading up to the financial crisis. This suggests that the collapse exhibited since 2007 must be somehow related to the crisis and the subsequent Great Recession and not to pre-existing adverse micro factors.[15]

The United States is often regarded as the technology leader and therefore its TFP record is particularly signifi-

14 This is the March 2011 update of the November 2009 release which includes more countries. Also the capital services measure is better since unlike in the 2011 release asset stocks are estimated using a common set of geometric depreciation rates.

15 An alternative possibility is that capital services growth after 2007 has been overstated and so TFP growth has been understated as a result of the recession. See online appendix B for discussion of this (available at: http://www.csls.ca/ipm/36/Oulton_appendix.pdf).

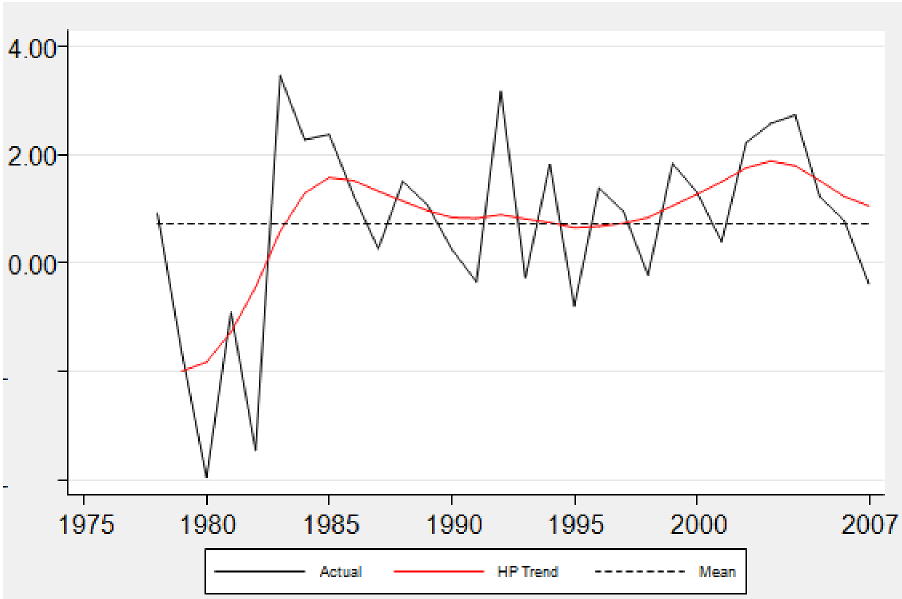
cant, so Chart 6 focuses on the US experience up to 2007. The HP trend confirms the earlier finding of Fernald (2015) that growth slowed after 2004. But it did not slow by all that much and was still 1.05 per cent per year in 2007, substantially above the trend rate in most of the 1980s and 1990s and also above the mean rate over 1978-2007.

Further evidence comes from comparing trend TFP growth as measured by the HP trend at the end of the boom in 2007 with the actual TFP growth after the boom, i.e. 2007-2015: see Table 5. (The HP trends are for the market sector so the actual growth rates after the boom are also for the market sector where possible.) The trend growth rate tells us what we would have predicted TFP growth to be in the years after 2007, if we had data only up to the end of the boom, i.e. if we place no reliance on hindsight. We see that there is a very substantial difference between the predicted and the actual rates: the outcome was below the predicted rate in every case except Australia and on average in these countries by 1.77 percentage points per year. This evidence goes against the view that the zero or negative TFP growth rates seen after the crisis are just a continuation of a pre-existing slowdown.

A more sophisticated analysis is available for the United States. Crafts and Mills (2017) estimate trend TFP growth in the United States, in the 1967-2016 period. They apply a time series model to Fernald's quarterly series for TFP growth in the business sector (Fernald, 2014). TFP growth is modelled as a random walk (the trend) plus a zero-mean, auto correlated "noise" process. Using Fernald's series for the whole period 1947-2015, Crafts and Mills (2007: Figure 3) find that the trend has been slowing continuously since 1967, from around 1.5 per cent per year in that year to around 1.0 per cent per year in 2016. The actual outturn according to Fernald's data over 2007-2015 was 0.56 per cent per year (0.63 per cent per year adjusted for utilisation). In other words the outturn was substantially lower than the trend as estimated by Crafts and Mills. Another way to look at it is to note that in 2016 the Crafts-Mills trend growth rate was about 0.1 per cent per year lower than in 2000, so the slowdown in trend growth is quite modest in relation to what actually occurred, about 0.6 per cent.[16] So the slump in US TFP growth since

16 From the spreadsheet accompanying Fernald (2014), dated 1 February 2018, it can be calculated that comparing 2007-2015 with 2000-2007, unadjusted TFP in the US business sector growth slowed down by 0.63 percentage points per year; adjusted for utilisation the slowdown was 0.57 percentage points per year. This is very similar to the slowdown of 0.54 percentage points per year in Table 1 which is for the whole economy.

**Chart 6: Market Sector Total Factor Productivity Growth in the United States, 1978-2007 (per cent per year)**




Source: EU KLEMS (March 2011).
Note: Trend growth rate is that of HP-smoothed TFP level. Dashed lines denotes mean of actual TFP growth

2007 is not correctly described as a decline in the trend rate. It was also not foreseeable using just the data up to 2007 since Crafts and Mills (2007: Figures 3 and 4) find a rising trend if only the 25 years of data up to 2007 are used.[17]

## An alternative explanation: the externality hypothesis

On the face of it, and in the light of the rise of the digital economy, it seems very implausible that a fortuitous and exogenous decline in the rate of innovation could account for slow productivity growth after 2007 in any of the countries studied here. The alternative explanation is that the recession itself has somehow adversely affected TFP growth. Two channels suggest themselves.

First, the amount of innovation taking place in the economy may be temporarily reduced, due to a loss of business confidence (Oulton and Sebastiá-Barriel, 2017). Innovation is implemented through or accompanied by investment in intangibles (e.g.

17 Antolin-Diaz *et al.* (2017) argue that most of the slowdown in US GDP occurred prior to the Great Recession. But Figure A.1 in their online appendix which uses the latest vintage of GDP data for their whole sample shows that their estimate of long run GDP growth fell sharply after 2007. They do not show rolling estimates which would enable one to see what their model would predict just using data up to 2007.

**Table 5: Trend TFP Growth Rate at the End of the Boom Versus Performance After the Boom (Market Sector[a], 14 Countries, % p.a.)**

| Country | HP trend growth rate at the end of the boom (2007) | Mean actual TFP growth rate after the boom(2007-2015) | Difference (actual minus trend) |
|---|---|---|---|
| Australia | -1.27 | -0.01 | 1.26 |
| Austria | 2.31 | -0.17 | -2.48 |
| Belgium | 0.76 | 0.17 | -0.59 |
| Czech Republic | 4.14 | -1.67 | -5.81 |
| Denmark | 0.39 | -0.25 | -0.64 |
| Spain | -0.28 | -0.43 | -0.15 |
| Finland | 3.32 | -0.73 | -4.05 |
| France | 0.93 | -0.69 | -1.62 |
| Germany | 1.51 | -0.14 | -1.65 |
| Italy | -0.01 | -0.51 | -0.5 |
| Netherlands | 2.19 | -0.09 | -2.28 |
| Sweden | 2.05 | -0.73 | -2.78 |
| United Kingdom | 2.09 | -0.41 | -2.5 |
| United States | 1.05 | 0.08 | -0.97 |
| Average (unweighted) | 1.37 | -0.40 | -1.77 |

Source: HP trend growth rates calculated from EU KLEMS (www.euklems.net, March 2011 update of November 2009 release): see Oulton (2016b). Mean actual TFP growth rates after 2007 from September 2017 releases of EU KLEMS.
Note: End of the boom is 2007 for all countries except Belgium for which it is 2006. All countries included for which TFP is available in both the March 2011 and September 2017 releases of EU KLEMS.
a. Czech Republic, Italy and Sweden after the boom: whole economy since market sector not available.

R&D, in-firm training, or expenditure of management time on corporate restructuring) or it could take the form of new entrants into an industry bringing new products, new technology or new business methods. All this is (arguably) what lies behind TFP growth as conventionally measured.

Now innovation is a cumulative process and the supply of workers and entrepreneurs capable of innovating is likely to be inelastic. So unlike with physical capital a reduction in innovation in one period cannot easily be made up in a subsequent one: in other words, less innovation today means that the future level of TFP is permanently lower. A reduction in the TFP level will also lead to a secondary effect, a reduction in the desired level of capital, again reducing labour productivity.

In short, more rapidly expanding output might raise animal spirits leading to a greater willingness to experiment with new business methods. Intangible investment seems to be particularly likely to generate externalities but is also riskier and so may have been particularly likely to be cut during the recession (Corrado *et al.*, 2017).

A second channel posits a positive connection between the growth of output and the growth of TFP. The starting point here is Fabricant's Law. In panel data on US manufacturing industries over the period 1899-1939 Fabricant (1942) observed a positive correlation between the growth of output and the growth of labour productivity.[18] In earlier work we observed the same pattern for 124 UK manufacturing industries over 9 subperiods within the overall span 1954-1986 (Oulton and O'Mahony, 1994). We also observed a positive correlation between output growth and TFP growth.

But which way does the causation run, from output to TFP or the reverse? The usual argument is that this correlation is uninteresting. TFP growth happens to be higher in some industries which initially leads to higher profits. This attracts entry leading to higher output which the market absorbs by lower prices. So causation runs from TFP growth to output growth via lower relative prices. We found however that the correlation between output growth and relative price growth was much weaker than that between output growth and TFP growth, which casts doubt on this explanation (Oulton and O'Mahony (1994), chapter 7).[19]

The alternative explanation for the positive correlation between TFP growth and output growth is that some form of increasing returns is involved. Hall (1988) and Bartelsman *et al.* (1994) found support for increasing returns in US data, and Caballero and Lyons (1990) in European data. Oulton (1996) found support on the same UK manufacturing data just described (in the latter the externality seemed to be at the manufacturing sector level rather than the industry level). Hall (1988) had invoked a "thick market externality" to explain the phenomenon: an example is the delivery van which travels as many miles on average in good

18 Fabricant's Law is also known as Verdoorn's Law (Verdoorn 1980). There is a parallel literature testing Verdoorn's Law and drawing inspiration from among others Kaldor (1966) who stressed the role of demand in promoting output and productivity growth in a virtuous circle; see e.g. Magacho and McCombie (2017).

19 There is also some evidence for a negative relationship between TFP growth and the growth of labour input over long periods, e.g. 1970-2007 (De Michelis*et al.*, 2013).

times as bad but delivers more packages when times are good.

This suggests the effect operates at business cycle frequencies and is due to varying utilisation, hence the term "short run increasing returns". But this is not the only possibility. Oulton (1996) found that the externalities seem to apply peak-to-peak as well as over the course of the business cycle, which is not consistent with the thick market story. A second possible type of externality is a learning effect: knowledge of new techniques and methods diffuses faster through the economy, the faster the rate of overall expansion. This type of effect would be expected to operate peak-to-peak.

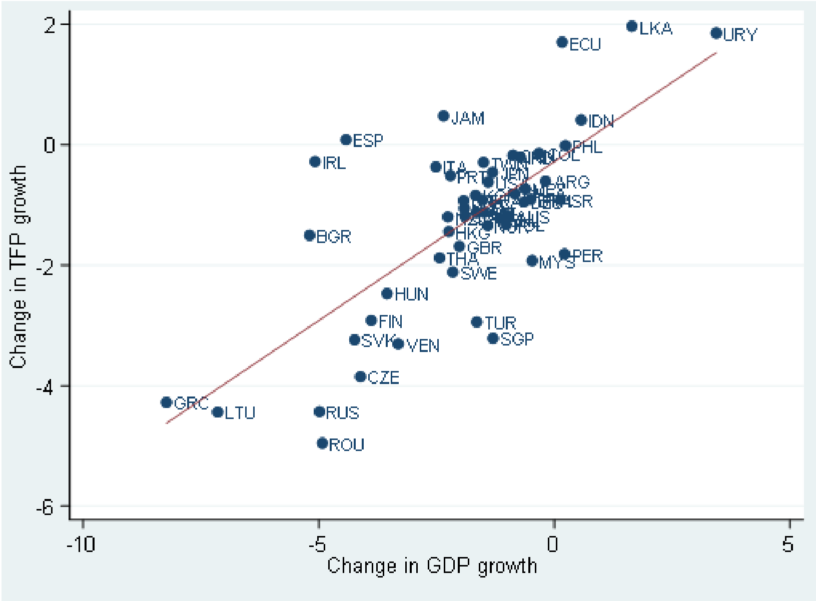
It is difficult to test these ideas using only macro data and particularly using the latest release of the EU KLEMS dataset since this dataset has TFP data for only 14 countries. So consequently, the latest release (version 9.0) of the Penn World Table, described in Feenstra *et al.* (2015) is used.[20] After eliminating countries with populations of less than 2 million and countries with no data on hours worked there remain 52 countries for which TFP is available. I use the PWT's "national accounts" variables for indices of real GDP, real capital stock and TFP; total hours worked is calculated as average hours per worker times the number of workers.[21] On average in these 52 countries TFP growth slowed down by 1.29 percentage points per year, GDP by 1.92 percentage points per year, capital by 0.26 percentage points per year, and hours by 1.00 percentage points per year.

The externality hypothesis suggests that, on cross-country data, the bigger the slowdown in GDP, the bigger the slowdown in TFP. Table 6 shows how the change in the TFP growth rate between the periods 2007-2014 and 2000-2007 relates to the change in the growth rate of GDP, the change in the growth rate of capital, and the change in the growth of hours between the same two period (columns 1-3). Much the strongest relationship is with GDP and it is positive: the bigger the slowdown in GDP, the bigger the slowdown in TFP (Chart 7). The coefficient on GDP is highly significant (t = 6.6). Taken literally, this says that a slowdown of one percentage point in GDP growth causes a slowdown of 0.53 percentage points in TFP growth. The coefficients on the other variables, capital and labour,

20 Freely downloadable from https://www.rug.nl/ggdc/productivity/pwt.

21 Two drawbacks of the Penn World Table should be noted. First, the capital variable is the aggregate capital stock, not the superior capital services measure. Second, the terminal year is 2014, not 2015.

**Chart 7: Change in TFP Growth Versus Change in GDP Growth (52 countries)**




Source: Penn World Table, version 9.0. Average annual growth rates over 2007-2014 minus annual average growth rates over 2000-2007.

are not significant. The pattern of the correlations is interesting. Each is between TFP and a component of TFP so it might be objected that any relationship is just mechanical. But why then is it much stronger with GDP than with capital or labour?

Column 4 of Table 6 is a test of the Solow model's predictions about the effect of a slowdown in TFP growth which that model takes to be exogenous. The Solow model predicts that a slowdown in TFP growth will cause a slowdown in the growth rate of capital intensity. But the coefficient on the latter, 0.28, is much smaller than the model predicts: with a capital share of about one third the coefficient should be about 1.5 (see equation (6)). It is also insignificant.

These correlations do not of course prove that a GDP slowdown causes a TFP slowdown. But they are certainly consistent with the industry-based studies cited above. They are also consistent with the neo-Lewis model which sees the GDP slowdown as caused by constrained demand for exports. The model now works through the TFP channel as well as the capital-deepening one to explain the labour productivity slowdown.[22]

## Conclusion

22 For further discussion and extensions of the neo-Lewis model and of the externality hypothesis, see online appendix B. For discussion of the policy implications if the present approach is accepted, see online appendix C (available at: http://www.csls.ca/ipm/36/Oulton_appendix.pdf).

**Table 6: Testing the Externality Hypothesis in 52 Countries**

| | Dependent Variable | | | |
|---|---|---|---|---|
| | Change in TFP growth | | | Change in K/L growth |
| Independent Variables | (1) | (2) | (3) | (4) |
| Change in GDP growth | 0.527*** | | | |
| | (0.0803) | | | |
| Change in capital growth | | 0.135 | | |
| | | (0.151) | | |
| Change in hours growth | | | -0.118 | |
| | | | (0.152) | |
| Change in TFP growth | | | | 0.283 |
| | | | | (0.194) |
| Constant | -0.281 | -1.259*** | -1.412*** | 1.105*** |
| | (0.168) | (0.221) | (0.218) | (0.363) |
| N | 52 | 52 | 52 | 52 |
| R-squared | 0.514 | 0.018 | 0.018 | 0.058 |

Note: Changes are measured as annual average growth over 2007-2014 minus annual average growth over 2000-2007. OLS estimates; robust standard errors in parentheses.*** $p<0.01$, ** $p<0.05$, * $p<0.1$.
Source: Penn World Table, version 9.0, and own calculations.

Rapid rates of immigration in conjunction with low rates of growth of export demand in the aftermath of the Great Recession can explain the UK productivity puzzle. Labour market flexibility can explain why we have also had low unemployment and high employment growth. The reason why the UK was not able to have fast labour productivity growth after the crisis even though immigration rates were similar to those of the pre-crisis period is that after the crisis the growth of foreign demand for UK exports fell. This has led to low rates of capital accumulation and consequently low rates of labour productivity growth. This has been compounded by virtually zero growth rates of TFP, but this last is a factor common to virtually all the countries studied here; indeed in some countries like Sweden the level of TFP has fallen substantially.

Due to the nature of their labour markets and social policies, most EU countries have had much less rapid growth rates of labour after the crisis. Consequently, they have had better labour productivity growth but worse labour market outcomes than the UK.

The factors leading to people from all over the world coming to the UK to work are of course complex. Much must depends on conditions of the immigrants' countries of origin. But by the nature of its flexible labour market and other institutions, the UK has been much more welcoming to migrants as workers than have most other EU countries.

That the facts are consistent with this explanation has been demonstrated by a simple modification of the workhorse Solow growth model. Taking inspiration from the early work of Arthur Lewis the Solow model has been adapted to make the growth of demand for a country's exports depend on the growth of foreign demand. In normal times this constraint does not bind. In abnormal times, like the Great Recession and its aftermath, foreign demand acts as a constraint on the home economy. If labour supply is rising sufficiently rapidly in this situation due to immigration while output is constrained by foreign demand, then capital intensity will rise less rapidly or even fall, leading to stagnant or falling labour productivity, a situation which might be described as "growth with unlimited supplies of labour." Output in other countries is also constrained by foreign demand but their inflexible labour markets plus their adherence to the European Social Model mean that the effects show up as higher unemployment and lower job creation, accompanied by lower immigration.[23]

Slow growth of capital intensity is not however the whole story. The UK and the other countries studied here have seen a large fall in TFP growth as well. It is argued that this is a consequence of slow growth in GDP since 2007, in turn due to constrained demand for exports as emphasised by the neo-Lewis model. The countries with the largest falls in GDP growth also had the largest falls in TFP growth. Based on earlier industry-based studies, I argue that this relationship is causal, due to a form of increasing returns but working here in reverse, so that slow growth of GDP leads to slow growth of TFP.

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# Online Appendices: The UK and Western Productivity Puzzle: Does Arthur Lewis Hold the Key?

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## Appendix A: Proof of Proposition

The main article puts forward the following proposition comparing the growth of labour productivity and capital intensity under "good" and "bad" conditions for a country's exports. This appendix provides a proof of that proposition.

*Proposition:* Assume that in the good regime the economy was in a steady state in which output $(Y)$, investment $(I)$ and capital $(K)$ were growing at the same rate $g + n$, i.e. labour productivity $(y)$ and capital intensity $(k)$ were growing at rate $g$. Then in the bad regime, with a constant investment ratio, and given the same growth of labour supply in the two regimes, labour productivity and capital intensity grow more slowly than in the good regime. That is,

$$\begin{aligned} \widehat{Y} &= \theta\widehat{Z} < g + n \\ \text{and} \quad \widehat{K} &< g + n \end{aligned} \tag{1}$$

*Proof.* Let $S_{bad}$ be the investment ratio in the bad regime, for the moment taken to be constant. It is assumed

$$0 < S_{bad} \leq S \tag{2}$$

i.e. the "bad" investment ratio cannot exceed the old ("good") one which prevailed in the previous steady state. Equation (20) from the main text now becomes

$$D + X = (1 - S_{bad})Y \tag{3}$$

1 The main article is available at http://www.csls.ca/ipm/36/Oulton.pdf.

whence using equation (25) from the main text

$$\widehat{Y} = \theta \widehat{Z} < g + n \tag{4}$$

or

$$\widehat{y} < g \tag{5}$$

Putting (31) and (19) from the main text together we also have:

$$\widehat{Y} = (1 - s_{bad})\theta \widehat{Z} + s_{bad}\widehat{I} \tag{6}$$

whence

$$\widehat{I} = \theta \widehat{Z} < g + n \tag{7}$$

It then follows from the capital accumulation equation $\widehat{K} = (I/K) - \delta$ that the growth of capital must also fall below its steady state level:

$$\widehat{K} =< g + n \tag{8}$$

or

$$\widehat{k} < g \tag{9}$$

which proves the Proposition. □

## Appendix B: Explaining Slower Productivity Growth in the United Kingdom

### Previous Explanations

Explanations for the productivity puzzle that have so far been put forward include the following:

- Distortion due to hard-to-measure or otherwise problematic sectors;
- Reallocation of labour to sectors where productivity is lower;
- Mis-measurement of GDP due to mis-measurement of banking output and of the digital economy;
- Overheating in the boom (so output was growing more rapidly than was sustainable;
- Labour hoarding;
- The impact of austerity;
- Lower human capital (skill);
- Flat or falling capital intensity; and
- Crippled banks and zombie firms.

I have reviewed these explanations extensively elsewhere (Oulton 2016a). Suffice it to say that I did not find any of them plausible by themselves though one at least, flat or falling capital intensity, has formed part of my own explanation. Of the other explanations, some do not fit the facts (reallocation, lower human capital, austerity), one has been rendered implausible by the length of time that productivity has stagnated (labour hoarding), and another fails to understand how GDP is measured in practice (banking output).

It may well be that the digital economy is mis-measured. But first, this affects only a small part of the economy, some of which drops out of GDP as it is intermediate consumption; second, outside the digital sector the productivity puzzle will remain; third, mis-measurement of digital products has been with us for a long time so to explain the productivity puzzle one needs to show that mismeasurement has become worse since 2007, for which there is no evidence (Byrne *et al.*, 2016).

Any explanation based around the banking crisis has to grapple with four facts: (1) while there is evidence that a banking crisis has a permanent adverse effect on the levels of GDP, employment and productivity, it is much harder to argue that it has a long run effect on their growth rates (Oulton and Sebastiá-Barriel 2017); (2) banks in the UK unlike in Europe lend predominantly to smaller firms, while larger firms rely on corporate bonds (where interest rates are low) and on retained profits which have been very healthy;[2] (4) most observers think that the UK banking system is now functioning normally again.[3]

Firm-level studies are potentially valuable in distinguishing between alternative explanations. For example, one might hypothesize that smaller, independent firms which have no access to the bond market would be particularly affected by restrictions on bank lending. But despite many interesting findings, no such smoking gun has yet been identified (Barnett *et al.*, 2014; Riley *et al.*, 2017).

Finally, as a general comment on all candidate explanations, it is important to show how and why the UK differs from other comparable countries. This is because the UK suffered one of the largest slowdowns in labour productivity growth after 2007; in fact, the eighth largest out of 24 countries. Among advanced countries, only in Finland and Sweden was the slowdown greater (Table 2).

## Lewis and the Lewis Model

Despite being awarded the Nobel Prize in Economics in 1979, W. Arthur Lewis (1915-1991) has fallen out of fashion in modern discussions of economic growth. Acemoglu (2009, chapter 21, section 21.3.1) presents

2 To quote Martin and Rowthorn (2012): "The emphasis placed on the impact of a sclerotic banking system on the pace of innovation by credit-constrained small and medium-sized enterprises belies the quantitatively small role of SMEs in explaining innovation and productivity growth. Independent SMEs account for just 3.5 per cent of business R&D spending."

3 Tenreyro (2018) is also sceptical about explanations based on the banking crisis. But she does argue that productivity is likely to rise in finance once the deleveraging process is completed.

a model of dualistic growth based on Lewis (1954). But it formalises only the closed economy version of the Lewis model and lacks the crucial element of foreign demand. He takes the essential element of the model to be a barrier preventing free migration between urban and rural areas whereas Lewis emphasises the ease of migration. In Barro and Sala-i-Martin (2004) Lewis's 1954 article appears in the list of references but he is not mentioned in the text. Lewis does not appear at all in Jones (2002).

Interestingly, Lewis himself foresaw the possible application of his model to a modern industrial economy like the UK. He writes: "When capital accumulation catches up with the labour supply, wages begin to rise above the subsistence level, and the capitalist surplus is adversely affected. However, if there is still surplus labour in other countries, the capitalists can avoid this in one of two ways, by encouraging immigration or by exporting their capital to countries where there is still abundant labour at a subsistence wage. ... If there were free immigration from India and China to the U.S.A., the wage level of the U.S.A. would certainly be pulled down towards the Indian and Chinese levels. ... This is one of the reasons why, in every country where the wage level is relatively high, the trade unions are bitterly hostile to immigration, except of people in special categories, and take steps to have it restricted. The result is that real wages are higher than they would otherwise be, while profits, capital resources, and total output are smaller than they would otherwise be." Lewis has correctly predicted that business interests would be strongly in favour of immigration in the UK today but so far he has been wrong about the attitude of the trade unions.

### Aggregate Demand Shocks or Export Demand Shocks?

The thesis of this article has some resemblance to Pessoa and Van Reenen (2015) who argued that wage flexibility explains both puzzles (low or zero productivity growth accompanied by full employment). Their analysis is framed around the growth accounting equation which in my notation is

$$\Delta\ln(Y/L) = \Delta\ln TFP + \alpha\Delta\ln(K/L) \tag{10}$$

They then argue that a "demand shock" which lowers $Y$ will, given TFP growth, lead to a fall in capital intensity if wages are sufficiently flexible. They do not refer to export demand and do not mention immigration. The latter omission is bit surprising given that with real wage flexibility a positive labour supply shock would also lower both $Y/L$ and

$K/L$. Their approach suggests that the solution to the problem is a fiscal and/or monetary expansion sufficient to compensate for the adverse demand shock. In contrast, my approach relies on shocks to export demand. And in my bad regime model an expansionary fiscal or monetary policy would not solve the problem since it would not increase export demand.[4]

The fundamental difficulty with the Pessoa-Van Reenen story is the inability of the Solow model to explain the UK's productivity puzzle. In conditions of full employment, which is what we currently have in the UK, an increase in labour supply creates an incentive to invest: the marginal product of labour is lower so the real wage falls, but equally the marginal product of capital is higher, so firms want to invest more. This is the mechanism in the Solow model to keep the economy on, or drive it back towards, its long run growth path. But it is this mechanism which has been conspicuously malfunctioning in the UK since 2007. And the neo-Lewis model explains why this is the case.

## Export Demand Shocks

Demand for a country's exports as a cause of growth has received surprisingly little attention in the literature on economic growth, as opposed to the literature on economic development (e.g. Thirlwall, 1979). It plays no role for example in the influential study of Mankiw *et al.* (1992) which tested the Solow model on 98, mostly open, countries. The case for export demand shocks as an important cause of recessions and subsequent slow growth, or even slumps, is strengthened by considering the example of smaller countries or subnational units (regions and cities).

Consider Finland. Between 1990 and 1993 Finland's GDP fell by 9 per cent. It did not surpass its 1990 level till 1996. This had little to do with anything happening in Finland itself but was due rather to the collapse of Finland's then principal trading partner, the Soviet Union. This was followed by a favourable export demand shock when Finland joined the EU in 1995. Finland has undergone a major depression after 2007, with GDP falling nearly 9 per cent in 2009. Since then GDP has largely stagnated; in 2015 it was still over 7 per cent below its 2008 level.[5]

It seems likely that a bad situation has been made worse by the loss of comparative advantage suf-

4 Other papers emphasising the role of aggregate demand in accounting for the productivity puzzle include Martin and Rowthorn (2012) and Carlin and Soskice (2018). The latter is a model of a closed economy.

5 Source: EU KLEMS, September 2017 release.

fered by Finland's largest company, Nokia. As the Nokia Annual Report for 2016, "Rebalancing for growth", delicately puts it: "By 1998 Nokia was the world leader in mobile phones, a position it enjoyed for more than a decade."[6] At its peak in 2007 Nokia accounted for 70 per cent of the total market capitalization of firms quoted on the Helsinki stock exchange when its market cap was 106 billion euros. This fell to some 6 billion euros in 2012, though it recovered somewhat to 26 billion euros in 2015 (information from Wikipedia). So on top of the effects of the financial crisis Finland has suffered an additional, Nokia-related, shock as world demand has shifted towards non-Finnish companies such as Apple and Samsung.

The case for export demand shocks is even stronger if one looks at cities and regions. It would be odd to discuss the decline of Detroit without mentioning the problems of its main export industry, cars.

It seems likely that these idiosyncratic shocks affecting small countries are not fully captured by the EWI index. The latter shows a substantial fall for Finland after 2007 but nothing exceptional (Table 2).

If the effect of export demand shocks is easier to spot in the case of smaller countries, it may be that they are less important usually for larger ones. In the model the imported good cannot be produced at home. This is clearly less realistic for larger countries as evidenced by the fact that the imports-GDP ratio falls with country size. So for a large country a fall in exports could still lead to a parallel fall in imports but this may have only a small effect on domestic production and demand since import-competing industries can expand; in the limit when domestic products are perfect substitutes for foreign ones the effect of a foreign demand shock is zero. This may help to explain why the United States has done better than even the large European countries since 2007.

## What is Different About the UK Labour Market?

By comparison at least with continental EU countries the UK is very attractive to migrants for several reasons. First, when eight new countries (the A8), consisting of Poland, Hungary, Slovakia, Slovenia, the Czech Republic and the three Baltic states, joined the EU in 2004, the UK government immediately opened the labour market to citizens of these countries; it followed the same policy when Bul-

6 https://www.nokia.com/sites/default/files/files/nokia$_ar16_full_report_english_3$.pdf, accessed on 01/12/2107.

garia and Romania joined the EU in 2007 and when Croatia joined in 2013. Other EU countries required a transition period before opening their labour markets.

Second, potential migrants, whether from the EU or elsewhere, are more likely to speak at least some English rather than say French, German or Italian, which makes the UK more attractive as a destination.

Third, the UK labour market is very flexible, in several relevant ways. For a great many jobs, particularly unskilled ones, no formal qualifications are necessary and occupational licensing is comparatively rare. Firing costs are low (employment protection legislation is weak), which makes firms more willing to offer employment. Trade unions are weak, except in the public sector.

And the UK has never adopted any of the continental versions of the European Social Model.[7] The latter gives a very important role to the "social partners" unions, employers and government in setting wages and working conditions at the industry level. The aim here is to prevent "social dumping", which would allow firms to undercut the wages of indigenous workers by importing cheaper foreign labour.[8]

Finally, in the case of illegal migrants or overstayers, it is comparatively easy to escape the attention of the authorities since the UK has no system of national identity cards.[9]

A striking demonstration of the advantages of the UK as perceived by migrants themselves is the illegal encampment known as the "jungle" erected outside Calais. Until its demolition by the French authorities in October 2016 it held many thousands of migrants who had often been living there for months or even years in

7 The European Social Model comes in four varieties: Nordic, Continental (as in e.g. Austria, Belgium, France, and Germany), Mediterranean (Greece, Italy, Portugal and Spain) and Anglo-Saxon, the latter applying only to the UK and Ireland. (Perhaps after Brexit it will be renamed the Celtic model). The Continental version is characterised by strong "employment protection" legislation and an important role for trade unions (Sapir, 2005). Sapir notes: "Although their membership is on the decline, unions remain strong as regulations extend the coverage of collective bargaining to non-union situations."

8 The hostility to social dumping in Europe is exemplified by the opposition of President Macron to the Posted Workers Directive which allows firms in (say) France to import workers from (say) Romania and pay Romanian not French social charges, thus doing an end run round French wage policy. Macron has recently (October 2017) succeeded in convincing his fellow heads of government to agree to water down this directive (Financial Times, 2017). An earlier example of opposition to social dumping is the process of German reunification. This initially threatened a large influx of workers from the East into the West and also greater competition for Western workers if firms moved in the opposite direction to take advantage of cheap Eastern labour. The German trade unions were successful in preventing this by obliging the East to adopt the West's wages and other conditions, at the cost initially of high unemployment in the East (Carlin *et al.*, 2014).

9 David Wood, former head of immigration enforcement at the Home Office, told the House of Commons home affairs committee recently that he believes that there are about a million illegal migrants currently in the UK

squalid conditions. The one aim of these migrants was to smuggle themselves into Britain where they confidently expected to find work. The point here is that these migrants had already reached safety on the territory of the European Union. But they clearly felt that their chances of finding work in France (or any other continental EU country to which they could have travelled) were greatly inferior to their chances in Britain.

### Benefits and Costs of Immigration to Natives

There is a large literature which mostly claims that the impact of immigration on the wages of natives is negligibly small. One strand was started by Card (1990) who studied the Mariel boatlift. His results have been disputed by Borjas (2015) and (2016). These studies attempt to identify the short run elasticity of wages to a labour supply shock. So they are of doubtful relevance to the UK productivity puzzle where the issue is the failure of capital accumulation to respond to additional labour. For the UK, Nickell and Saleheen (2008) also found small effects of immigration on native wages. But their study used data from the boom period, so again is not evidence against the hypothesis of this article.

Standard growth theory suggests another way in which native living standards can be damaged by immigration, which so far as I am aware has not been discussed in the literature on immigration (it is not mentioned in Borjas (2014) for example). In the Solow model the long run growth rate of labour ($n$) has no effect on the long run growth rate of labour productivity. It does however affect the long run level of labour productivity and capital intensity at each point in time: the higher is $n$, the lower is output per hour ($y$) and capital intensity ($k$).

Using the notation of equations (1)-(6) of the main text, the long run steady state level of output per hour at time $t$ is given by

$$y^*(t) = A(t)^{1/(1-\alpha)} \left[ \frac{s}{n+g+d} \right]^{\alpha/(1-\alpha)} \tag{11}$$

So the ratio of long run output per hour in an economy with fast growing labour to an otherwise identical economy with slow growing labour is

$$\left[ \frac{n_{slow}+g+\delta}{n_{fast}+g+\delta} \right]^{\alpha/(1-\alpha)} \tag{12}$$

Parameters values appropriate for the UK are $\alpha = 0.35$, $g = 2\%$, $\delta = 7\%$, $n_{slow} = 0.32\%$ and $n_{fast} = 0.95\%$. The value for $n_{slow}$ is the growth rate of native-born employment in the UK while that for $\mathrm{n_{fast}}$ is the growth rate of total (native- and foreign-born) employment, both over 2000-2007 (Table 1). Then the level of labour productivity and hence of the standard of living (consumption per hour worked) in the economy with fast growth of labour will be only 97 per cent of that in the other economy.

In other words, at any moment in time the standard of living in the fast-labour-growth country will always be about 3 per cent less than in the slow-labour-growth one, a significant effect, in fact comparable to the per capita cost of Brexit according to the OECD's projection quoted earlier (OECD, 2016).

### Skilled or Unskilled Immigrants?

I have assumed so far that labour is homogeneous. The case for large-scale immigration is often made on the grounds that migrants bring valuable skills lacking in the native population. No doubt some do but is this true on average? The evidence would suggest not. The OECD skills study (Kuczera *et al.*, 2016) recently measured basic skill levels amongst adults in England on two dimensions, literacy and numeracy:

- Literacy: the ability to read and understand the label on a bottle of Aspirin. To pass you need to be able to answer a question like "What is the maximum number of days you should take this medicine? List 3 situations for which you should consult a doctor"
- Numeracy: the ability to read the petrol gauge on a truck and calculate how much fuel remains in the tank. To pass, you need to be able to see that the tank is three quarters full and to calculate that 36 gallons remain if you are told that the tank holds 48 gallons.

They found that more than a quarter of adults aged 16-65 in England (and 10 per cent of university graduates!) have low basic skills: they fail one or both of these tests, which is worrying enough. But the more relevant finding in the present context is that the skill levels of migrants are lower than those of the native born.[10]

### Has TFP Growth Been Understated After 2007?

At least some of the TFP component of the productivity puzzle would go away if it could be shown that TFP growth had been understated after 2007. This could occur if the growth of capital services has been overstated since the recession began. A high scrapping rate after the recession would lead to this outcome since EUKLEMS uses constant de-

10 A migrant was defined as someone born abroad, at least one of whose parents was also born abroad. Thus this definition excludes the children born to British parents temporarily working abroad. Migrants so defined made up 13 per cent of the population aged 16-65.

preciation rates. But all assets are scrapped, or depreciate essentially to zero, eventually. So premature scrapping may affect TFP estimates during the recession itself but its impact washes out as time goes on and GDP starts growing again. The fact that the post-boom period is eight years long (2007-2015) protects against this potential distortion. However, it is not clear that recessions do lead, on net, to unusually high scrapping rates. There is the countervailing tendency to delay routine replacement during a recession so asset lives lengthen temporarily (Gordon, 2000). If so, TFP growth after 2007 might have been overstated, accentuating the puzzle.

## Appendix C: Policies to Raise Productivity Growth

I have made the case that rapid rates of immigration since the Great Recession began in 2008, along with slow growth rates of export demand, have caused the UK's productivity problem. Since Great Recessions fortunately happen rarely it is very difficult to establish this hypothesis at a fully rigorous empirical level. But policy makers are frequently (always?) in the position of having to make decisions without the economics profession having reached a full consensus. So I list here seven possible policies for raising the rate of productivity growth which merit consideration if the hypothesis is accepted.

### Do Nothing

Doing nothing is a possible response. Immigration after all raises GDP and a larger GDP enables the UK to have larger armed forces and to play a bigger role in world affairs ("punching above our weight"). However at the moment the British people show little appetite for any more foreign interventions, even so-called humanitarian ones. They seem much more concerned with raising living standards, which means raising productivity. Hence doing nothing is not a democratic response, provided that there is some alternative with a chance of success.

### Wait for the World Economy to Revive

When work on this project began there was much optimism amongst international organizations and commentators about growth prospects in Western countries, particularly in Europe. More recently (March 2019) opinion has become more pessimistic. So these earlier hopes may turn out to be misplaced or exaggerated as have others before them. Of course if we wait long enough and growth in China and the rest of Asia continues at its present rate, then eventually this will drag Europe out of its current stagnation. But this is clearly not a riskless strategy.

### Revive the World Economy

According to the estimates in Table 3, columns (3) and (4), raising the growth rate of demand for UK exports by 1 percentage point would raise productivity growth by between 0.87 and 1.27 per cent per year. The problem here is that it is not clear what policy tools are available to achieve this. What the UK needs is a rise in demand for exports which will in turn lead to a revival of investment, with the growth of labour supply held at something like its current rate or below. So just "ending austerity" in the UK will not do the trick. The effect would be just to worsen further the balance of trade, increase debt, and possibly raise inflation above target. The benefit of higher UK imports would spill over to our suppliers but the consequent second round effect on UK exports would be minimal. One theoretical possibility is a coordinated fiscal and/or monetary expansion across the Western world, combined with incentives to raise investment. To state it in these terms merely emphasises how implausible such a policy sounds. But it is possible that a single, large country or a bloc of smaller ones could adopt such policies in an uncoordinated way, which might have something of the desired effect.

### Adopt the European Social Model

The aim here would be to make inward migration unattractive to potential migrants (whether from the EU or elsewhere) by setting wages and other conditions at levels which lower the demand for labour, via dialogue between the social partners. This is a very unattractive alternative. First, higher wages would attract more migrants so the policy would have to incorporate mechanisms to discriminate in favour of natives ("British jobs for British workers"). Second, in practice the European Social Model (at least as practiced outside the Nordic countries) discriminates against the disadvantaged among the native population: consider for example the very high unemployment and low employment rates in the Parisian banlieues. Third, the flexible labour market has arguably been at the root of the UK's success prior to the Great Recession (Aghion *et al.*, 2013; Oulton, 2016a). To revert to something like the labour market institutions of the pre-Thatcher era would be a very retrograde step.

### Restructure UK Trade Towards Faster Growing Areas

There are no doubt numerous micro interventions which could help in this aim. And Brexit may well provide a considerable negative incentive for firms to develop new markets outside the EU, helped by new trade deals. How much effect such policies can be expected to have remains controversial.

### New Incentives for Investment

A policy which the UK could adopt on its own is to give radical new incentives for investment, for example allowing full expensing of all types of investment in the year in which they are made (100 per cent depreciation for tax purposes). This could even be accompanied by an increase in corporation tax. The motivation for an increase is that a low tax rate reduces the incentive to invest since it reduces the value of existing depreciation allowances. A complementary policy which would also encourage private investment is an expansion of public capital spending on infrastructure and R&D.

### Control Immigration

According to the estimates in Table 3, columns (3) and (4), reducing the growth rate of labour by 1 percentage point would raise productivity growth by between 0.43 and 0.51 per cent per year. Assuming Brexit occurs on the scheduled date at the end of October 2019 free movement of labour from the EU can come to an end (at least after the transition period has expired, supposedly at the end of 2020) but as emphasised earlier migrants from the EU constitute less than half the total foreign-born stock.

In theory it should have been easy to reduce migration from the rest of the world, which after all has been the stated policy of the government since 2010, but in practice this has proved not to be the case; since 2010 and up to mid-2017 EU-born workers rose by a million while non-EU ones rose by "only" 700 thousand (Table 1). Perhaps there are countervailing pressures, either from business interests or from the ethnic minority communities already settled here, which make it difficult.

Nevertheless if the basic hypothesis of this article is accepted, then the case for an immigration policy which responds to the needs of the economy is a strong one. The ten years of stagnating productivity could have been avoided had an "emergency brake" on immigration (from all sources) been imposed. This does not mean no immigrants at all. Rather it suggests varying the total in accordance with the state of the economy and severely limiting unskilled immigration. The examples of Canada and Australia both of whom ban unskilled immigrants (except under humanitarian and family reunion programmes) suggest that such a policy is perfectly feasible.[11]

Finally, none of the discussion above should be taken to imply that export demand or immigration are the only things holding back productivity growth in the UK and preventing us from closing the long-standing productivity gap between the UK and other developed countries like France, Germany and the US.. To list just a few widely-cited and discussed problems, the low investment ratio, particularly in R&D, inadequate infrastructure, and poor levels of intermediate and even basic skills have contributed. All these issues are to be addressed we must hope by the government's new Industrial Strategy (HM Government, 2017).

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# Japan's Prefectural-level KLEMS: Productivity Comparison and Service Price Differences


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Abstract

We compile a prefectural-level KLEMS database for Japan and conduct productivity comparisons for Japanese 47 prefectures. One of the difficulties in compiling regional KLEMS database is how to handle variation in service prices across regions. To cope with this problem, we estimated cross-regional price-level differences in each industry in the service sector based on prefectural-level item-wise data of service prices. For estimation, we applied the Country-Product-Dummy (CPD) method, a method used to estimate absolute purchasing power parities among countries. As a result of re-calculation, the standard deviation of cross-regional TFP difference indices in 2009 decreased by around 13 per cent. In addition, by using the derived cross-regional price difference indices, we confirmed that the Balassa-Samuelson effect, which holds among international economies, also holds among regional economies in Japan.


For the purpose of conducting productivity comparison among Japanese 47 prefectures, we compile Japan's prefectural-level KLEMS database,[2] which we call the Regional-level Japan Industrial Productivity (R-

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2 For R-JIP Database 2017 and its brief technical explanation see the RIETI's website at https://www.rieti.go.jp/en/database/R-JIP2017/index.html. The R-JIP 2017 contains real value added, quantity of labour input (man-hours), quality of labour input, and capital service input, covering 23 industry classifications in 47 prefectures, which are comprehensively measured from 1970 to 2012.

JIP) database. One of the difficulties in compiling regional KLEMS database is how to handle possible variation in the levels of service prices across different regions.[3] Japan is not a geographically large country, and the prices of many easily-transported goods can converge among regions by arbitrage transactions. However, many service prices do not hold the same property because they are produced and consumed at the same time in the same place.

How we handle the possibility of variation in prices of the same product across different regions is more important due to the one of the distinguishing features of the R-JIP database. Faithful to the KLEMS spirit, the databese takes accont of regional differences in labour input composition and their wage levels and measures differences in quality of labour input among regions.[4] Because of this feature of the database, if we ignore differences in output prices among regions, we may obtain biased measurement of productivity differentials that cannot be ignored, particularly for service industries. Tokui *et al.* (2013) and Fukao *et al.* (2015) analyze productivity difference among Japanese prefectures in the manner of Caves, Christensen and Diewert (1982), but these analyses are potentially susceptible to such biases.

In order to cope with this problem, we apply the method of measuring absolute purchasing power parity (PPP), i.e. the Country-Product-Dummy (CPD) method of Rao and Timmer (2000), to the variety of service prices among prefectures to calculate price differences in service among prefectures.[5] Item-wise data of prices of services in each prefecture are available in the Retail Price Survey compiled by the Statistic Bureau of the Ministry of Internal Affairs and Communications.[6] We estimate cross-regional price-level differences in five service industries, namely construction, electricity/gas/water, real estate, transportation and communication, and other services in the private sector.

3 United Nations *et al.* (2009) points out two main difficulties regarding regional accounts. One difficulty stems from transactions with other regions, and the other from possible variation in prices of the same product across different regions.

4 See the Appendix 4 of Fukao *et al.* (2015) for the detailed characteristics of the R-JIP database and its construction.

5 In the case of comparing productivity levels among different countries, currencies' valuations should be converted, which requires estimation of absolute purchasing power parities. See, for example, Jorgenson, Kuroda and Nishimizu (1987) who conduct such international comparison in their work to estimate differences in productivity levels between Japan and the United States. In case of the EU KLEMS project, which compares productivity levels within the Eurozone with the single currency, values are converted by absolute purchasing power parities to reflect differences in price levels within the zone.

6 We used the results of surveys conducted in the capital city of each prefecture.

Applying estimsted cross-regional price-level differences, productivity comparison among prefectures are recalculated. As a byproduct, we can obtain the cross-regional price difference index in the Törnqvist formula, by taking the difference between cross-regional TFP differences before and after reflecting regional differences in price levels. The index is used to test whether the Balassa-Samuelson effect, which holds among international economies, also holds among regional economies in Japan.[7] If we can find that high labour productivity regions tend to have higher service prices than low labour productivity regions, this relation can be called the regional version of Balassa-Samuelson effect.

In section 1, we explain how to measure regional differences in price levels of services and its results. Section 2 reports the results of our recalculated productivity analysis factoring in the measured price-level differences among regions. Section 3 reports whether the regional version of the Balassa-Samuelson effect holds, by seeing the correlation between cross-regional price difference indices and cross-regional differences in labour productivity.

## Measuring Service-Price Differences across Regions

To compare productivity levels in absolute terms among different countries, one must convert prices into a common currency as they are expressed in different currencies. This problem becomes easy when arbitarage by trade is at work so that law of one price holds internationally. However, there are some goods and services that are "non-tradable," thus complicating the issue.

Likewise, in our study of different regions within the same country, although no adjustment for differences in price levels is necessary for goods whose prices can be arbitraged between regions through domestic trade, any goods that "cannot be traded" across regions even in the same country pose the same problem as in the context of the international economy. The service sector is typically known for its "simultaneous consumption and production," where, for many types of services, price arbitrage is unlikely to happen through interregional trade.

Hence, our task is to measure different price levels of services across regions. This can be accomplished

7 A phenomenon that poor countries tend to have cheaper domestics prices than rich countries is known as the Balassa-Samuelson effect. The original explanation of this phenomenon is offered by referring to the difference of productivity growth between traded goods and non-traded goods. In rich countries productivity growth tends to be more rapid for traded goods than for non-traded goods, leading to the rise in labour cost and the price of non-traded goods.

by simply applying a method used in international economics to measure absolute purchasing power parities. We use the CPD method à la Rao and Timmer (2000) that measures absolute purchasing power parities based on results of regression analyses of price data collected for individual items in each country.

As for prices of individual items in each region, we use the Retail Price Survey data collected by the Statistic Bureau (of the Ministry of Internal Affairs and Communications) that tracks prices of items in each prefecture over time. The Survey, as one would expect, has changed its composition over years through replacement of items. Some price data may not be necessarily available in all prefectures. Such replacement and missing data in some regions can be handled by the CPD method, which is one of this method's advantages. The Survey makes efforts to ensure consistency in the quality of covered items by specifying them in detail. Although we are rather doubtful of how much they can ensure such consistency in items of the service sector, we would not delve into this topic here.

The CPD method has the additional advantage of only needing price data of individual items, unlike the conventional method of constructing an index that requires data of each item's weight. This is accomplished by using an assumption specific to the CPD method as expressed in the following equation:

$$p_{ir} = \pi_r^* \cdot \eta_i^* \cdot v_{ir}^* \tag{1}$$

- $p_{ir}$: Price of item $i$ in prefecture $r$
- $\pi_r^*$: Cross-regional price-level ratio at industry classification level in the R-JIP database
- $\eta_i^*$: Relative price among items within the same industry classification in the R-JIP database
- $v_{ir}^*$: Random disturbance term

This means that the price of a certain item in each region, if ignoring the random disturbance term, can be expressed by a product of the cross-regional price ratio at industry classification level and the relative price of the item within that industry classification. In other words, relative prices of items within an industry classification are assumed to be the same regardless of region.

Under these assumptions, we take the logarithm of both sides of Equation (1) to obtain Equation (2) below:

$$\begin{aligned} \log p_{ir} &= \log \pi_r^* + \log \eta_i^* + \log v_{ir}^* \\ &= \pi_r + \eta_i + u_{ir} \end{aligned} \tag{2}$$

Equation (2) can be estimated by Ordinary Least Squares, using an equation with the following dummy variables:

$$\log p_{ir} = \pi_1 D_1 + \pi_2 D_2 + \cdots + \pi_{47} D_{47} + \eta_1 D_1^* + \eta_2 D_2^* + \cdots + \eta_n D_n^* + u_{ir} \quad (3)$$

where these two kinds of dummy variables are defined as below:

- $D_r$: The value is 1 if $p_{ri}$ on the left side of the equation is data for prefecture $r$, and equals zero otherwise.
- $D_i^*$: The value is 1 if $p_{ri}$ on the left side of the equation is data for item $i$, and equals zero otherwise.

Since this formula will generate perfect multicollinearity among explanatory variables if left as it is, we imposed a restriction where data of the first prefecture is taken as the numeraire, i.e., $\pi_1^* = 1$ or $\pi_1 = \log \pi_1^* = 0$. Here, we decided to take Tokyo as a reference point (r = 1 for Tokyo) and measure relative price levels in all other prefectures. The value of $\widehat{\pi_r}$ thus estimated gives the cross-regional price ratio at industry classification level in the R-JIP database by using the following equation:

$$\widehat{\pi_r^*} = exp(\widehat{\pi_r}) \quad (4)$$

In our measurement of regional differences in service-price levels, we choose five industries: construction, electricity/gas/water, real estate, transportation and communication, and other private service sectors (including private non-profit sectors). In recent years, these five industries account for 40 per cent - a significantly large share - of total nominal value added in the nation.[8] The largest among them is other private service sectors, accounting for between 23 per cent (in 2000) and 29 per cent (in 2009) of value added by all industries.

Other than those five industries, the R-JIP database contains wholesale and retail, finance and insurance, and the government sector as service-sector industries. However, we excluded those three industries from our study of measuring regional differences in price levels due to conceptual

8 The share was stable at between 43 per cent and 44 per cent during the period from 2000 to 2008. It jumped to 47.5 per cent in 2009 due to the Global Financial Crisis precipitated by the collapse of Lehman Brothers, decreasing value added by manufacturing industries.

**Table 1: Number of Items by Industry: 1970-2010**

| | R-JIP industries | 1970 | 1980 | 1990 | 2000 | 2010 |
|---|---|---|---|---|---|---|
| 16 | Construction | 15 | 16 | 17 | 17 | 19 |
| 17 | Electricity/Gas/Water | 13 | 15 | 24 | 28 | 27 |
| 20 | Real estate | 3 | 3 | 9 | 7 | 7 |
| 21 | Transportation and Communication | 8 | 8 | 18 | 35 | 49 |
| 22 | Other private service industries | 39 | 50 | 78 | 85 | 98 |
| Total | | 78 | 92 | 146 | 172 | 200 |

Source: Statistical Bureau's Retail Price Survey.

difficulty in measuring prices.[9] But in the next section, our analysis of productivity levels output of government sector is adjusted by regional differences in price levels of other private service sectors. Consequently, we made adjustment to the productivity analysis for regional differences in price levels, covering six industries in the service sector, which account for between 50 per cent and 60 per cent of total value added by all industries.

Table 1 shows the number of items in those five industries covered in the Retail Price Surveys at intervals of ten years from 1970 to 2010. The total number of items for all of those five industries in the Survey gradually increased from 78 in 1970 to 200 in 2010.[10] Because the number of data points in a single year is not sufficient to estimate the intended regression equation, we pooled data for every five years up to a year whose last digit was zero or five (for instance, an estimating equation for 1970 used data from 1966 to 1970) and conducted regression at intervals of five years. Accordingly, the approximate number of data points used for each estimating equation is the number of items in Table 1 times 47 (prefectures) times 5 (years).[11] Since our regression uses pooled data of five years, we add year dummies to our regression equation (3) in order to control a macroeconomic shock at a specific year.

Using these data we estimate Equation (3) for five service industries at intervals of five years from 1970 to

9 The value added shares in 2009 of the three industries excluded from adjustment for regional price differences in this study are respectively 13 per cent for the wholesale and retail industries, 6 per cent for the finance and insurance industries, and 12 per cent for the government service. For the wholesale and retail industries, one possible method would be to calculate cross-regional price difference index based on regional differences in commercial margins. This method, however, requires significantly large numbers of merchandise items and data points. As such, we will address this issue in the future.

10 In construction such prices as the cost of hiring carpenters, plasterers, and installing water supply, kitchen facilities, and bath facilities are included. In electricity/gas/water such prices as various types of charges of electricity, gas and water as well as paraffin oil are include. In real estate rents of various types of housing are included. In transportation and communication fares of various types of transport (train, bus, and taxi) and various types of telephone services are included. In other private service industries prices for haircuts, laundry, house cleaning, newspapers, hospital charges, various types of private education, and various types of food services are included.

11 The actual numbers of data points used for estimation are somewhat less than these numbers because some data were missing for items that were not used in certain prefectures.

2010.[12] We can obtain quite robust estimated coefficients for each prefecture dummies. As estimated coefficients of Equation (3) are expressed in logarithmic form, we used the exponential function of Equation (4) to obtain regional relative price levels relative to Tokyo (= 1). These results are shown for the five service industries in 1970, 1990 and 2010 in Tables A1-A5 in the Appendix.[13]

Among those five industries, the real estate industry shows the largest differences in relative price levels across regions. This reflects large differences in levels of rents of various properties across regions in the itemwise data used in the estimation.[14] In the electricity, gas and water industry, regional differences narrowed during the period between 1970 and 1990 but started widening in 2010, showing fluctuations, presumably in reflection of energy price movement during this period. Similar trends are observed in the transportation and communication industry. We also believe this is due to the inclusion of the transportation industry that greatly consumes energy.

Most notable among all is other private service industries (including nonprofit private services). In this industry, relative price levels in most of the prefectures had been lower than those in Tokyo from the beginning and price differentials relative to Tokyo have been growing even wider in recent years in many prefectures. To illustrate this trend, we show the case of Hokkaido in Chart 1, which shows changes in price levels in this industry relative to Tokyo every five years. The falling price relative to Tokyo occurred from 1980s through the first half of the 1990s. After that, the situation has been stable. Other private service industries (including nonprofit private services), accounting for between 20 per cent and 30 per cent of value added by all industries, may also have a significant effect on the measurement of productivity, which is recalculated as described in the next section.[15]

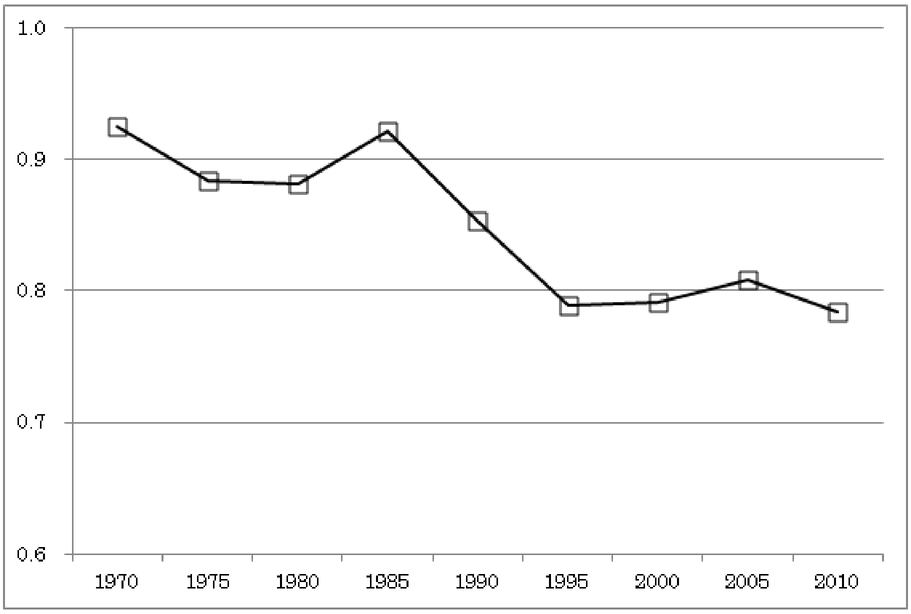
12 Estimation for 1970 uses 45 prefectural dummies because of lack of data of Okinawa prefecture, which is still under the administration of US government. Estimations for 1975 and thereafter use 46 prefectural dummies including reverted Okinawa.

13 Available at: http://www.csls.ca/ipm/36/Tokui_appendix.pdf.

14 Although regional differences in levels of rent on real estate may be divergent from those of real estate brokerage fees, their possible influence on recalculated productivity should be small because the real estate industry accounts for 2 per cent - not a large share - of value added by all industries.

15 The impact of regional price differences in the service industry (private sector and non-profit) is even greater, because they are also applied to the government service industry when we conduct productivity analysis as mentioned above.

**Chart 1: Changes in Relative Price in Other Private Service Industries (including Non-profit Private Serrvices) in Hokkaido, Tokyo=1, 1970-1=2010**




Source: Drawn from Table A5 (see Online Appendix).

## Productivity Analysis Corrected for Regional Differences in Service-Price Levels

Using the R-JIP database, indices to compare productivity levels across prefectures have been developed and analyzed by Tokui *et al.* (2013) and Fukao *et al.* (2015). Their studies, as shown below, measured relative productivity levels of individual industries in each prefecture (hereinafter referred to as relative TFPs), by assuming a translog production function based on value added for each industry and each prefecture, and by using the method of Cave, Christensen and Diewert (1982) for constructing an index for cross-sectional productivity comparison. Adjustment for quality was made only to labour input. For capital input, industry-specific quality was taken into consideration, but regional quality differences were not.

$$RTFP_{ir} = \log\left(\frac{V_{ir}}{\overline{V}_i}\right) - \frac{1}{2}(S_{ir}^K + \overline{S}_i^K)\log\left(\frac{K_{ir}}{\overline{K}_i}\right) - \frac{1}{2}(S_{ir}^L + \overline{S}_i^L)\left[\log\left(\frac{H_{ir}}{\overline{H}_i}\right) + \log\left(\frac{Q_{ir}^L}{\overline{Q}_i^L}\right)\right] \quad (5)$$

- $V_{ir}$: Real value added by industry $i$ in prefecture $r$
- $K_{ir}$: Real capital stock in industry $i$ in prefecture $r$
- $H_{ir}$: Labour input in man-hours in industry $i$ in prefecture $r$
- $Q_{ir}^L$: Labour quality in industry $i$ in prefecture $r$

Variables with a bar on top represent the national averages (geometric means) of individual industries, which are expressed by the following equations:

- $\log \overline{V}_i = \frac{1}{47}\sum_{r=1}^{47} \log V_{ir}$
- $\log \overline{K}_i = \frac{1}{47}\sum_{r=1}^{47} \log K_{ir}$
- $\log \overline{H}_i = \frac{1}{47}\sum_{r=1}^{47} \log H_{ir}$
- $\log \overline{Q}_i^L = \frac{1}{47}\sum_{r=1}^{47} \log Q_{ir}^L$

Here, $S_{ir}^K$ represents the cost share of capital and $S_{ir}^L$ the cost share of labour. Those with a bar on top are the national averages (arithmetic means) of the respective shares of individual industries, which are obtained from:

- $\overline{S}_i^K = \frac{1}{47}\sum_{r=1}^{47} S_{ir}^K$
- $\overline{S}_i^L = \frac{1}{47}\sum_{r=1}^{47} S_{ir}^L$

The prefecture- and industry-specific relative TFPs are multiplied with value-added weights and aggregated over all industries with the following equations to derive the relative TFP for each prefecture. $S_{ir}^V$ stands for the value-added weight of an industry in a particular prefecture. The symbol with a bar on top is the national average (arithmetic mean) of the industry.

$$RTFP_r = \sum_{i=1}^{23} \frac{1}{2}(S_{ir}^V + \overline{S}_i^V)RTFP_{ir} \quad (6)$$

$$\overline{S}_i^V = \frac{1}{47}\sum_{r=1}^{47} S_{ir}^V$$

Our previous analyses (Tokui *et al.* (2013) and Fukao *et al.* (2015)) utilize the R-JIP database, whose nominal value added by prefecture and industry is derived by breaking down national totals from the Japan Industrial Productivity (JIP) database by multiplying the prefectural shares caluculated from the Prefectural Accounts as well as the Census of Manufactures.[16] To obtain real value added, we apply industry-level deflators from the JIP database. Our previous analyses implicitly assumed that price-levels by industry were identical across prefectures.

In this study, we estimate differences in price levels across prefectures for each service industry as derived in Section 1. We use these estimated results to recalculate relative TFPs. To distinguish the symbol for the real

16 The JIP database is Japan's KLEMS project and covers 108 industries at the multinational level. For details of the JIP database, see Fukao *et al.* (2007) and the RIETI's website at https://www.rieti.go.jp/en/database/JIP2015/index.html. Although Japan's SNA is now based on the 2008 SNA, the Prefectural Accounts are still based on 1993 SNA. For consistency, value added and investment of the R-JIP database are also based on 1993 SNA.

value added by an industry in a prefecture that reflected regional differences in price levels of output from the previously used symbol, we expressed it by ($V_{ir}^{\#}$) with the superscript #. The cross-regional price difference for output of industry i is denoted $P_{ir}$ (for those industries that were not subject to our adjustment for regional price differences, the index always takes the value of 1.) Then the relationship between the two can be expressed as follows:[17]

$$V_{ir}^{\#} = \frac{V_{ir}}{P_{ir}} \tag{7}$$

Since the numerator of (7) is value added, a more exact approach would be double deflation,[18] not simply deviding by the price index. But to construct deflatos consistent with double deflation we need input-output tables for each prefecture. A lack of consistent prefectural input-output tables is the main reason why we cannot use double deflation. In this article we restrict the application of regional price-level adjustment to service sectors, in which the ratio of intermediate inputs to the value of output is relatively low compared with non-service sectors, especially manufacturing. This provides some justification for this procedure. By letting the variables in the above equation with a bar on top denote the respective national averages (geometric means) of the industry, we obtain:

$$\log\left(\frac{V_{ir}^{\#}}{\overline{V}_i^{\#}}\right) = \log\left(\frac{V_{ir}}{\overline{V}_i}\right) - \log\left(\frac{P_{ir}}{\overline{P}_i}\right) \tag{8}$$

- $\log \overline{V}_i^{\#} = \frac{1}{47}\sum_{r=1}^{47} \log V_{ir}^{\#}$
- $\log \overline{P}_i = \frac{1}{47}\sum_{r=1}^{47} \log P_{ir}$

Relative TFPs that factor in cross-prefectural price level gaps can be computed by replacing real value added in Equation (5) with the newly calculated $V_{ir}^{\#}$, which gives us the following equation.

17 $P_{ir}$ in the denominator of (7), which is in capital letters, is the cross-regional price ratio derived by CPD method, while $p_{ir}$ in (1), which is in small letters, is price row of individual service items.

18 The EU-KLEMS project produces output PPPs, intermediate input PPPs, labour input PPPs, and capital input PPPs to convert the corresponding nominal values into real values. See Inklaar and Timmer (2008) to know the method used in the EU KLEMS project. Our R-JIP database has already dealt with labour input PPPs, as labour input values are obtained while taking into account regional differences in the compositions of worker attributes and wages. The database, however, does not factor in capital input PPPs on the assumption that there is no regional difference in capital cost in each industry. Also, instead of implementing double deflation by calculating output PPPs and intermediate input PPPs as EU KLEMS do, which is a more exact approach, we settle with a simplified method in which we derive regional price differences in each industry as the equivalent of output PPPs and apply them to value added in a single deflation approach, as our study is limited to the service sector. If we could use input-output table by prefecture compiled under the same standard, we would be able to obtain value added PPPs in a manner consistent with the R-JIP database with output PPPs and intermediate input PPPs. This is an issue to be addressed in future.

$$RTFP^{\#}_{ir} = \log\left(\frac{V^{\#}_{ir}}{\overline{V}^{\#}_{i}}\right) - \frac{1}{2}\left(S^{K}_{ir} + \overline{S}^{K}_{ir}\right)\log\left(\frac{K_{ir}}{\overline{K}_{i}}\right) - \frac{1}{2}\left(S^{L}_{ir} + \overline{S}^{L}_{i}\right)\left[\log\left(\frac{H_{ir}}{\overline{H}_{i}}\right) + \log\left(\frac{Q^{L}_{ir}}{\overline{Q}^{L}_{i}}\right)\right] \quad (9)$$

Comparing this equation and the original Equation (5) and considering the relationship expressed in Equation (8), we found the following relationship between the newly calculated and previously calculated TFPs.

$$RTFP^{\#}_{ir} = RFTP_{ir} - \log\left(\frac{P_{ir}}{\overline{P}_{i}}\right) \quad (10)$$

The prefecture- and industry-specific relative TFPs obtained above can be aggregated over all industries in the way we do with Equation (6) so that we can compare levels of prefectural productivity, as with the following equation:

$$RTFP^{\#}_{r} = \sum_{i=1}^{23}(S^{V}_{ir} + \overline{S}^{V}_{i})RTFP^{\#}_{ir} \quad (11)$$

Substitution of Equation (10) into this equation produces Equation (12), which reveals that the difference between the newly calculated and previously calculated prefectural relative TFPs can generate a value that represents cross-prefectural price-gap index values for output for individual industries aggregated over all industries with the Törnqvist Index.

$$RTFP^{\#}_{r} = RFTP_{r} - \sum_{i=1}^{23}(S^{V}_{ir} + \overline{S}^{V}_{i})\log\left(\frac{P_{ir}}{\overline{P}_{i}}\right) \quad (12)$$

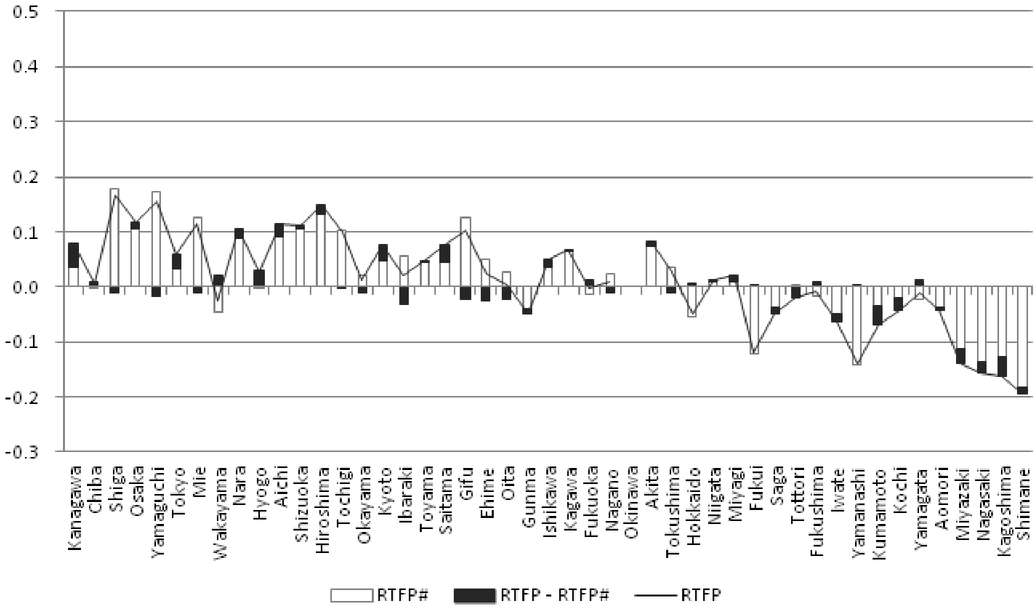
Now, let us look at the result of the calculated relative TFPs that reflect differences in price levels among prefectures.[19] Chart 2 shows calculated results for 1970 and 2009 respectively. Lines on the charts are relative TFPs previously calculated before price adjustment. The white bar graphs show newly calculated relative TFPs. The black portions of bars show the magnitude of corrections made by adjusting for relative price levels in the service sector. In prefectures where relative price levels in service industries are high, their relative TFPs that have been inflated without such adjustment decrease and in prefectures with lower service-price levels, adjustment goes in the opposite direction.

In each chart, the horizontal axis represente prefectures, which are sorted in the decending order of labour productivity from left side

19 Here, the relative TFP is recalculated based on the R-JIP Database 2014 covering the data period between 1970 and 2009.

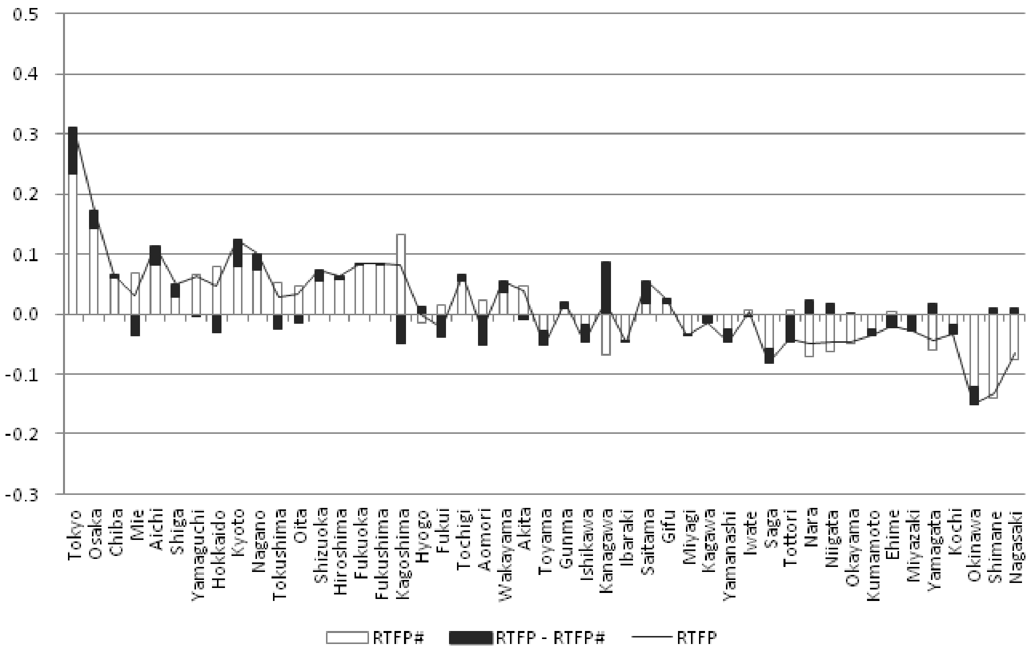
**Chart 2: Relative TFPs Reflecting Differences in Price Levels among Prefectures, 1970 and 2009**

**(a) 1970**




The horizontal axis represents prefectures, which are arrenged in order of labour productivity. Prefectures with higher labour producitivity are placed on the left side. See Chart 3: Panel A.

**(b) 2009**




The horizontal axis represents prefectures, which are arrenged in order of labour productivity. Prefectures with higher labour producitivity are placed on the left side. See Chart 3: Panel B.

Source: Authors' calculations based on Statistical Bureau's Retail Price Survey and R-JIP database.

to right side. By taking account of regional price differences, TFP tends to be revised downward in high labour productivity prefectures and TFP tends to be revised upward in low labour productivity prefectures. In other words, service price-levels are high in high labour productivity prefectures and low in low labour productivity prefectures. While on regional-version of Balassa-Samuelson effect we discuss more in detail in the next section, this tendency revealed in Chart 2 is additional evidence that we can observe something like the Balassa-Samuelson effect across domestic regions.

Comparison between Chart 2: Panel A for 1970 and Chart 2: Panel B for 2009 shows that incorporation of regional differences in price levels of services produces greater impact on regional differences in relative TFPs in 2009. This is for two reasons mentioned in the previous section. First, the value-added weight of service industries in all industries become larger in 2009. Second, in other privte service industries (including non-profit private services), which has a large weight, regional price differences become wider.

It is hard to tell whether the degree of differences in relative TFPs across prefectures narrowed or widened on the whole only by looking at Chart 2 after making the corrections. Hence, we calculate standard deviations that show degrees of dispersion of the newly calculated and the previously calculated relative TFPs across prefectures and compare them at 10-year intervals as shown in Table 2. The result shows that, in all years, the values for relative TFPs that reflect prefectural price-level differences are smaller than those without reflecting such price-differentials. This means that the measures of cross-regional productivity gaps have been somewhat exaggerated by not considering regional price-level differentials in the service sector. Differences between the two is larger in and after 1990. For instance, our result shows that for 1970, the standard deviation of cross-regional TFP difference index values decreases by around 7 per cent from 0.089 per cent to 0.083 per cent, while for 2009, the standard deviation of the index decreases by around 13 per cent, going from 0.079 to 0.069.

Let us conclude this section by looking at how cross-prefectural differences in labour productivity are decomposed (into capital-labour ratio, labour quality, and relative TFP) based on our results of newly calculated relative TFPs obtained by reflecting regional differences in service-price levels. Chart 3 illustrates the results of the decomposition for 1970 and 2009. Forty years ago, regional differences in capital-labour ra-

Table 2: Comparison of Standard Seviations of Two Regional TFP Indexes for Japanese Prefectures

| | 1970 | 1980 | 1990 | 2000 | 2008 | 2009 |
|---|---|---|---|---|---|---|
| Old regional TFP | 0.089 | 0.074 | 0.080 | 0.069 | 0.084 | 0.079 |
| New regional TFP | 0.083 | 0.070 | 0.065 | 0.055 | 0.072 | 0.069 |

Source: Authors' calculations.

tios (bars in black) played a major role in regional differences in labour productivity. Their influence has gradually decreased in recent years to be replaced by regional differences in relative TFPs (bars in white), which plays a significant role. This is the same results found by Tokui *et al.* (2013), Fukao *et al.* (2015), and others.

To put it another way, although factoring into regional differences in service price levels has an effect of moderately correcting overestimation of cross-regional differences in relative TFPs, the effect is not significant enough to reverse the conclusion that regional gaps in relative TFPs have become an important factor in explaining regional differences in labour productivity in recent years.[20]

## Regional Differences in Service-Price Levels and the Balassa-Samuelson Effect

Our results, so far, showed not only that regional differences in productivity still exist even within Japan, but also that regional differences in price levels are observed in the service sector. This led us to the question of whether such regional differences in price levels observed within Japan are consistent with the Balassa-Samuelson effect, which is well-known in international economics.[21] Balassa (1964) and Samuelson (1964) explained why absolute purchasing power parities across countries do not converge to one even in the long-run because of differences in productivity between the tradable and non-tradable goods sectors. The Balassa-Samuelson effect explains why domestic prices tend to be high in developed countries than in developing countries.

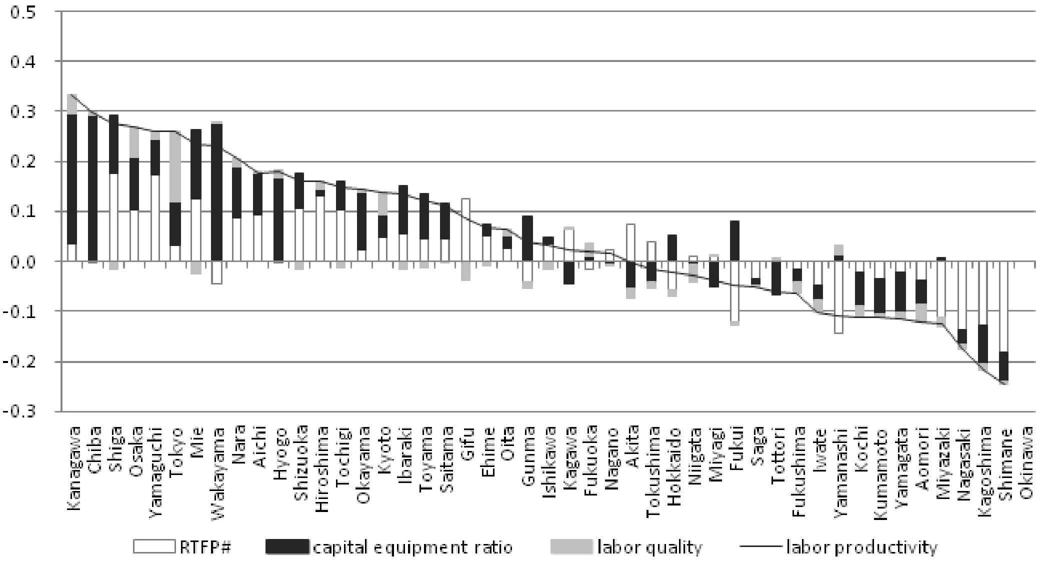
If the comparison between developed and developing countries corresponds to, within a country, dif-

20 Tokui *et al.* (2013) and Fukao *et al.* (2015) conduct more detailed analyses and conclud that many of the differences in relative TFPs, the major source of regional differences in labour productivity still remaining in recent years, are caused by regional differences in the service sector. It is important that this study has confirmed the importance of regional differences in relative TFPs, even after factoring in regional price differences in the service industry.

21 We defines the "Balassa-Samuelson (BS) effect" as the phenomenon that prices of services (non-tradable goods) are higher in relatively rich countries and lower in relatively poor countries. As a mechanism behind such phenomenon observed, they focused on differences in productivity levels between traded and non-traded goods. This article, however, does not include discussion of such underlying mechanism.

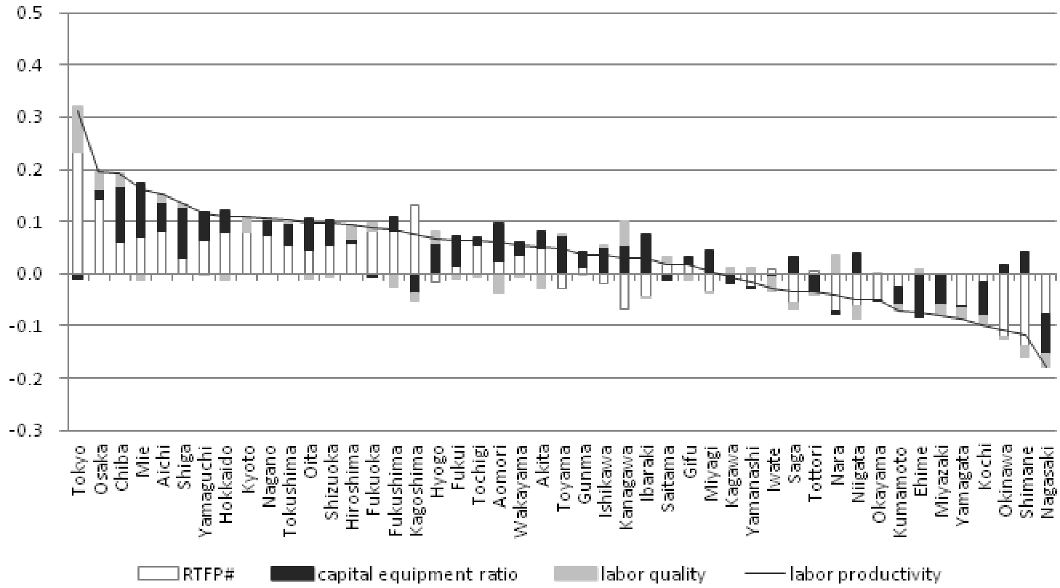
**Chart 3: Decomposition of Differences in Regional Labour Productivity, 1970 and 2009**

**(a) 1970**




The horizontal axis represents prefectures, which are arrenged in order of labour productivity. Prefectures with higher labour producitivity are placed on the left side.

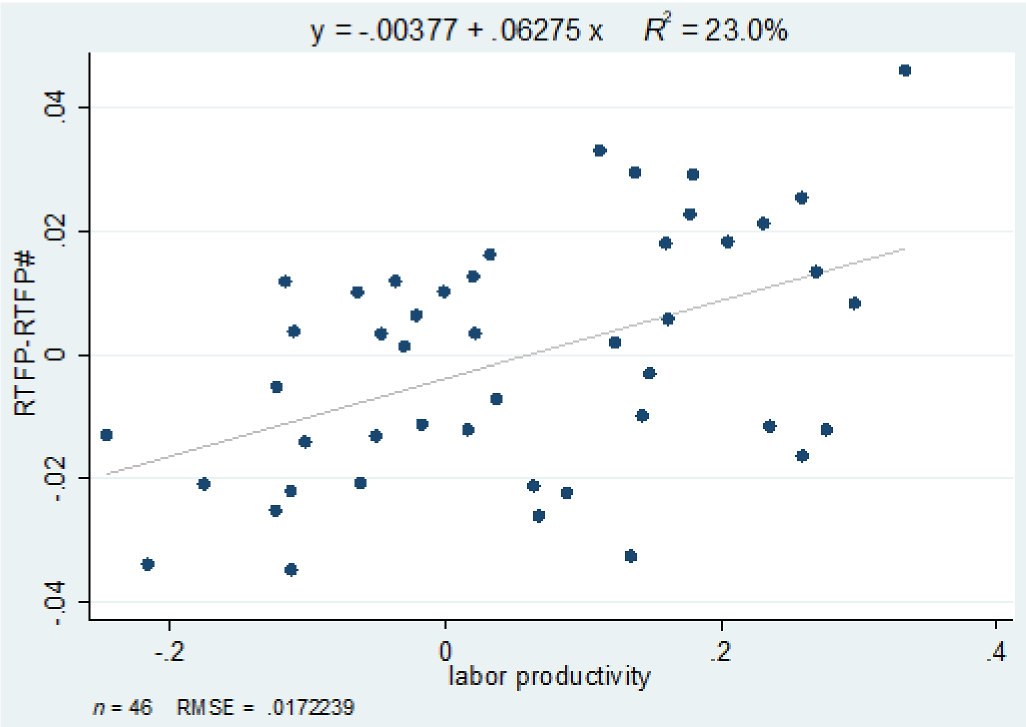
**(b) 2009**



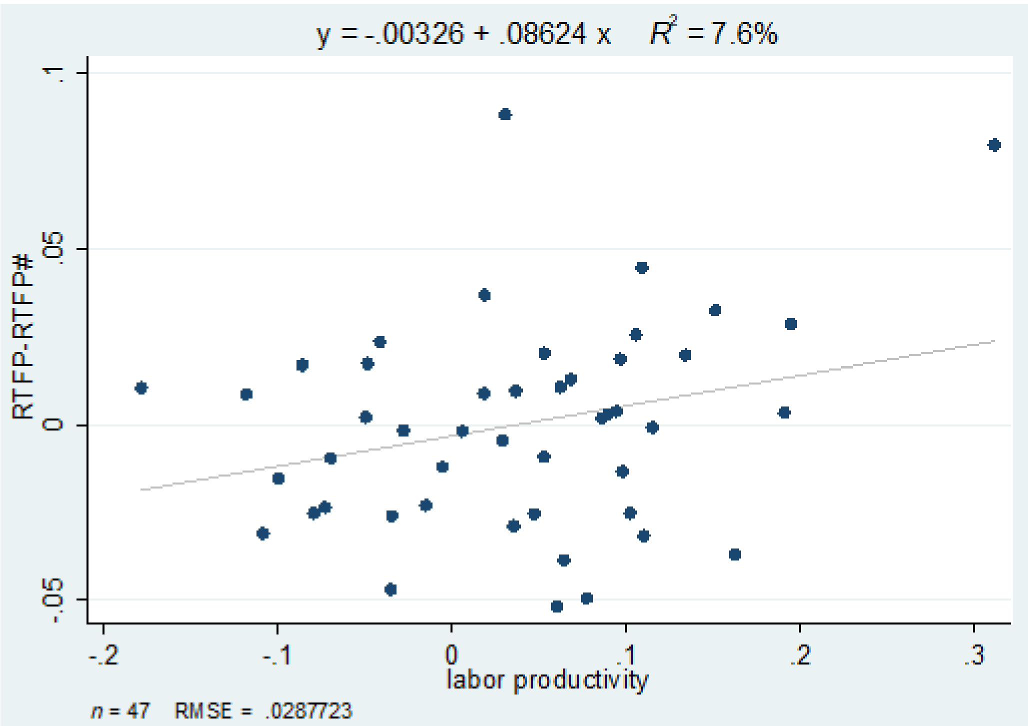

The horizontal axis represents prefectures, which are arrenged in order of labour productivity. Prefectures with higher labour producitivity are placed on the left side.
Source: Authors' calculations.

**Chart 4: Correlation between Regional Differences in Price Levels and Differences in Labour Productivity, 1970 and 2009**

**(a) 1970**




**(b) 2009**




Source: Drawn based on authors' calculations.

**Table 3: Correlation Coefficients between Regional Differences in Price Levels and Differences in Labour Productivity and Their Significance Level from 1970 through 2009**

| | 1970 | 1980 | 1990 | 2000 | 2008 | 2009 |
|---|---|---|---|---|---|---|
| Correlation coef. | 0.480 | 0.371 | 0.612 | 0.332 | 0.322 | 0.276 |
| Significance level | 0.001 | 0.010 | 0 | 0.023 | 0.028 | 0.06 |

Source: Authors' calculations.

ferences between regions with high and low labour productivity, we would expect that in regions with high labour productivity relative price levels should be higher due to higher prices of non-tradable services. As we can obtain cross-regional price difference indices by using Equation (12) as explained in the previous section, we can look at the correlation between these values and levels of regional labour productivity to test whether the domestic version of the Balassa-Samuelson effect holds.

Our cross-regional price difference index, which appears in the second term of equation (12), depends by its construction not only on price differences of each industry but also their value-added share in each region. But we take into calculation only regional price-level differences in service industries and assume that there are no price-level differences in non-service industries by arbitrage transactions among regions.

Chart 4 is a scatter plot diagram to analyze correlation between cross-regional price difference indices and differences in labour productivity at prefecture level for 1970 and 2009. The chart shows a regression line where the cross-regional price difference index is regressed on the labour productivity difference. These scatter plots indicate weak positive correlation between the two. Table 3 summarises these scatter plots in correlation coefficients between the two variables and their level of significance. With the exception of 2009, in nearly all years in the table, the correlation coefficient is significant at the 1 per cent or 5 per cent level.[22] We can conjecture that in regions with high labour productivity levels, wages become relatively higher in excess of productivity differences in the service sector, which raises relative price levels of services in these regions.

22 We observe much higher correlation between cross-regional price difference and labour productivity in 1990. 1990 is one of the years of the "bubble economy" in Japan, in which service industries boomed especially in megalopolis regions. Theses regions are places with high labour productivity, which experienced economic boom causing higher service prices in those years. It is the background of unusuary high correlation in that particular year.

## Conclusion

The objective of this study has been to correct the shortcoming of the R-JIP database, which has been published without reflecting regional differences in price levels in service industries, even though service industries are thought to have gained importance in cross-regional productivity analysis. Based on the R-JIP database, earlier studies conclude that, as the underlying factors to explain regional differences in labour productivity in Japan in recent years, differences in productivity levels within an industry, as measured by relative TFPs, came to play a more important role, and among industries, differences in relative TFPs in service industries were becoming more important.

To estimate cross-regional relative price levels, we use item-wise price data compiled by the Retail Price Survey, and we apply the CPD method that is developed to measure absolute purchasing power parities. The results are then incorporated into our productivity analysis to make recalculation.

Our study finds out that although factoring in regional differences in service price levels has an effect of moderately correcting overestimation of regional differences in relative TFPs, an effect is not large enough to change the conclusion that cross-regional differences in relative TFPs have become an important factor in explaining the regional differences in labour productivity in recent years. Furthermore, we test an intra-national version of the Balassa-Samuelson effect by calculating the correlation between the cross-regional price difference index values, a byproduct of our productivity analysis, and regional differences in labour productivity. We find that relationships indicative of the Balassa-Samuelson effect can be observed among Japanese regions.

The issue of regional price-level differences in service industries discussed in this study, while not going so far as to significantly correct the previous studies on decomposition of regional differences in labour productivity, is likely to gain more importance because the share of service industries in the total value added of all industries has been expanding and because regional price-level gaps have widened in other private service industries. This suggests that, in cross-regional productivity analysis, it is necessary to carefully handle regional price-level differences arising from service industries' salient feature of simultaneous consumption and production.

We conclude by highlighting two major issues that could not be addressed in this study. First, we did not adjust for regional price-level differences in the wholesale and retail industry due to unavailability of appropriate item-wise data that would fit the method used in this study. However, the wholesale and retail industry, accounting for more than 10 per cent of total value added, might affect our result. Therefore, we need to devise ways to include it in our adjustment for regional price-level differences by imposing some assumption, such as an assumption that regional price-level differences for merchandise are refleted in regional price-level differences in commercial margins. Second is the issue of the deflation of value added given that output is measured by value added in the R-JIP database. In principle, it is preferable to adopt double deflation. That, however, requires input-output tables by region, indicating the needs to refine and expand our database.

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# Online Appendix: Japan's Prefectural-level KLEMS: Productivity Comparison and Service Price Differences[a]

a The main article is available at http://www.csls.ca/ipm/36/Tokui.pdf.

**Table A1: Relative Price Levels by Prefecture in the Construction Industry, Tokyo = 1, Comparisons in Years 1970, 1990, and 2010**

| | prefecture | 1970 | | 1990 | | 2010 | |
|---|---|---|---|---|---|---|---|
| | | Relative Price | Std.Err. | Relative Price | Std.Err. | Relative Price | Std.Err. |
| 1 | Hokkaido | 0.961 | 0.035 | 1.035 | 0.036 | 0.973 | 0.031 |
| 2 | Aomori | 0.925 | 0.033 | 0.901 | 0.032 | 1.005 | 0.032 |
| 3 | Iwate | 0.888 | 0.031 | 0.848 | 0.030 | 0.992 | 0.032 |
| 4 | Miyagi | 0.930 | 0.033 | 0.917 | 0.032 | 0.944 | 0.030 |
| 5 | Akita | 0.981 | 0.035 | 0.871 | 0.031 | 0.932 | 0.030 |
| 6 | Yamagata | 1.053 | 0.037 | 0.822 | 0.029 | 0.971 | 0.031 |
| 7 | Fukushima | 0.934 | 0.033 | 0.880 | 0.031 | 1.001 | 0.032 |
| 8 | Ibaraki | 0.900 | 0.032 | 0.907 | 0.032 | 0.973 | 0.031 |
| 9 | Tochigi | 0.917 | 0.033 | 0.829 | 0.029 | 0.979 | 0.031 |
| 10 | Gunma | 0.929 | 0.033 | 0.904 | 0.032 | 0.926 | 0.030 |
| 11 | Saitama | 0.970 | 0.034 | 0.885 | 0.031 | 0.942 | 0.030 |
| 12 | Chiba | 0.965 | 0.034 | 0.889 | 0.031 | 0.955 | 0.031 |
| 13 | Tokyo | 1 | . | 1 | . | 1 | . |
| 14 | Kanagawa | 1.009 | 0.036 | 1.046 | 0.037 | 1.105 | 0.035 |
| 15 | Niigata | 0.955 | 0.034 | 0.907 | 0.032 | 1.001 | 0.032 |
| 16 | Toyama | 0.926 | 0.033 | 0.870 | 0.031 | 0.949 | 0.030 |
| 17 | Ishikawa | 0.957 | 0.034 | 0.954 | 0.033 | 0.983 | 0.032 |
| 18 | Fukui | 0.888 | 0.032 | 0.939 | 0.033 | 1.023 | 0.033 |
| 19 | Yamanashi | 0.900 | 0.032 | 0.917 | 0.032 | 0.940 | 0.030 |
| 20 | Nagano | 0.996 | 0.035 | 0.908 | 0.032 | 0.934 | 0.030 |
| 21 | Gifu | 0.928 | 0.033 | 0.949 | 0.033 | 0.935 | 0.030 |
| 22 | Shizuoka | 0.959 | 0.034 | 0.890 | 0.031 | 0.988 | 0.032 |
| 23 | Aichi | 1.089 | 0.038 | 1.063 | 0.037 | 0.990 | 0.032 |
| 24 | Mie | 0.886 | 0.031 | 0.890 | 0.031 | 0.990 | 0.032 |
| 25 | Shiga | 0.908 | 0.032 | 0.923 | 0.032 | 1.022 | 0.033 |
| 26 | Kyoto | 1.015 | 0.036 | 0.995 | 0.035 | 0.957 | 0.031 |
| 27 | Osaka | 0.920 | 0.032 | 0.967 | 0.034 | 1.027 | 0.033 |
| 28 | Hyogo | 0.967 | 0.034 | 0.980 | 0.034 | 0.983 | 0.032 |
| 29 | Nara | 0.981 | 0.035 | 0.893 | 0.031 | 0.948 | 0.030 |
| 30 | Wakayama | 0.986 | 0.035 | 0.941 | 0.033 | 1.058 | 0.034 |
| 31 | Tottori | 0.922 | 0.033 | 0.863 | 0.030 | 0.976 | 0.031 |
| 32 | Shimane | 0.978 | 0.035 | 0.887 | 0.031 | 0.981 | 0.031 |
| 33 | Okayama | 0.914 | 0.032 | 0.869 | 0.031 | 0.960 | 0.031 |
| 34 | Hiroshima | 0.981 | 0.034 | 0.951 | 0.033 | 0.932 | 0.030 |
| 35 | Yamaguchi | 0.962 | 0.034 | 0.873 | 0.031 | 1.018 | 0.033 |
| 36 | Tokushima | 0.936 | 0.033 | 0.897 | 0.031 | 0.941 | 0.030 |
| 37 | Kagawa | 0.900 | 0.032 | 0.783 | 0.027 | 0.876 | 0.028 |
| 38 | Ehime | 0.934 | 0.033 | 0.876 | 0.031 | 0.854 | 0.027 |
| 39 | Kochi | 0.956 | 0.034 | 0.854 | 0.030 | 0.954 | 0.031 |
| 40 | Fukuoka | 0.903 | 0.032 | 0.880 | 0.031 | 0.955 | 0.031 |
| 41 | Saga | 0.895 | 0.032 | 0.782 | 0.027 | 0.980 | 0.031 |
| 42 | Nagasaki | 0.879 | 0.031 | 0.957 | 0.034 | 1.010 | 0.032 |
| 43 | Kumamoto | 0.951 | 0.034 | 0.877 | 0.031 | 1.046 | 0.034 |
| 44 | Oita | 0.924 | 0.033 | 0.768 | 0.027 | 1.009 | 0.032 |
| 45 | Miyazaki | 0.861 | 0.031 | 0.781 | 0.027 | 0.887 | 0.028 |
| 46 | Kagoshima | 0.899 | 0.032 | 0.779 | 0.027 | 0.935 | 0.030 |
| 47 | Okinawa | | . | 0.778 | 0.027 | 0.884 | 0.028 |

Source: Authors calculations based on Statistical Bureaus Retail Price Survey.

**Table A2: Relative Price Levels by Prefecture in the Electricity, Gas and Water Industry, Tokyo = 1, Comparisons in Years 1970, 1990, and 2010**

| | prefecture | 1970 | | 1990 | | 2010 | |
|---|---|---|---|---|---|---|---|
| | | Relative Price | Std.Err. | Relative Price | Std.Err. | Relative Price | Std.Err. |
| 1 | Hokkaido | 1.274 | 0.077 | 0.899 | 0.031 | 1.201 | 0.053 |
| 2 | Aomori | 1.752 | 0.104 | 0.808 | 0.028 | 1.141 | 0.050 |
| 3 | Iwate | 0.922 | 0.056 | 0.763 | 0.027 | 1.128 | 0.049 |
| 4 | Miyagi | 1.092 | 0.065 | 0.679 | 0.024 | 1.080 | 0.048 |
| 5 | Akita | 1.023 | 0.061 | 0.847 | 0.030 | 1.181 | 0.053 |
| 6 | Yamagata | 0.975 | 0.058 | 0.932 | 0.033 | 1.167 | 0.052 |
| 7 | Fukushima | 0.991 | 0.059 | 0.861 | 0.030 | 1.211 | 0.054 |
| 8 | Ibaraki | 0.970 | 0.059 | 0.809 | 0.028 | 1.131 | 0.050 |
| 9 | Tochigi | 0.914 | 0.054 | 0.906 | 0.032 | 1.100 | 0.049 |
| 10 | Gunma | 1.104 | 0.065 | 0.774 | 0.027 | 1.056 | 0.048 |
| 11 | Saitama | 1.073 | 0.064 | 0.851 | 0.030 | 1.114 | 0.050 |
| 12 | Chiba | 1.114 | 0.067 | 0.815 | 0.029 | 0.960 | 0.042 |
| 13 | Tokyo | 1 | . | 1 | . | 1 | . |
| 14 | Kanagawa | 1.035 | 0.063 | 0.936 | 0.033 | 0.990 | 0.043 |
| 15 | Niigata | 0.969 | 0.059 | 0.781 | 0.027 | 1.055 | 0.047 |
| 16 | Toyama | 1.051 | 0.062 | 0.742 | 0.026 | 1.093 | 0.048 |
| 17 | Ishikawa | 0.931 | 0.055 | 0.824 | 0.029 | 1.064 | 0.047 |
| 18 | Fukui | 0.938 | 0.056 | 0.724 | 0.026 | 1.014 | 0.044 |
| 19 | Yamanashi | 0.948 | 0.056 | 0.855 | 0.031 | 0.987 | 0.044 |
| 20 | Nagano | 0.995 | 0.059 | 0.917 | 0.033 | 1.093 | 0.048 |
| 21 | Gifu | 0.932 | 0.055 | 0.888 | 0.031 | 1.022 | 0.046 |
| 22 | Shizuoka | 0.931 | 0.055 | 0.808 | 0.028 | 1 | 0.044 |
| 23 | Aichi | 0.901 | 0.054 | 0.919 | 0.033 | 1.159 | 0.051 |
| 24 | Mie | 0.973 | 0.059 | 0.673 | 0.024 | 0.885 | 0.039 |
| 25 | Shiga | 0.996 | 0.060 | 0.920 | 0.033 | 1.135 | 0.051 |
| 26 | Kyoto | 0.999 | 0.060 | 0.921 | 0.033 | 1.161 | 0.052 |
| 27 | Osaka | 0.936 | 0.057 | 0.766 | 0.027 | 0.977 | 0.043 |
| 28 | Hyogo | 1.025 | 0.062 | 0.952 | 0.034 | 1.097 | 0.049 |
| 29 | Nara | 1.121 | 0.068 | 0.934 | 0.034 | 1.125 | 0.052 |
| 30 | Wakayama | 1.006 | 0.060 | 0.831 | 0.029 | 1.043 | 0.046 |
| 31 | Tottori | 0.968 | 0.057 | 0.789 | 0.028 | 1.035 | 0.045 |
| 32 | Shimane | 1.016 | 0.060 | 0.972 | 0.034 | 1.212 | 0.053 |
| 33 | Okayama | 0.924 | 0.055 | 0.807 | 0.028 | 1.102 | 0.048 |
| 34 | Hiroshima | 0.955 | 0.057 | 0.793 | 0.028 | 1.054 | 0.045 |
| 35 | Yamaguchi | 0.940 | 0.056 | 0.937 | 0.033 | 1.172 | 0.051 |
| 36 | Tokushima | 0.964 | 0.057 | 0.740 | 0.026 | 1.066 | 0.047 |
| 37 | Kagawa | 0.972 | 0.058 | 0.843 | 0.030 | 1.145 | 0.050 |
| 38 | Ehime | 0.999 | 0.059 | 0.843 | 0.030 | 1.057 | 0.046 |
| 39 | Kochi | 0.953 | 0.058 | 0.817 | 0.029 | 0.904 | 0.039 |
| 40 | Fukuoka | 1.016 | 0.061 | 0.958 | 0.034 | 1.005 | 0.044 |
| 41 | Saga | 1.069 | 0.064 | 0.955 | 0.034 | 1.293 | 0.058 |
| 42 | Nagasaki | 1.088 | 0.066 | 0.996 | 0.035 | 1.125 | 0.051 |
| 43 | Kumamoto | 1.001 | 0.060 | 0.742 | 0.026 | 1.110 | 0.049 |
| 44 | Oita | 0.977 | 0.059 | 0.831 | 0.029 | 1.200 | 0.054 |
| 45 | Miyazaki | 0.966 | 0.058 | 0.863 | 0.031 | 1.140 | 0.052 |
| 46 | Kagoshima | 0.843 | 0.052 | 0.757 | 0.027 | 0.980 | 0.043 |
| 47 | Okinawa | | . | 0.865 | 0.031 | 1.215 | 0.053 |

Source: Authors calculations based on Statistical Bureaus Retail Price Survey.

**Table A3: Relative Price Levels by Prefecture in the Real Estate Industry, Tokyo = 1, Comparisons in Years 1970, 1990, and 2010**

| | prefecture | 1970 | | 1990 | | 2010 | |
|---|---|---|---|---|---|---|---|
| | | Relative Price | Std.Err. | Relative Price | Std.Err. | Relative Price | Std.Err. |
| 1 | Hokkaido | 0.652 | 0.051 | 0.571 | 0.035 | 0.503 | 0.022 |
| 2 | Aomori | 0.422 | 0.033 | 0.489 | 0.032 | 0.430 | 0.022 |
| 3 | Iwate | 0.443 | 0.034 | 0.503 | 0.034 | 0.435 | 0.022 |
| 4 | Miyagi | 0.648 | 0.050 | 0.682 | 0.043 | 0.494 | 0.022 |
| 5 | Akita | 0.433 | 0.034 | 0.502 | 0.033 | 0.506 | 0.024 |
| 6 | Yamagata | 0.482 | 0.037 | 0.494 | 0.033 | 0.476 | 0.024 |
| 7 | Fukushima | 0.363 | 0.028 | 0.399 | 0.026 | 0.437 | 0.021 |
| 8 | Ibaraki | 0.535 | 0.042 | 0.556 | 0.036 | 0.488 | 0.023 |
| 9 | Tochigi | 0.469 | 0.036 | 0.527 | 0.034 | 0.569 | 0.027 |
| 10 | Gunma | 0.384 | 0.030 | 0.384 | 0.024 | 0.482 | 0.023 |
| 11 | Saitama | 0.972 | 0.075 | 0.667 | 0.043 | 0.731 | 0.033 |
| 12 | Chiba | 0.820 | 0.064 | 0.634 | 0.041 | 0.674 | 0.030 |
| 13 | Tokyo | 1 | . | 1 | . | 1 | . |
| 14 | Kanagawa | 0.948 | 0.074 | 0.737 | 0.046 | 0.835 | 0.037 |
| 15 | Niigata | 0.540 | 0.042 | 0.575 | 0.038 | 0.556 | 0.025 |
| 16 | Toyama | 0.425 | 0.033 | 0.517 | 0.035 | 0.466 | 0.023 |
| 17 | Ishikawa | 0.428 | 0.033 | 0.550 | 0.034 | 0.487 | 0.022 |
| 18 | Fukui | 0.519 | 0.040 | 0.440 | 0.028 | 0.426 | 0.020 |
| 19 | Yamanashi | 0.455 | 0.035 | 0.547 | 0.035 | 0.481 | 0.023 |
| 20 | Nagano | 0.335 | 0.026 | 0.494 | 0.032 | 0.499 | 0.023 |
| 21 | Gifu | 0.508 | 0.039 | 0.527 | 0.034 | 0.414 | 0.019 |
| 22 | Shizuoka | 0.576 | 0.045 | 0.592 | 0.037 | 0.573 | 0.027 |
| 23 | Aichi | 0.664 | 0.051 | 0.657 | 0.042 | 0.666 | 0.029 |
| 24 | Mie | 0.341 | 0.026 | 0.466 | 0.030 | 0.437 | 0.020 |
| 25 | Shiga | 0.392 | 0.030 | 0.519 | 0.034 | 0.557 | 0.026 |
| 26 | Kyoto | 0.484 | 0.038 | 0.740 | 0.046 | 0.614 | 0.027 |
| 27 | Osaka | 0.620 | 0.048 | 0.710 | 0.044 | 0.745 | 0.032 |
| 28 | Hyogo | 0.759 | 0.059 | 0.716 | 0.044 | 0.657 | 0.028 |
| 29 | Nara | 0.463 | 0.036 | 0.499 | 0.033 | 0.567 | 0.027 |
| 30 | Wakayama | 0.524 | 0.041 | 0.421 | 0.027 | 0.509 | 0.024 |
| 31 | Tottori | 0.376 | 0.029 | 0.455 | 0.029 | 0.378 | 0.018 |
| 32 | Shimane | 0.379 | 0.029 | 0.536 | 0.034 | 0.435 | 0.020 |
| 33 | Okayama | 0.550 | 0.043 | 0.388 | 0.024 | 0.407 | 0.019 |
| 34 | Hiroshima | 0.611 | 0.047 | 0.590 | 0.037 | 0.471 | 0.021 |
| 35 | Yamaguchi | 0.412 | 0.032 | 0.372 | 0.024 | 0.453 | 0.021 |
| 36 | Tokushima | 0.486 | 0.038 | 0.481 | 0.031 | 0.413 | 0.019 |
| 37 | Kagawa | 0.512 | 0.040 | 0.485 | 0.031 | 0.473 | 0.022 |
| 38 | Ehime | 0.474 | 0.037 | 0.430 | 0.028 | 0.370 | 0.019 |
| 39 | Kochi | 0.483 | 0.037 | 0.519 | 0.034 | 0.442 | 0.021 |
| 40 | Fukuoka | 0.737 | 0.057 | 0.526 | 0.033 | 0.565 | 0.025 |
| 41 | Saga | 0.395 | 0.031 | 0.410 | 0.027 | 0.452 | 0.023 |
| 42 | Nagasaki | 0.518 | 0.040 | 0.548 | 0.036 | 0.514 | 0.024 |
| 43 | Kumamoto | 0.434 | 0.034 | 0.541 | 0.035 | 0.512 | 0.023 |
| 44 | Oita | 0.435 | 0.034 | 0.410 | 0.027 | 0.424 | 0.020 |
| 45 | Miyazaki | 0.448 | 0.035 | 0.484 | 0.031 | 0.422 | 0.019 |
| 46 | Kagoshima | 0.593 | 0.046 | 0.538 | 0.033 | 0.462 | 0.020 |
| 47 | Okinawa | | . | 0.574 | 0.037 | 0.502 | 0.024 |

Source: Authors calculations based on Statistical Bureaus Retail Price Survey.

**Table A4: Relative Price Levels by Prefecture in the Transportation and Communication Industry, Tokyo = 1, Comparisons in Years 1970, 1990, and 2010**

| | prefecture | 1970 | | 1990 | | 2010 | |
|---|---|---|---|---|---|---|---|
| | | Relative Price | Std.Err. | Relative Price | Std.Err. | Relative Price | Std.Err. |
| 1 | Hokkaido | 1.032 | 0.061 | 0.952 | 0.030 | 1.026 | 0.019 |
| 2 | Aomori | 1.061 | 0.067 | 0.934 | 0.030 | 0.926 | 0.017 |
| 3 | Iwate | 1.100 | 0.070 | 0.923 | 0.030 | 0.955 | 0.018 |
| 4 | Miyagi | 1.149 | 0.070 | 0.976 | 0.032 | 0.940 | 0.017 |
| 5 | Akita | 1.063 | 0.067 | 0.913 | 0.030 | 0.954 | 0.018 |
| 6 | Yamagata | 1.070 | 0.068 | 0.912 | 0.029 | 0.946 | 0.018 |
| 7 | Fukushima | 1.247 | 0.075 | 0.947 | 0.028 | 0.900 | 0.016 |
| 8 | Ibaraki | 0.977 | 0.059 | 0.975 | 0.032 | 0.970 | 0.018 |
| 9 | Tochigi | 0.969 | 0.059 | 0.931 | 0.027 | 0.934 | 0.017 |
| 10 | Gunma | 1.016 | 0.061 | 0.966 | 0.028 | 0.931 | 0.017 |
| 11 | Saitama | 1.142 | 0.072 | 1.001 | 0.033 | 0.944 | 0.017 |
| 12 | Chiba | 0.982 | 0.059 | 0.827 | 0.024 | 0.900 | 0.016 |
| 13 | Tokyo | 1 | . | 1 | . | 1 | . |
| 14 | Kanagawa | 1.269 | 0.074 | 0.918 | 0.027 | 0.985 | 0.018 |
| 15 | Niigata | 1.011 | 0.059 | 1.010 | 0.029 | 0.928 | 0.017 |
| 16 | Toyama | 1.002 | 0.059 | 1.018 | 0.029 | 0.969 | 0.018 |
| 17 | Ishikawa | 1.213 | 0.072 | 1.067 | 0.031 | 0.978 | 0.018 |
| 18 | Fukui | 1.201 | 0.070 | 1.081 | 0.031 | 0.968 | 0.018 |
| 19 | Yamanashi | 1.081 | 0.068 | 0.954 | 0.031 | 0.933 | 0.017 |
| 20 | Nagano | 0.980 | 0.059 | 0.933 | 0.028 | 0.959 | 0.018 |
| 21 | Gifu | 1.150 | 0.067 | 0.962 | 0.027 | 0.927 | 0.017 |
| 22 | Shizuoka | 0.977 | 0.059 | 0.907 | 0.027 | 0.932 | 0.017 |
| 23 | Aichi | 1.234 | 0.072 | 1.020 | 0.030 | 0.950 | 0.017 |
| 24 | Mie | 1.180 | 0.071 | 0.940 | 0.027 | 0.943 | 0.017 |
| 25 | Shiga | 1.040 | 0.063 | 0.934 | 0.029 | 0.907 | 0.017 |
| 26 | Kyoto | 1.247 | 0.073 | 0.927 | 0.026 | 0.961 | 0.018 |
| 27 | Osaka | 1.289 | 0.076 | 0.947 | 0.027 | 0.984 | 0.018 |
| 28 | Hyogo | 1.273 | 0.074 | 0.964 | 0.028 | 0.936 | 0.017 |
| 29 | Nara | 1.156 | 0.070 | 0.926 | 0.027 | 0.956 | 0.017 |
| 30 | Wakayama | 1.257 | 0.076 | 0.968 | 0.028 | 0.929 | 0.017 |
| 31 | Tottori | 0.997 | 0.063 | 0.881 | 0.029 | 0.924 | 0.017 |
| 32 | Shimane | 0.958 | 0.058 | 0.956 | 0.028 | 0.938 | 0.017 |
| 33 | Okayama | 0.852 | 0.050 | 0.855 | 0.026 | 0.873 | 0.016 |
| 34 | Hiroshima | 1.142 | 0.067 | 0.837 | 0.024 | 0.955 | 0.017 |
| 35 | Yamaguchi | 0.971 | 0.061 | 0.904 | 0.029 | 0.906 | 0.017 |
| 36 | Tokushima | 1.061 | 0.067 | 0.909 | 0.029 | 0.921 | 0.017 |
| 37 | Kagawa | 1.195 | 0.072 | 0.906 | 0.027 | 0.982 | 0.018 |
| 38 | Ehime | 0.988 | 0.058 | 0.956 | 0.027 | 0.951 | 0.017 |
| 39 | Kochi | 1.022 | 0.060 | 0.947 | 0.029 | 0.954 | 0.017 |
| 40 | Fukuoka | 1.185 | 0.069 | 0.990 | 0.029 | 0.875 | 0.016 |
| 41 | Saga | 0.980 | 0.062 | 0.931 | 0.030 | 0.896 | 0.017 |
| 42 | Nagasaki | 0.988 | 0.060 | 0.887 | 0.028 | 0.878 | 0.016 |
| 43 | Kumamoto | 0.942 | 0.055 | 0.911 | 0.027 | 0.891 | 0.016 |
| 44 | Oita | 0.991 | 0.063 | 0.934 | 0.030 | 0.896 | 0.017 |
| 45 | Miyazaki | 0.985 | 0.062 | 0.947 | 0.031 | 0.918 | 0.017 |
| 46 | Kagoshima | 1.013 | 0.061 | 0.957 | 0.030 | 0.905 | 0.017 |
| 47 | Okinawa | | . | 0.945 | 0.031 | 0.922 | 0.018 |

Source: Authors calculations based on Statistical Bureaus Retail Price Survey.

**Table A5: Relative Price Levels by Prefecture in Other Private Service Industries (including Non-profit Private Services), Tokyo = 1, Comparisons in Years 1970, 1990, and 2010**

| prefecture | | 1970 | | 1990 | | 2010 | |
|---|---|---|---|---|---|---|---|
| | | Relative Price | Std.Err. | Relative Price | Std.Err. | Relative Price | Std.Err. |
| 1 | Hokkaido | 0.925 | 0.034 | 0.853 | 0.017 | 0.784 | 0.020 |
| 2 | Aomori | 0.903 | 0.034 | 0.765 | 0.015 | 0.762 | 0.020 |
| 3 | Iwate | 0.913 | 0.034 | 0.802 | 0.016 | 0.855 | 0.022 |
| 4 | Miyagi | 0.944 | 0.034 | 0.864 | 0.017 | 0.863 | 0.022 |
| 5 | Akita | 0.987 | 0.036 | 0.826 | 0.016 | 0.843 | 0.022 |
| 6 | Yamagata | 0.946 | 0.035 | 0.864 | 0.017 | 0.893 | 0.023 |
| 7 | Fukushima | 0.974 | 0.036 | 0.877 | 0.017 | 0.857 | 0.022 |
| 8 | Ibaraki | 0.836 | 0.031 | 0.866 | 0.017 | 0.845 | 0.022 |
| 9 | Tochigi | 0.995 | 0.037 | 0.887 | 0.017 | 0.881 | 0.022 |
| 10 | Gunma | 0.940 | 0.035 | 0.875 | 0.017 | 0.896 | 0.023 |
| 11 | Saitama | 1.005 | 0.037 | 0.939 | 0.018 | 0.928 | 0.024 |
| 12 | Chiba | 0.927 | 0.034 | 0.917 | 0.018 | 0.876 | 0.022 |
| 13 | Tokyo | 1 | . | 1 | . | 1 | . |
| 14 | Kanagawa | 1.023 | 0.038 | 0.925 | 0.018 | 1.013 | 0.026 |
| 15 | Niigata | 0.958 | 0.035 | 0.867 | 0.017 | 0.893 | 0.023 |
| 16 | Toyama | 0.986 | 0.036 | 0.865 | 0.017 | 0.810 | 0.021 |
| 17 | Ishikawa | 0.995 | 0.036 | 0.874 | 0.017 | 0.800 | 0.020 |
| 18 | Fukui | 0.952 | 0.035 | 0.874 | 0.017 | 0.785 | 0.020 |
| 19 | Yamanashi | 0.995 | 0.037 | 0.846 | 0.016 | 0.828 | 0.021 |
| 20 | Nagano | 0.919 | 0.034 | 0.853 | 0.017 | 0.919 | 0.023 |
| 21 | Gifu | 0.828 | 0.031 | 0.839 | 0.016 | 0.900 | 0.023 |
| 22 | Shizuoka | 0.987 | 0.036 | 0.941 | 0.018 | 0.905 | 0.023 |
| 23 | Aichi | 0.897 | 0.033 | 0.850 | 0.017 | 0.927 | 0.024 |
| 24 | Mie | 0.917 | 0.034 | 0.870 | 0.017 | 0.793 | 0.020 |
| 25 | Shiga | 0.931 | 0.034 | 0.918 | 0.018 | 0.898 | 0.023 |
| 26 | Kyoto | 1.002 | 0.037 | 0.895 | 0.018 | 0.947 | 0.024 |
| 27 | Osaka | 0.931 | 0.034 | 0.908 | 0.018 | 0.899 | 0.023 |
| 28 | Hyogo | 0.967 | 0.036 | 0.874 | 0.017 | 0.877 | 0.023 |
| 29 | Nara | 0.981 | 0.036 | 0.886 | 0.017 | 0.901 | 0.023 |
| 30 | Wakayama | 0.969 | 0.036 | 0.903 | 0.018 | 0.896 | 0.023 |
| 31 | Tottori | 0.905 | 0.034 | 0.857 | 0.017 | 0.788 | 0.020 |
| 32 | Shimane | 0.923 | 0.034 | 0.833 | 0.016 | 0.872 | 0.022 |
| 33 | Okayama | 0.989 | 0.037 | 0.891 | 0.017 | 0.887 | 0.023 |
| 34 | Hiroshima | 0.978 | 0.036 | 0.819 | 0.016 | 0.878 | 0.022 |
| 35 | Yamaguchi | 0.913 | 0.034 | 0.817 | 0.016 | 0.856 | 0.022 |
| 36 | Tokushima | 0.904 | 0.033 | 0.840 | 0.016 | 0.826 | 0.021 |
| 37 | Kagawa | 0.940 | 0.034 | 0.839 | 0.016 | 0.843 | 0.021 |
| 38 | Ehime | 0.855 | 0.032 | 0.817 | 0.016 | 0.841 | 0.021 |
| 39 | Kochi | 0.873 | 0.032 | 0.830 | 0.016 | 0.848 | 0.022 |
| 40 | Fukuoka | 0.940 | 0.034 | 0.869 | 0.017 | 0.882 | 0.023 |
| 41 | Saga | 0.942 | 0.035 | 0.831 | 0.016 | 0.803 | 0.021 |
| 42 | Nagasaki | 0.897 | 0.033 | 0.843 | 0.016 | 0.883 | 0.023 |
| 43 | Kumamoto | 0.858 | 0.032 | 0.828 | 0.016 | 0.839 | 0.021 |
| 44 | Oita | 0.894 | 0.033 | 0.844 | 0.016 | 0.834 | 0.021 |
| 45 | Miyazaki | 0.917 | 0.034 | 0.816 | 0.016 | 0.833 | 0.021 |
| 46 | Kagoshima | 0.853 | 0.031 | 0.828 | 0.016 | 0.787 | 0.020 |
| 47 | Okinawa | | . | 0.755 | 0.015 | 0.819 | 0.021 |

Source: Authors calculations based on Statistical Bureaus Retail Price Survey.

# Education Intensity and the Sources of, and Prospects for, U.S. Economic Growth

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Abstract

We identify a new mechanism whereby education impacts economic growth: industry educational intensity. We define educational intensity as the share of an industry's workforce with a college degree and above and use this new classification to build estimates of the sources of U.S. economic growth from the bottom up across industries. We find that that since 1995, the contribution of education intensive industries to aggregate value added growth exceeds that of non-education intensive industries and that this difference was driven by larger contributions of capital, labour, and TFP growth in these industries. The shift toward educationally intensive industries has not been enough to revive aggregate labour productivity and GDP growth over the medium term; we find that growth over the next ten years will be restrained by slower growth in capital and labour quality.

In previous accounting of the sources of economic growth, improvements in the educational attainment of the workforce manifest as increases in labour quality. The basic economic mechanism is that more educated workers are more productive than workers with lower levels of education attainment and this difference in marginal productivities is reflected in their relative wages. Using this basic setup, growth accounting can identify the contribution of improvements in education to growth. For

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example, Jorgenson, Ho, and Stiroh (2005) found that increases in educational attainment accounted for approximately 10 per cent of U.S. GDP growth between 1948 and 2002, and about 15 per cent of labour productivity growth.

This approach to including labour quality in accounting for the sources of aggregate growth is widely used, for example, in the various country studies in Jorgenson, Fukao and Timmer (2016). In this article we examine the impact of education on aggregate growth and productivity from a new dimension: educational intensity of industries. We define educational intensity for each industry based on the composition of workers within the industry. This allows us to first associate economic growth at the industry level with the educational characteristics of the work force, and then link educational intensity with aggregate U.S. growth and productivity. Our approach within the KLEMS framework allows us to decompose the sources of economic growth between industries that are education intensive and those that are not.

There is a large literature examining the role of information technology and intellectual capital in productivity growth at the industry level (Biagi, 2013) but little discussion of the link between these capital inputs and characteristics of the workers. Here we examine the relationship between the share of educated workers in an industry and its productivity growth and use of information technology, and whether education intensity is related to intensity of research and development.

An important motivation for focusing on industry educational intensity is that prospects for labour quality growth due to continued improvement in educational attainment are weak. Jorgenson, Ho, and Samuels (2019) have estimated that labour quality growth is likely to contribute only 0.12 percentage points per year to growth, less than half of the contribution it made between 1990 and 2015. By focusing on educational intensity of industries, we are able to examine the impact of shifts toward industries that are educational intensive and assess the impacts of this on the prospects for growth.

Another motivation for classifying industries by educational intensity is that education is related to employment probability and the distribution of employment across industries. Labour force participation (or employed share of population) are important for future economic growth. Less educated workers are generally less likely to be employed than workers with more education. Furthermore, it has been established in previous work that the 2008 financial crisis and Great Recession affected less educated workers disproportionately as they suffered much higher rates of unemployment.

However, there is less discussion about the differences of impacts at the industry level, and no discussion of whether industries that are education intensive provided some insulation for workers with less education. If all industries had the same educational intensity, then shifts of workers out of and into the labour market would have a proportional impact on economic growth. But, because educational intensity differs across industries and because the dynamics of highly educated worker differs from less educated workers, it is important to account for industry education intensity and educational attainment in 1) analyzing the sources of U.S. economic growth, and 2) assessing the prospects for growth going forward.

We take on these two tasks in turn. In the first part of the article, we present new results on the role of industry educational intensity in economic growth. To do this, we develop a set of growth accounts that identifies the 63 industries in the U.S. National Accounts and classifies them according to their intensity of use of highly educated workers. We find that a disproportionate share of the high TFP growth industries are in the education intensive group. As part of this TFP calculation, we extend the U.S. growth accounts in Jorgenson *et al.* (2017) to cover the postwar period 1947-2015.

We then modify our previously published projection model (Jorgenson, Ho, Samuels, 2019) to explicitly account for industry educational intensity. The projection here is based on the following: (i) employment-population ratios that account for age and educational attainment, (ii) industry TFP growth that accounts for educational intensity, (iii) capital quality growth, and (iv) an extrapolation of the trend shift to industries that are intensive in educated workers. We also include a projection of labour quality growth, which continues to be low in comparison to our historical estimates.

The article proceeds as follows: in Section 1, we implement our educational intensity measure and calculate its impact on the industry level sources of growth. In Section 2, we relate industry educational intensity to information technology, research and development intensity, and industry TFP growth while in Section 3 we relate education to participation in the labour market. The relationship between education and employment participation is important for evaluating the prospects for economic growth, and we take up medium term projections of growth in Section 4. Section

5 concludes.

## Educational Intensity at the Industry Level and the Source of Growth

Our first objective is to introduce a classification of industry-level educational intensity to analyze the sources of economic growth. The starting point is the latest available industry accounts from the BEA which include measures of output and capital, labour and intermediate inputs for 65 industries covering 1998-2015.[2] To this, we add historical data for the same series from Jorgenson, Ho, and Samuels (2019). We then aggregate over the industries in the manner described in Jorgenson, Ho and Stiroh (2005, Chapter 8), which yields our basic information on the industry-level sources of growth.

One of our main contributions in this article is to group industries in this dataset into those that are intensive in relatively highly educated workers and other industries. Table 1 gives the share of workers with BA, or higher degrees, out of all workers in each industry in 2007, on the eve of the Great Recession. We also give a measure of the relative size of the industries by showing the share of all workers going to each industry. The share of highly educated workers ranges from 8.0 per cent in truck transportation to 68.2 per cent in computer systems and 68.5 per cent in securities.

The national average share is 30.7 per cent and we divide the industries into two groups. The educationally intensive (or skill intensive) group consists of those industries with a share larger than the national average. The other industries are allocated to the non-educationally intensive group. The categories are listed in the column marked "skill intensive." The last two columns give indices of IT-intensity and R&D intensity (described below).

While our industry classification of education intensity is based on a single year of data (in part to allow for a tractable classification of industries), we note that education intensity has shifted significantly over time and all industries have become more intensive in the use of college educated labour between 1947 and 2015. In 1947, the median share across industries of total labour compensation paid to workers with a BA degree and above was 0.09, so that workers without a college degree earned more than 90 percent of total labour compensation at

2 The methods and the data sources of our industry growth accounts is given in detail in Jorgenson *et al.* (2005).

**Table 1: Skill Intensity by Industry, 2007**

| | | Industry share of workers(%) | Workers with BA+(%) | Skill intensive | IT category | R&D Intensity |
|---|---|---|---|---|---|---|
| 1 | Farms | 1.01 | 14.9 | | | 0 |
| 2 | Forestry, fishing, and related | 0.4 | 13.8 | | | 0 |
| 3 | Oil and gas extraction | 0.1 | 38.1 | Yes | | 0.009 |
| 4 | Mining, except oil and gas | 0.15 | 11.9 | | | 0.012 |
| 5 | Support activities for mining | 0.2 | 25.3 | | | 0.011 |
| 6 | Utilities | 0.36 | 26.7 | | | 0.003 |
| 7 | Construction | 6.32 | 11.0 | | | 0.013 |
| 8 | Wood products | 0.35 | 9.7 | | Using | 0.026 |
| 9 | Nonmetallic mineral products | 0.33 | 15.1 | | | 0.082 |
| 10 | Primary metals | 0.3 | 15.3 | | | 0.042 |
| 11 | Fabricated metal products | 1.03 | 12.7 | | | 0.095 |
| 12 | Machinery | 0.78 | 21.1 | | | 0.27 |
| 13 | Computer and electronic products | 0.83 | 46.4 | Yes | Producing | 0.477 |
| 14 | Electrical equipment | 0.28 | 25.1 | | | 0.34 |
| 15 | Motor vehicles and parts | 0.65 | 21.2 | | | 0.401 |
| 16 | Other transportation equipment | 0.47 | 37.3 | Yes | Using | 0.388 |
| 17 | Furniture and related products | 0.37 | 12.7 | | Using | 0.091 |
| 18 | Miscellaneous manufacturing | 0.46 | 26.8 | | Using | 0.404 |
| 19 | Food, beverage and tobacco | 1.11 | 16.0 | | | 0.072 |
| 20 | Textile mills and textile product | 0.23 | 12.0 | | | 0.049 |
| 21 | Apparel and leather products | 0.18 | 15.2 | | | 0.094 |
| 22 | Paper products | 0.3 | 17.4 | | | 0.12 |
| 23 | Printing and support activities | 0.43 | 19.7 | | Using | 0.106 |
| 24 | Petroleum and coal products | 0.08 | 30.9 | Yes | | 0.103 |
| 25 | Chemical products | 0.56 | 42.6 | Yes | | 0.512 |
| 26 | Plastics and rubber products | 0.49 | 14.7 | | | 0.132 |
| 27 | Wholesale trade | 4.05 | 29.6 | | Using | 0.017 |
| 28 | Retail trade | 10.83 | 16.9 | | Using | 0.009 |
| 29 | Air transportation | 0.32 | 35.5 | Yes | Using | 0.009 |
| 30 | Rail transportation | 0.13 | 12.1 | | | 0.004 |
| 31 | Water transportation | 0.04 | 28.9 | | Using | 0.008 |
| 32 | Truck transportation | 1.14 | 8.0 | | | 0.005 |
| 33 | Transit, ground passenger transp. | 0.32 | 14.6 | | | 0.005 |
| 34 | Pipeline transportation | 0.03 | 29.9 | | Using | 0.006 |
| 35 | Other transportation activities | 0.83 | 17.9 | | Using | 0.005 |
| 36 | Warehousing and storage | 0.44 | 11.3 | | | 0.004 |
| 37 | Publishing, ex. internet (incl software) | 0.65 | 55.9 | Yes | Using | 0.089 |
| 38 | Motion picture and sound recording | 0.29 | 45.3 | Yes | | 0.001 |
| 39 | Broadcasting, telecommunications | 0.92 | 38.8 | Yes | Using | 0.032 |
| 40 | Data proc, internet pub., info. svc | 0.22 | 56.4 | Yes | Producing | 0.13 |
| 41 | Fed Res banks, credit intermediation | 1.91 | 37.8 | Yes | Using | 0.005 |
| 42 | Securities, comm contracts, inv. | 0.63 | 68.5 | Yes | Using | 0.019 |
| 43 | Insurance carriers | 1.59 | 43.9 | Yes | Using | 0.014 |
| 44 | Funds, trusts, financial vehicles | 0.06 | 67.5 | Yes | | 0 |
| 45 | Real estate | 1.3 | 37.8 | Yes | | 0 |
| 46 | Rental and leasing services | 0.45 | 22.7 | | Using | 0 |
| 47 | Legal services | 0.91 | 62.1 | Yes | Using | 0 |
| 48 | Computer systems design, services | 0.99 | 68.2 | Yes | Producing | 0.276 |
| 49 | Misc. prof., scientific, tech svcs | 3.89 | 61.5 | Yes | Using | 0.25 |
| 50 | Management of companies | 1.21 | 52.6 | Yes | Using | 0.009 |
| 51 | Administrative and support vcs | 5.77 | 19.6 | | Using | 0 |
| 52 | Waste management | 0.25 | 10.2 | | | 0.01 |
| 53 | Educational services | 2.09 | 62.1 | Yes | Using | 0.085 |
| 54 | Ambulatory health care services | 3.83 | 41.9 | Yes | Using | 0.034 |
| 55 | Hospitals, Nursing, resid care | 4.89 | 33.3 | Yes | Using | 0.031 |
| 56 | Social assistance | 1.94 | 29.9 | | Using | 0.008 |
| 57 | Performing arts, spectator sports | 0.58 | 47.3 | Yes | | 0.005 |
| 58 | Amusements, gambling, recreation | 0.98 | 19.9 | | | 0.011 |
| 59 | Accommodation | 1.24 | 16.6 | | | 0.009 |
| 60 | Food services and drinking places | 6.42 | 9.2 | | | 0.008 |
| 61 | Other services, ex. government | 5.19 | 22.9 | | Using | 0.055 |
| 62 | Federal government | 3.31 | 32.3 | Yes | Using | 0.424 |
| 63 | State and local government | 12.61 | 19.6 | | | 0.026 |
| | All industry average | 100.00 | 30.7 | | | 0.087 |

Source: Authors' calculations.

the median industry. By 2015, this median share of labour compensation paid to BA and above workers had increased to about 0.44, demonstrating the seismic shift in educational intensity across all industries.

This broad increase demonstrates an important point in considering the prospects for economic growth going forward: the overall educational attainment distribution of workers is distinct from the relative intensity in which industries use different types of workers. In forming our industry classifications, we base our analysis on the latter concept (relative intensity) so that we can identify shifts in the economic contributions of industries that are relatively intensive in the use of educated workers.

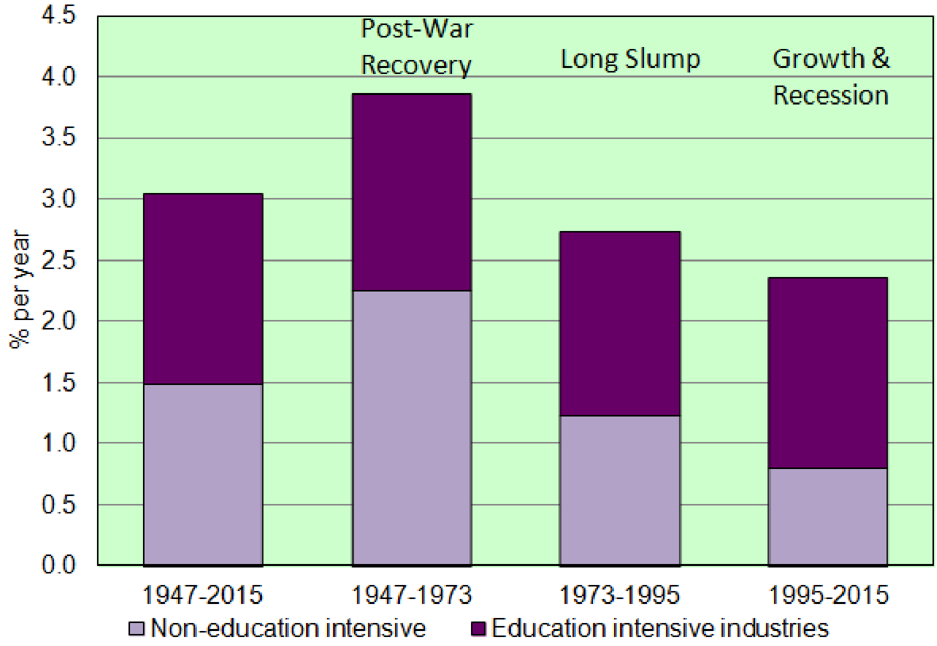
We start by presenting the contributions to aggregate value added of the educationally intensive (EI) and non-educationally intensive (NEI) groups in Chart 1. The contribution of an industry is its growth rate of value-added, multiplied by its share of total value-added (GDP).[3] The sum over all industries in the educationally intensive (EI) group is given by the dark bars in Chart 1 while the light bars gives the non-educationally intensive (NEI) group.

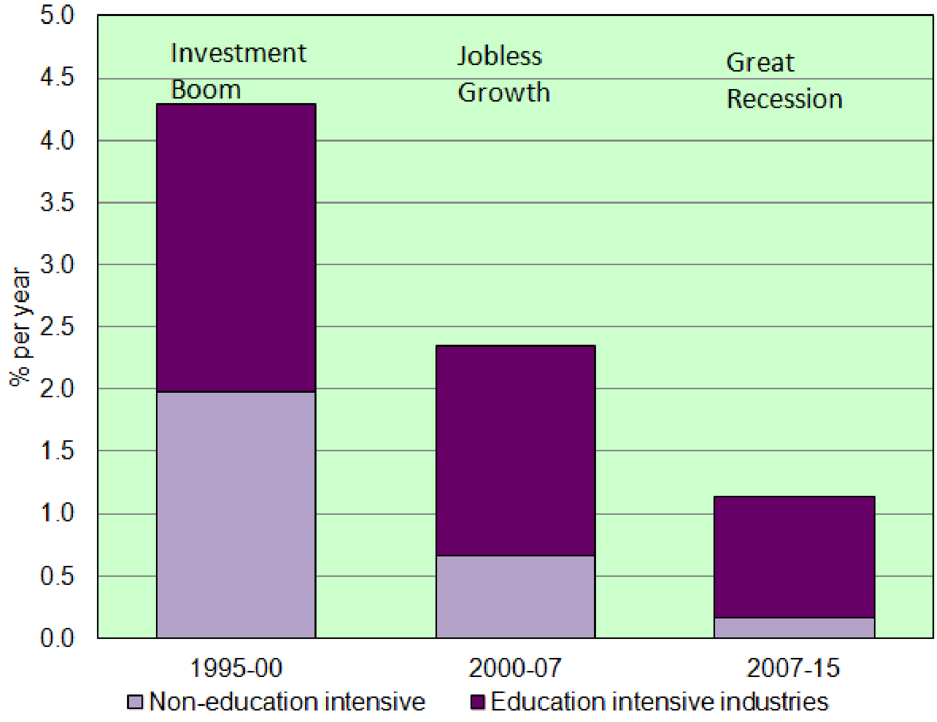
We divide the post-war period into three eras, reflecting the well-known break points in productivity growth—the Post-War Recovery, 1947-73, the Long Slump, 1973-1995, and Growth and Recession, 1995-2015. The last era is further sub-divided among the Investment Boom, 1995-00, Jobless Growth, 2000-07, and the Great Recession, 2007-15. Over the entire 1947-2015 period the two groups made almost the same contribution to aggregate value-added.

The educationally intensive (EI) group was smaller during the period 1947-1973, but dominated after that. In the Growth and Recession period, the EI group contributed 1.6 percentage points, compared to 0.8 points for the NEI group. The bottom half of Chart 1 shows the dramatic change between these two groups. During the Investment Boom they contributed about equally (2.3 versus 2.0 percentage points). In the Jobless Growth period the EI group contributed 1.69 versus 0.67 points and during the Great Recession (2007-15) the EI group contributed 0.98 versus 0.16 points. Many NEI sectors had negative growth in value-added, including furniture and related products, apparel and leather and allied products, textile mills and textile product mills, paper products,

3 We use a production possibility frontier method to aggregate over the value-added of each industry (Jorgenson, Ho and Stiroh (2008, equation 8.21).

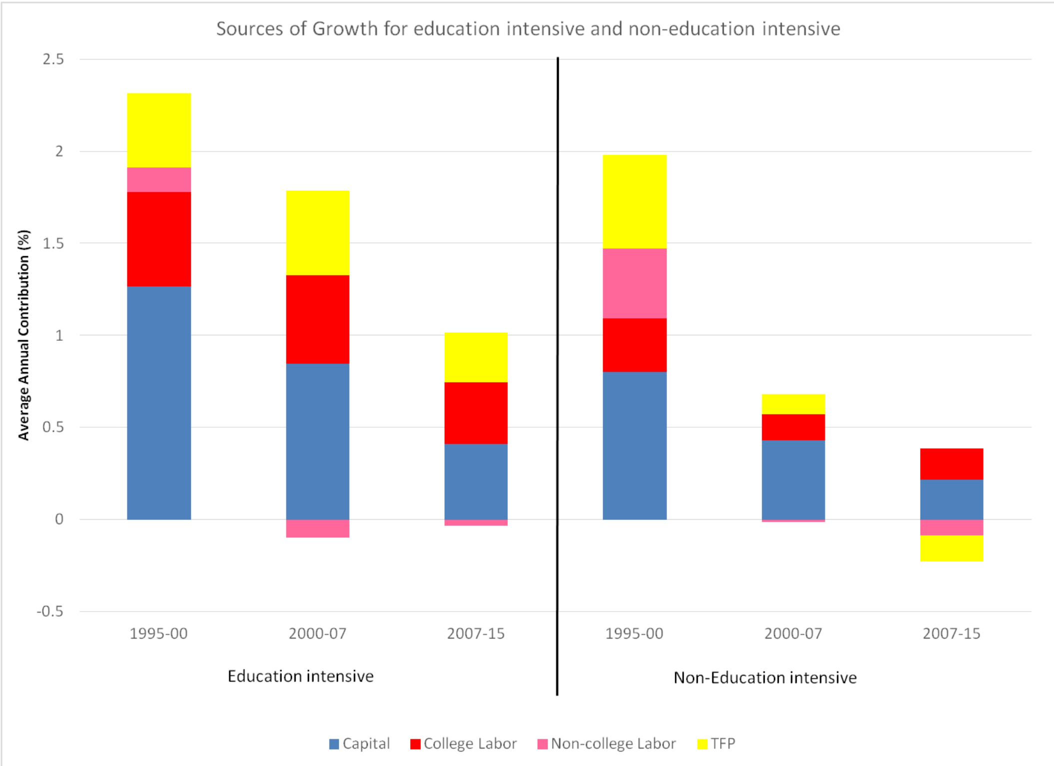
**Chart 1: Contributions of Education Intensive and Non-education Intensive Groups to Value Added Growth, 1947-2015**




Source: Author's calculations.

**Chart 2: Sources of Growth of Education Intensive and Non-education Intensive Industries, 1995-2015**




Source: Author's calculations.

and construction. Most of these were manufacturing industries (excluding computers and electronic products).

We next discuss the sources of growth for the EI and NEI groups. Chart 2 gives the contributions of capital, college-labour, non-college labour and TFP to their growth for the three sub-periods of the Growth and Recession era (1995-2015). The sources of growth are constructed from the bottom up across industries, that is, the contributions of capital, labour, and TFP of each detailed industry are summed up using "Domar weights." The use of Domar weights (industry j's value added share of GDP divided by the value added share of gross output in j) in aggregation is described in Jorgenson, Ho and Stiroh (2005, eq. 8.33).

First, we see that the growth of value-added in the EI group (total height of the bars in Chart 2) is higher in all three sub-periods. Second, college labour contributed positively to both groups after 2000, but non-college labour contributed negatively. This came after the Investment Boom of 1995-2000 when non-college labour grew rapidly, especially in the NEI group. The college labour contribution to value-added growth is a higher share in the EI group for all three sub-periods. During the Great Recession and Recovery (2007-15) the college-labour share reached 34 per cent in the EI group, compared to the average 25 per cent share for the whole economy during the entire 1995-2015 period.

Third, the TFP contribution is significantly different between the EI and NEI groups. During the Investment Boom TFP growth was high and contributed more than 17 per cent to value-added growth in both groups. During the Jobless Growth period TFP growth remained strong in the EI group, rising to a contribution to growth of 27 per cent. In the NEI group TFP growth remained positive and contributed about 16 per cent to growth. However, in the Great Recession period (2007-2015) TFP growth was positive in EI (a 28 per cent contribution) but negative in the NEI group.

Chart 3 shows the U.S. productivity record in another way by giving the decomposition of aggregate TFP growth into the sum over industry TFP growth, reallocation of capital and reallocation of labour.[4] Reallocations capture the aggregate effects of movement of factor inputs across industries. Aggregate TFP growth reaches a peak of 0.84 per cent per year during the Investment Boom, remains high at 0.65 per cent during Jobless Growth, but crashes to 0.11 per cent after the Financial Crisis. During the Jobless Growth period the EI group contributed 0.46 percentage points to the 0.65 per cent total change, while the NEI group contributed 0.11 points and reallocation effects contributed 0.08 points. During the 2007-2015 period, the EI group contributed 0.27 points to the 0.11 per cent while NEI contributed -0.14 points.

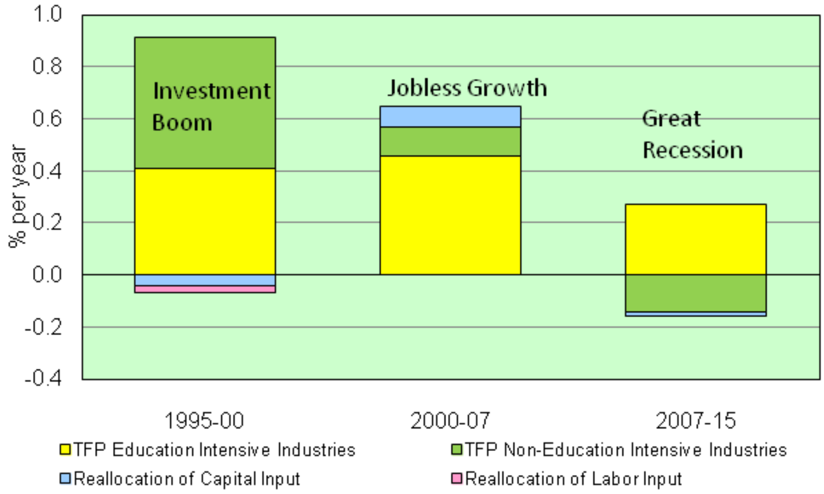
In summary, there are substantial differences between the two groups of industries. The differences in both output and TFP growth performance widened during the Great Recession and the current recovery. Next, we relate educational intensity to previous work on information technology and research and development (R&D), and then we incorporate this information into our outlook for medium term economic growth.

## Skill Intensity, IT-intensity, R&D Intensity and Industry TFP Growth

We now turn to a discussion of the input characteristics at the industry level to display the relationship between educational intensity, R&D, and TFP growth. There are many

4 The decomposition is explained in Jorgenson, Ho and Stiroh (2005) equation 8.34. The contribution of TFP from an industry group to aggregate TFP is the Domar-weighted sum of the TFP growth in each of the member industries.

**Chart 3: Contribution of Industry Groups to Aggregate Productivity Growth, 1995-2015**




Source: Authors' calculations.

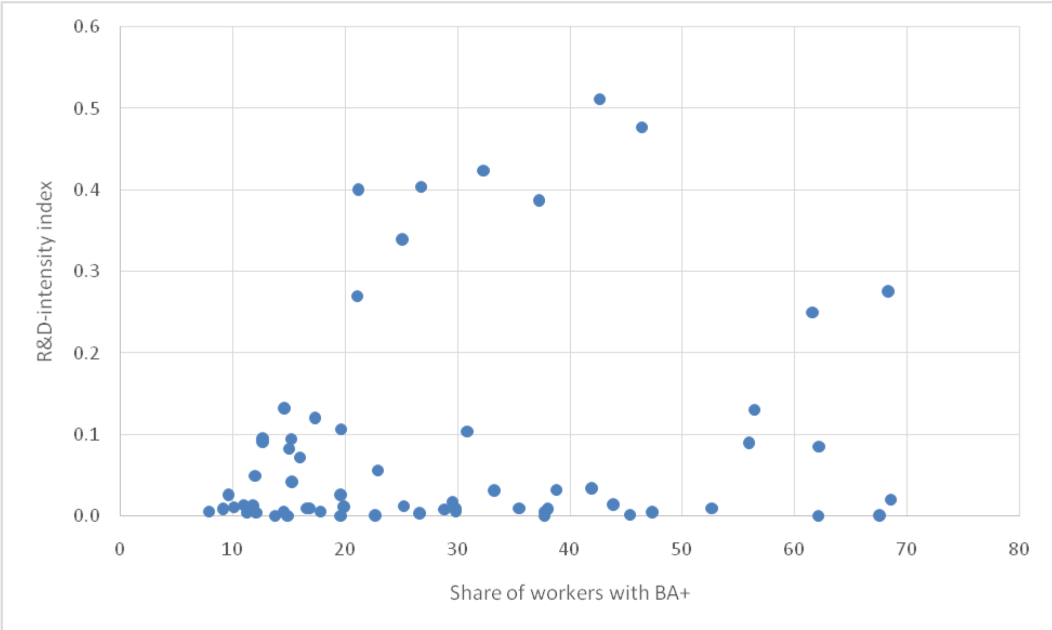
models that link human capital, productivity and growth (e.g. Stokey, 2018). Corrado, Hulten and Sichel (2009) is one of the earlier estimates of the role R&D. They find that intangible capital (excluding software) contributed 0.57 points of the 3.09 per cent annual growth in non-farm business labour productivity during 1995-2003. In our earlier accounting of growth (Jorgenson *et al.* 2016) we distinguished IT-capital, R&D capital and other capital, and estimated that R&D capital contribution as modest: about 0.12 percentage points of the 2.37 per cent annual growth rate of GDP (including the non-business sector) during 1995-2012 compared to 0.64 points for IT-capital and 0.53 points for other capital. The R&D contribution is slightly bigger over the 1947-73 period when it was 0.26 points of the 3.73 per cent aggregate growth rate.

To give a more detailed portrait of the role of R&D we provide the intensity of R&D capital for each industry in 2007 in the last column in Table 1.[5] We plot the relation between R&D intensity and share of BA+ for these 63 industries in Chart 4. More than half the industries have R&D intensity smaller than 0.02, but there is no simple monotonic relation between skill-intensity and R&D shares. The correlation coefficient between them is 0.19 for the whole set of 63 industries.

In another accounting for US growth in Jorgenson *et al.* (2007) and Jorgenson *et al.* (2017) we divided the U.S. industries into three groups—IT-

5 The intensity of R&D capital is defined in Jorgenson *et al.* (2016).

**Chart 4: R&D Intensity versus Education-Intensity in 63 U.S. Industries, 2007**




Source: Authors' Calculations

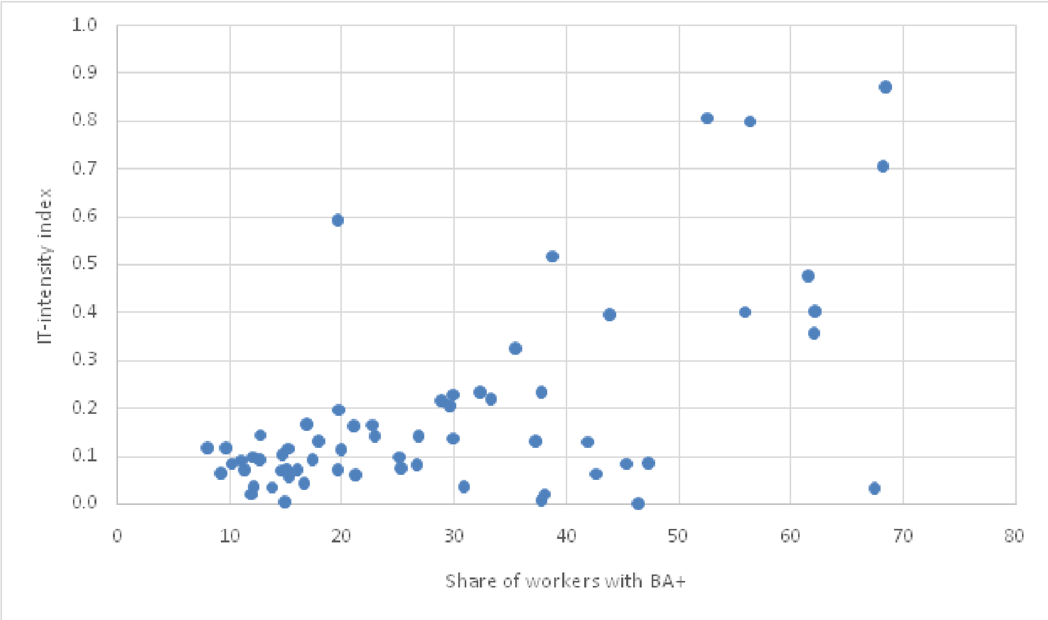
producing, IT-using (relatively IT intensive) and Non-IT (relatively non-IT intensive)—and showed how the tiny IT-producing sector with less than 4 per cent of total value added contributed more than half of aggregate TFP growth during 2000-2007, and essentially all of aggregate TFP growth after the Financial Crisis (2007-2015).[6]

The IT-producing group and many of the IT-intensive sectors are also intensive users of highly educated workers. In the "IT category" column of Table 1 we indicate which industries are IT-producing, IT-using and Non-IT based on their inputs in 2005. All the IT-producing industries are skill-intensive (computers, data processing, computer systems design), but are relatively small. The industries with many well-educated workers include banks, professional services, education, health services, hospitals and the federal government. The relation between IT-intensity and skill-intensity is plotted in Chart 5 which shows a much stronger correlation (0.62) than that between R&D and skill-intensity. This industry level relation should inform the literature on skill-biased technical change and polarization of labour markets[7] (e.g. Acemoglu and Autor 2010, Michaels,

6 Non-IT industries use some information technology but are relatively less intensive of their use in IT. IT-intensity is given by the ratio of IT input to total capital plus IT intermediate input, where IT input is the sum of IT capital and IT intermediates (details in Jorgenson, Ho, Samuels, 2016, eq. 1).

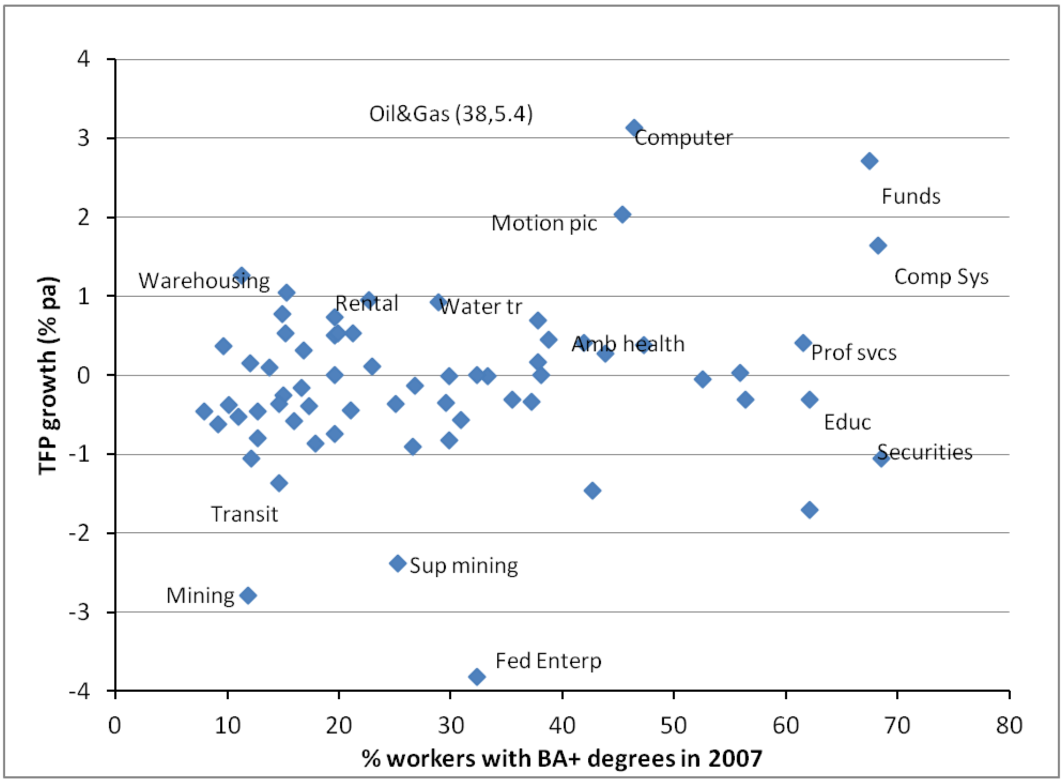
7 Our industry database includes wages by education attainment and other demographic characteristics for each industry and year.

**Chart 5: IT-Intensity versus Education-Intensity in 63 U.S. Industries, 2007**




Source: Authors' Calculations

**Chart 6: TFP Growth (2007-15) versus Skill Intensity by Industry and Linear Trend**




Source: Authors' Calculations

Natraj, van Reenen 2014).

From our updated industry growth accounts for 1947-2015 we derive the growth rate of total factor productivity (TFP) in a manner described in detail in Jorgenson, Ho and Stiroh (2005). This allows us to discuss the correlates of TFP growth at the industry level and can inform the discussion of endogenous growth of technology and skills. We first have Chart 6 where we plot industry TFP growth during the Great Recession and Recovery period (2007-2015) versus the skill intensity given in Table 1 (oil and gas is a outlier with a TFP growth of 5.4 per cent and left out of the plot). The positive but weak relation between them is clear (the correlation coefficient is 0.21). The high skill intensity industries such as computer systems, funds, computer manufacturing, and professional services have high TFP growth rates. The low skill intensity industries such as mining (excluding oil and gas), transit and ground passenger transportation, rail transportation, and fabricated metal products have large negative TFP growth rates. There are some service industries with high skill intensities but low TFP growth—securities, education, legal services and data processing and information services. These are sectors with well-known difficulties in measurement.

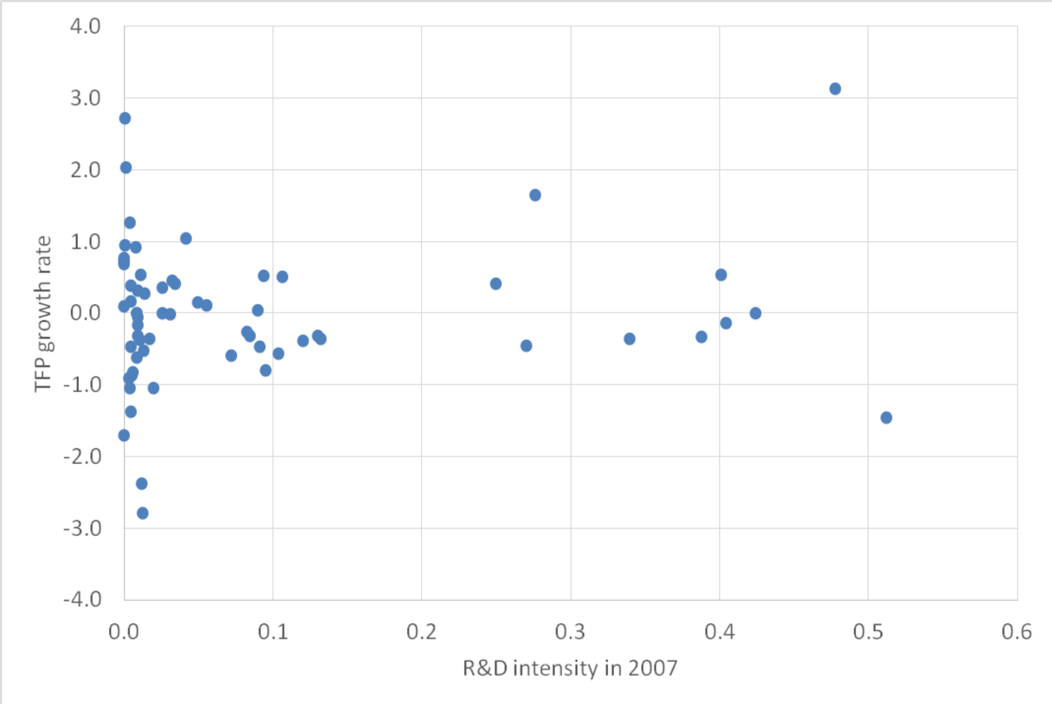
Chart 5 shows that IT-intensive industries tend to be more skill intensive, and we just noted that TFP growth is very weakly related to skill-intensity.[8] Turning now to R&D capital and TFP, the scatterplot in Chart 7 shows that TFP growth over the 2007-2015 period is not strongly correlated with the R&D capital intensity in 2007 (correlation of 0.11). A plot of TFP growth over 1995-2015 shows an even weaker correlation.

## Education and Employment

At the outset, we noted that the traditional mechanism in sources of growth analysis that drives the contribution of education to economic growth is increases in labour quality. The previous sections of this article have demonstrated that education attainment matters not only as an input to production, but that the output and productivity of industries that are relatively more intensive in educated workers differs considerably from the NEI industries. This implies, that as employment participation (employment-population ratio) recovers from the large fall dur-

8 Jorgenson, Ho and Samuels (2016: Chart 5) have a scatterplot like Chart 6 showing a weak correlation between IT-intensity and TFP growth for 1995-2012.

**Chart 7: TFP Growth (2007-15) and R&D Intensity for 63 US Industries**




Source: Authors' Calculations

ing the Great Recession, the impact on industries depends on the skill mix of the workers returning to work. To fix ideas, suppose that as a result of the recession there was a 10 per cent reduction of workers without a college degree. As these workers return to work, the industries most impacted would most likely be NEI industries. Furthermore, this would impact the aggregate share of output of the EI versus the NEI industries that we take as an input into our projection model below.

To examine whether changes in employment status are related to education we compare employment population ratios by gender, age group, and educational attainment. A substantial literature has discussed the extent and causes of the falling trend in labour force participation rates (LFPR) since the peak in 2000. Earlier studies of the LFPR, such as Kudlyak (2013) and Toossi (2013), took into account the differences among age and gender groups but did not consider the education dimension. Aaronson, Hu et al (2014), Aaronson, Cajner *et al.* (2014), Jorgenson *et al.* (2017), Montes (2018) and Abraham and Kearney (2018) included the effects of the sharper drop in participation rates among the less educated workers during the Great Recession.

The strand of papers focused on the LFPR, or employment-population ratios, does not make an explicit link between them and effective labour input. There are at least two possible ways in which they are related. The first is that the differential rise in participation rates among different age and education groups leads to a change in labour quality. For example, population aging lowers the aggregate participation rate (and thus effective labour input) by increasing the population weights of older age groups with lower participation rates. The second is that industries with their differing gender-age-education composition of workers could respond differently to an increase in the relative supply of highly educated workers. As we document in Charts 6 and 7, industries have wide range of TFP growth so that uneven recoveries of the LFPR's could affect the growth of aggregate TFP.

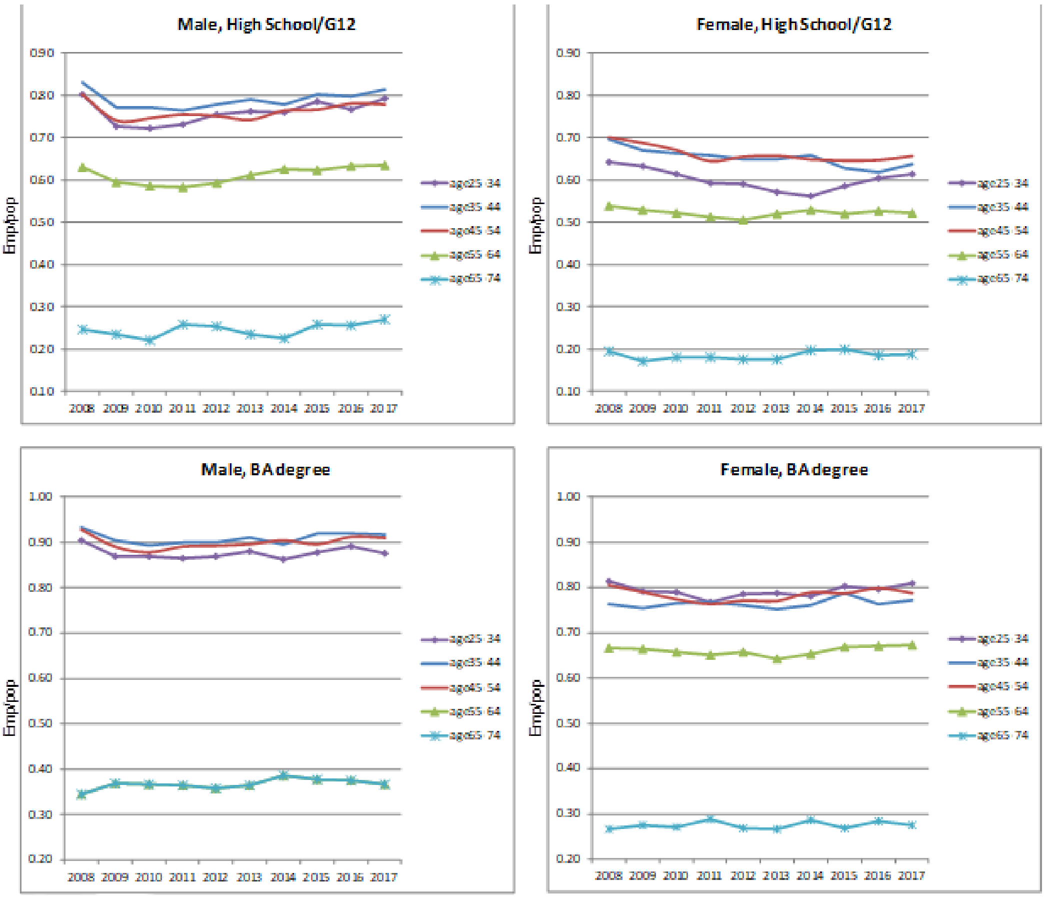
Projections by the Congressional Budget Office (CBO, 2018) take the total number of workers from LFPR models and use this directly in an aggregate output function. The Social Security Administration (SSA, 2018) assumes an aggregate labour productivity growth rate independent of the labour force projections. The only studies that explicitly recognize the implications of different LFPR's for labour quality are Bosler, Daly, Fernald and Hobijn (2017) and Jorgenson, et al. (2017).

Before projecting the employment-population trends for the medium-term, we first describe the large differences in levels and trends for the various demographic groups in Chart 8.[9] Comparing the male rates in the left-hand graphs with the female rates on the right, we see that there is a gap of 10 percentage points or more. The largest gap is during the peak fertility age. Across the age groups for the college-educated men and women, the differences in employment-participation (EP) rates within the 25-54 age group are small. For women with only high school education, the EP rate for the 25-34 age group is significantly lower than that for the 35-54 group. For prime-age (25-54) men, those with BA's have EP rates around 90 per cent, while those with High School diplomas have rates less than 80 per cent. Prime-age women with BA's have rates around 75-80 per cent compared to the High School group rates around 60-70 per cent.[10] The employment-population ratio for the 65-75 age group is significantly lower than the 55-64 group. Thus, the aging of the workforce

9 These ratios are tabulated from the Annual Social and Economic (ASEC) files in the Current Population Survey. In recent years the ASEC has a sample size of about 180,000 persons. The employment-population ratio is defined as the ratio of workers to total population, whereas the LFPR also includes the unemployed in the numerator.

10 We do not present the data for those with less than high school since they are quite similar to those with high school, and those with MA+ degrees are somewhat similar to those with BAs.

**Chart 8: Employment-Population Ratios after the Financial Crisis; Differences among Demographic Groups, 2008-2017**




Source: Authors' Calculations

would lead to lower employment, and slower growth of labour input, ceteris paribus.

The period covered in Chart 8, 2008-2017, shows the impact of the Great Recession and the slow recovery of participation rates. We note the following features of these trends. For men in the 25-54 age group, for all education levels, the EP ratios have not recovered to the pre-crisis levels in 2007. For men aged 55-64, the ratio recovered to or exceeded the 2007 levels. For all age groups of women with high school education the EP ratios have not recovered. For women with BA degrees, the EP ratios have largely recovered, and in the 55-64 age group, exceeded the 2007 level.

These results demonstrate the importance of education in medium-term prospects for returning to employment from non-employment. Because we do not have a model of how trends in employment-population will evolve, in the medium term projection below we fix employment-population ratios by demographic groups at their

2017 levels.[11] But we do take into account (as discussed below) that as less educated workers return to the workforce this may impact the distribution of economic output between education intensive and other industries.

## Medium Term Projections

Medium term projections of economic growth are essential components of policy analysis and public program planning. The Congressional Budget Office is an important source of carefully considered outlooks for the U.S. economy (CBO, 2018), including an analysis of labour force participation trends. The BLS and Federal Reserve provide projections of LFPR and output growth, e.g. Toossi (2013), Lacey *et al.* (2017) and Aaronson, *et al.* (2014). The Social Security Administration (2018) also considers labour supply and productivity issues but over a much longer horizon.

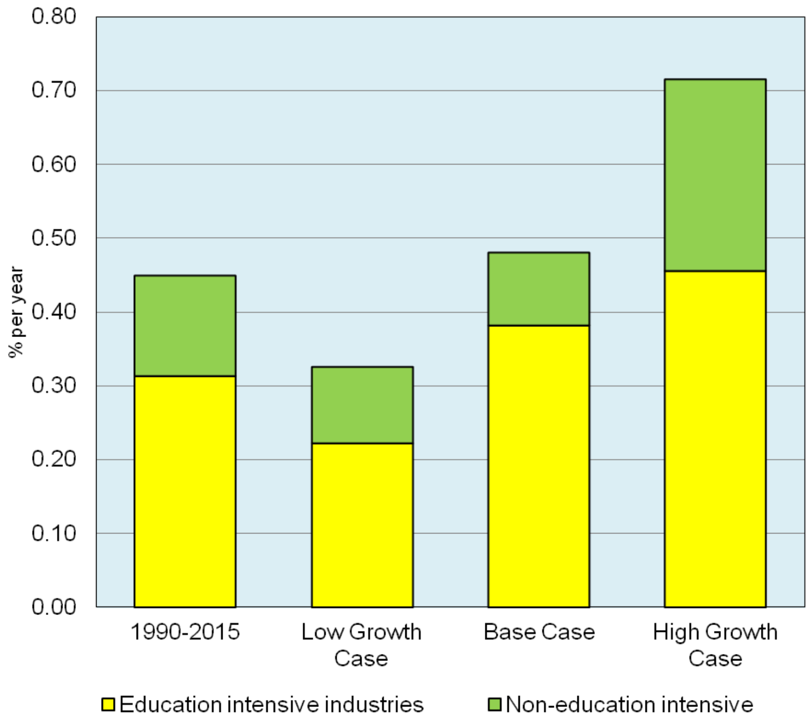
Projections of the GDP use methods ranging from projections from growth accounts to Solow-type growth models. Here we present a method of projecting medium term growth that takes into account labour quality, capital quality and TFP growth. This method is described in detail in Jorgenson, Ho and Stiroh (2008) and Jorgenson, Ho, and Samuels (2019, eq. 1A.5). We first express labour productivity growth (output per hour worked) as a function of capital quality growth, labour quality growth, TFP growth and an adjustment for the share of reproducible capital in total capital. That equation is derived under the long-run assumption that output growth equals capital growth. Output growth is then the sum of labour productivity and hours growth.

We present three alternative projections for U.S. economic growth for the period 2017-2027 in Table 2: Base Case, Low Growth, and High Growth. This enables us to give some historical bounds on the uncertainty in projections of the growth of capital quality and TFP growth, and the share of output accounted for by industries intensive in highly educated workers. We present the three alternative projections in Charts 9, 10 and 11 where we also give historical data for 1990-2015 for comparison.

We use the following assumptions for all three projections. The capital share in value added and the share of reproducible capital in total cap-

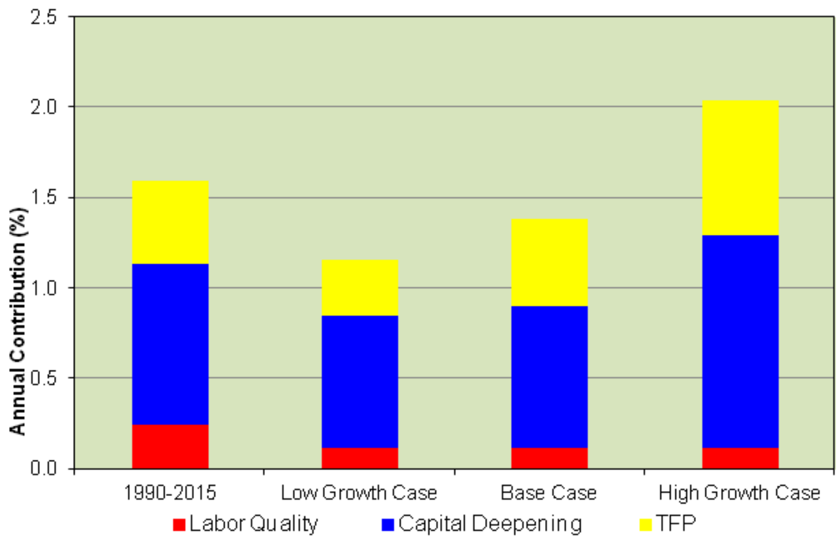
11 The trends in the EP ratios may have structural and cyclical components. For example, enrollment rates may affect the EP ratio, and enrollment rates may have risen during the Great Recession as a cyclical response to weakness in the labour market. The continued recovery may reduce enrollment rates and thus impact EP ratios and labour quality in ways that we have not accounted for.

**Chart 9: Contribution of Industry Groups to Aggregate TFP Growth, 2017-2027**




Source: Authors' Calculations

**Chart 10: Range of Labour Productivity Projections, 2017-2027**



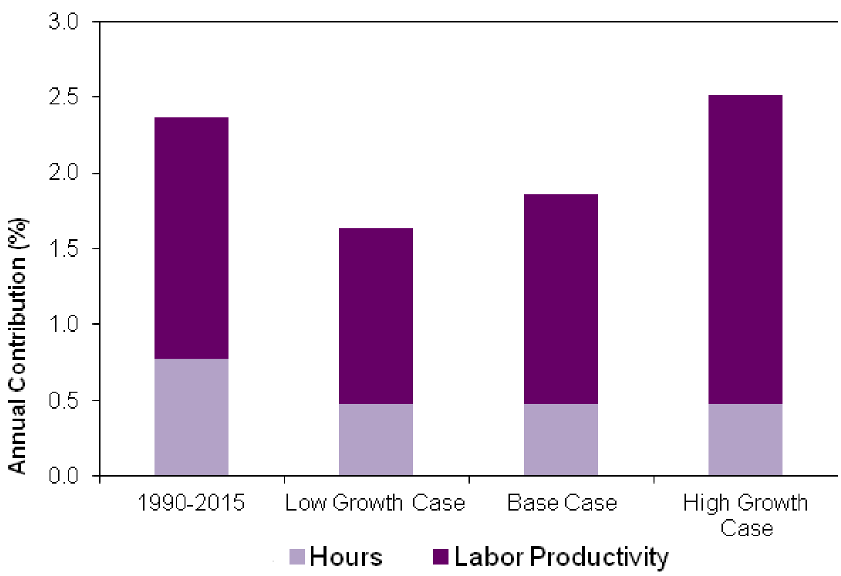

Source: Authors' Calculations

**Table 2: Output and Labour Productivity Projections, Total Economy**

| | | Projections 2017-2027 | | |
|---|---|---|---|---|
| | 1990-2015 | Low | Medium | High |
| | | | Projections | |
| Value Added Growth | 2.37 | 1.64 | 1.86 | 2.52 |
| ALP Growth | 1.59 | 1.16 | 1.38 | 2.04 |
| Effective Capital Stock | 2.19 | 1.24 | 1.41 | 1.91 |
| | | | Common Assumptions | |
| Hours Growth | 0.77 | 0.47 | 0.47 | 0.47 |
| Labour Quality Growth | 0.43 | 0.21 | 0.21 | 0.21 |
| Capital Share | 0.424 | 0.436 | 0.436 | 0.436 |
| Reproducible Capital Stock Share | 0.668 | 0.757 | 0.757 | 0.757 |
| | | | Alternative Assumptions | |
| Education Intensive Industry Output Share | 0.853 | 0.790 | 0.885 | 1.005 |
| Non-Education-Intensive Industry Output Share | 0.938 | 1.008 | 0.907 | 0.791 |
| TFP Growth in Education Intensive Industries | 0.37 | 0.25 | 0.43 | 0.52 |
| Contribution of Education Intensive Industries | 0.31 | 0.20 | 0.38 | 0.52 |
| TFP Growth in Non-education Intensive Industries | 0.14 | 0.11 | 0.11 | 0.29 |
| Contribution of Non-education Intensive Industries | 0.14 | 0.12 | 0.10 | 0.23 |
| Other TFP Contribution | 0.01 | 0.00 | 0.00 | 0.00 |
| Capital Quality Growth | 0.88 | 0.90 | 0.86 | 1.27 |
| Implied Capital Deepening Contribution | 0.88 | 0.73 | 0.78 | 1.18 |

Source: Authors' calculations. Capital share and reproducible capital stock shares are 1947-2015 averages, and output shares are averages for 2000-2015. Low growth projections use 1973-2015 average growth of capital quality and TFP growth. Base case projections use 1995-2015 averages and high growth projections use 1995-2007 averages. Output shares are defined as gross output over aggregate value added. Projections of hours and labour quality assume that employment-population ratios remain constant at 2017 levels and weekly hours worked remain constant at 2015 levels. Optimistic case assumes that the education intensive and non-education intensive industry output shares will change by the same amount it did between 1995 and 2015. Pessimistic case assumes that these shares will revert to the 1995 level.

**Chart 11: Range of U.S. Potential Output Projections, 2017-2027**




Source: Authors' Calculations

ital stock are set equal to the averages for the postwar period, 1947-2015. Next, we discuss the alternative assumptions that drive the differences between our three cases.

Chart 9 includes three alternative projections of total factor productivity growth for the period 2017-2027. For the Base Case we set future TFP growth rates for educationally intensive, and non-educationally intensive industries equal to growth rates for the period of Growth and Recession, 1995-2015. This includes the relative rapid TFP growth early in the period and slower TFP growth later in the sample, so that on average this yields the middle estimate of TFP growth over the projection period.

We set the share of educationally intensive and non-educationally intensive industries to the 2000-2015 share to reflect history. The Low Growth projection is based on total factor productivity growth rates for the period 1973-2015, which includes the Long Slump of 1973-1995, and we assume that the educationally and non-educationally intensive shares revert to the 1995 level. The High Growth projection incorporates high TFP growth during the period 1995-2007, which includes the Investment Boom and the Jobless Recovery of 2000-2007, but excludes the Great Recession. For the high growth case we assume that the economy will continue to shift toward more educationally intensive industries. In particular, we assume that over the next ten years, the output share of educationally intensive and non-educationally intensive industries will change at the same rate as occurred during 1995-2015. Our assumptions on TFP growth reflect that the 1973-2015 period had the weakest TFP growth, followed by 1995-2015 and 1995-2007.

Chart 10 gives the growth rates of labour productivity and its components for the Base Case, Low Growth and High Growth projections; the components are labour quality, capital deepening and aggregate TFP. Chart 11 presents the projected growth rates of output as the sum of hours and labour productivity. We have now discussed all the ingredients for the projections except for the projections of hours and labour quality, described in the Base Case below.

### Base Case

In our discussion of Chart 8 we noted that the employment-population ratios differ by gender, age, and education. They have slowly recovered towards the pre-recession peak in 2007 by the mid-2010s. Our projections of hours worked incorporate these differences for the two genders, seven age groups and six educational attainment groups. For each demographic category we assume that the employment-population ratio remains equal to the ratio in 2017. We fix weekly hours for each gender-age-education group at the 2015 levels, the latest year of our labour data.

The educational intensity of workers had temporarily grown due to the higher unemployment of the less-educated after 2000. A similar education index for the general population shows a steady fall in the growth rate after 2000 when the rapid rise in college enrollment decelerated. We examined the education attainment of the population for each gender-age cell in 2000, 2010 and 2015 using the Censuses and ASEC survey in comparison to the 1977-2000 history described in Jorgenson, Ho and Stiroh (2005). We see a rapid deceleration of improvement in educational attainment, especially for men, after 2000 compared to the prior period.

We therefore project a modest further improvement in educational attainment over the next ten years, as discussed in greater detail in Jorgenson, Ho, and Samuels (2019, eqn. 1A6, 1A7). The projection of the population by gender and age taken from the Census Bureau, combined with our projection of educational attainment and assumed EP ratios, gives the implied projection of labour quality. Our projections of the growth rates of labour quality for 2017-2027 are considerably below the averages for the period 1990-2015, due to declines in the rates of growth of average educational attainment and the entry of young workers who are the echo of the Baby Boomers.

In the Base Case we assume that the growth rates of capital quality and total factor productivity growth for the next ten years will equal average growth rates for the period of Growth and Recession, 1995-2015.[12] To recall, the Investment Boom of 1995-2000 combined rapid accumulation of IT capital and robust productivity growth. The Jobless Recovery of 2000-2007 had strong productivity growth but slower growth of IT capital. The Recession and Recovery of 2007-2015 had weak productivity growth and much slower accumulation of IT capital.

It should be noted that the growth rate of capital quality during the period 1995-2015 used in the projection is below the growth rate for the period that included five earlier years, 1990-2015, perhaps unintuitively, given the recession of 1991. In the projection period 2017-2027, capital deep-

12 We computed capital quality using our estimates of capital stocks and flows covering the 1947-2012 period in Jorgenson, Ho and Samuels (2016). In the extension to 2015 we use the capital flows estimated in the BEA-BLS integrated Industry accounts which, unfortunately, does not include stock estimates. For the projections we assume that the rate of capital quality growth during 1995-2015 is equal to the rate for 1995-2012 estimated using the data in Jorgenson, Ho, and Samuels (2016).

ening makes the largest contribution to labour productivity growth (0.86 points out of 1.38) while the growth of TFP in the education intensive sector makes the second largest contribution (0.38 points). We project that total factor productivity growth in the non-education intensive sector will be smaller than its contribution during 1990-2015, reflecting the observed deceleration.

Our Base Case projection of labour productivity growth over the period 2017-2027 is lower than growth during the period 1990-2015, 1.38 per cent per year versus 1.59 per cent. Our projection of labour quality growth in the Base Case is half that in 1990-2015. Total hours worked are projected to grow at 0.47 per cent per year, compared to 0.77 per cent during 1990-2015, reflecting the future changes in the age-structure and the assumption of fixed annual hours at 2015 levels for each demographic group.

Combining our projected growth rates in hours worked and average labour productivity, we project the GDP growth rate at 1.86 per cent per year over the period 2017-2027. This is a substantial decline from the growth rate of 2.37 per cent per year during the period 1990-2015. The slower growth in hours worked is reinforced by the slower growth of average labour productivity. We conclude by emphasizing that we do not model the determinants of employment, but rely on extrapolations of trends from the historical data.

### Low Growth Case

Our first alternative assumption to the Base Case is that capital quality and total factor productivity growth over the period 2017-2027 will equal the averages over 1973-2015, a period that includes the Long Slump and the Recession and Recovery. By including the Long Slump we dampen the growth rates compared to the Base Case. This Low Case takes averages over 1973-2015, and for capital quality growth this yields a rate that is very close to the growth rate for the period 1990-2015.

Our procedure gives a TFP growth in the education intensive sector that is below the rate for 1990-2015 (0.25 per cent versus 0.37 per cent per year). Using the 2000-2015 average share of that sector in output, we obtain a substantial contribution of TFP growth from the education intensive sector to growth of aggregate labour productivity. We project that the growth of total factor productivity in the non-education intensive sector will be slightly below that for the period 1990-2015 (0.11 per cent versus 0.14 per cent).

In the Low Growth Case our projected labour productivity growth for the period 2017-2027 is 1.18 per cent per year, compared to 1.38 per cent in the Base Case and 1.59 per cent observed for 1990-2015. The growth of hours worked is assumed to be the same in both scenarios. Summing the growth rates in hours worked and labour productivity, the Low Growth Case projects output growth at 1.65 per cent for the period 2017-2027 compared to 1.86 per cent in the Base Case.

### High Growth Case

For the High Growth Case we assume the same growth of hours and labour quality as the Base Case. We assume that growth rates of capital quality and total factor productivity for the period 2017-2027 will equal their averages over the period 1995-2007. This includes the Investment Boom and the Jobless Growth periods but excludes the Long Slump and the Great Recession as temporary slowdowns in economic growth. Taking averages over 1995-2007 yields a capital quality growth rate significantly higher than the growth rate over the period 1990-2015, 1.27 per cent versus 0.88 per cent.

In the High Growth Case TFP growth in the education intensive sector is more rapid than in the Base Case (0.52 per cent versus 0.43 per cent). This translates into a relatively high contribution of growth in total factor productivity to growth in average labour productivity. The growth of TFP in the NEI sector is also projected at a higher rate than in the Base Case (0.29 per cent versus 0.11 per cent). Adding over the capital quality, labour quality and TFP components, the growth rate of labour productivity is 2.00 per cent per year compared to 1.38 per cent in the Base Case.

Combining projections of growth in labour productivity and hours worked, the High Growth projection of GDP growth is 2.47 per cent per year, only slightly above the growth rate of 2.37 per cent during the period 1990-2015. Higher growth of total factor productivity and capital quality are offset by lower growth of labour quality and hours. Only if there is a recovery of participation rates to the 2000 peak during the Investment Boom will hours growth be much higher.

### Discussion and Comparison to Other Projections

Fernald, Hall, Stock and Watson (2017) attribute the slow recovery since 2009 to the slow growth of TFP and decline in labour force participation (adjusted for demographic changes), arguing that the capital shortfall was due to the fall in trend output. Our growth accounts are consistent with those observations and our projections reflect the slow growth of TFP and the slow growth of hours. Fernald (2016) presents a number of alternative projections of U.S. GDP growth and chooses a modal forecast of 1.6 per cent per year as the most likely outcome.

The Congressional Budget Office (2018, Table 1-2) presents potential GDP projections for 10 years. For the 2018-2028 horizon they project aggregate labour productivity at 1.4 per cent per year (1.8 per cent for nonfarm business) and hours worked at 0.4 per cent, very close to our Base Case values. Their projection of TFP is 1.1 per cent per year; however, their definition of TFP would include our measures of TFP (0.54), labour quality (0.21*labour share) and capital quality (0.86*capital share).

The BLS (Lacey *et al.* 2017) projects the labour force to grow at 0.6 per cent over the 2016-2026 period. This combines the Census Bureau population projections with their participation rate projections. They also make macro projections using a model from Macroeconomic Advisers, and project GDP to grow at 2.0 per cent. These numbers are slightly higher that our base case hours growth of 0.5 per cent and GDP growth of 1.9 per cent.

## Conclusion

We have determined that it is important to account for industry educational intensity in analyzing both the sources of, and prospects for, U.S. economic growth. This conclusion is based on a new industry classification that we have implemented in this article to divide industries into those that are intensive in educated workers and those that are not. Based on this classification, we have found that since 1995, the contribution of education intensive industries to aggregate value added growth exceeds that of non-education intensive industries. This difference was driven by larger contributions of capital, labour, and TFP growth in educationally intensive industries.

The larger contribution of labour was driven entirely by the contribution of workers with a college degree or above. Because the economy is shifting toward educationally intensive industries, it is important to take this into account when constructing medium term projections of labour productivity and GDP growth. This shift enters our projection via relatively faster growth in the TFP of education intensive industries and an ongoing shift in the share of economic output originating in these industries. Even so, we conclude that in the medium term, both labour productivity and aggregate value added growth will be below the historical 1995-2015 average, unless our most optimistic scenario comes to fruition. This is driven by our projections of slower labour and capital quality growth for the next ten years.

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# New BEA-BLS Estimates of the Industry-level Sources of U.S. Economic Growth between 1987 and 2016

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Abstract

This article describes new historical statistics for the BEA-BLS integrated industry-level production account. The dataset includes KLEMS and integrated MFP measures that are consistent with the official BEA GDP by Industry statistics and now covers 1987-2016. The most important source of economic growth over the period was the accumulation of capital input. More than three quarters of the contribution of capital was driven by the accumulation of capital inputs in the service sector. The next most important source of economic growth over the period was the accumulation of labour input. Growth in labour input in the services sectors accounted for almost all the economy-wide contribution of labor input. MFP growth accounted for about twenty percent of aggregate economic growth. Of this, the manufacturing sector contributed more than half of this

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growth, but almost all of this was due to growth in MFP of the computer electronic products industry. Finally, the new dataset shows that the decline in the aggregate income share paid to labour in the manufacturing sector was mostly due to a decrease in the share of income paid to workers without a college degree. In contrast, workers with a college degree accounted for most of the increase in the income share of labour in the service sectors.

This article describes recently released historical statistics for the BEA-BLS integrated industry-level production account. Release of this new dataset adds more than a decade of historical data to the time series of KLEMS data and enhances the usefulness of the production account by allowing analysis of economic trends over a longer period. The dataset presented covers 1987-2016, whereas the previous data covered only 1998-2015.

These statistics were prepared as part of an ongoing collaboration between the Bureau of Economic Analysis (BEA) and the Bureau of Labor Statistics (BLS). An important feature of the account is that it covers the total economy and is constructed to be consistent with the U.S. national accounts. There were two main challenges in assembling the new history presented in this article: the first was the conversion of historical SIC data to be consistent with NAICS industry classifications, and the second was a change in the reporting of educational attainment in data that was used to estimate labour composition.

These new historical data provide a view of the sources of economic growth at the industry level over roughly three decades of economic history. The data reveal that about half of economic growth over this period was due to the accumulation of capital inputs. About 30 per cent was due to growth in labour input, while the remainder (about 20 per cent) was due to growth in multifactor productivity (MFP).[2] The industry dataset shows that the aggregate growth in capital input was driven by capital services growth in the trade; information; and finance, insurance, and real estate sectors. The preponderance of the contribution of labour input was due to an increase of labour in the services industries, while most of aggregate MFP growth was accounted for by MFP growth in the computer and electronic manufacturing and trade

2 It is noteworthy that the estimates presented in this article differ from the official MFP growth estimates produced by the BLS for the business sector. For example, the BLS estimates that business sector MFP grew by 0.86 per cent per year over the 1987-2016 period, while MFP growth for the total economy is estimated to be 0.43 per cent per year for the same period. The difference is mostly attributable to the scope of the accounts (business versus total economy) but also reflects other details. See Fleck *et al.*(2012) for a broader discussion.

sectors.

The longer time series of data more clearly shows the shift from manufacturing to the services sector and the sources of this change from the input side of the production account. For example, more than three quarters of the contribution of aggregate capital input over the period as a whole was driven by the accumulation of capital inputs in the service sector and almost all of the aggregate contribution of labour input was accounted for by labour input growth in the services sectors. MFP growth in manufacturing was strong compared to its contributions of labour and capital inputs, but this was mostly as a result of MFP growth in the computer and electronics product industry.

The conceptual framework that underpins the estimates is identical throughout the time series. However, more limited data availability requires that different techniques be employed to prepare estimates in the earlier periods. The primary purpose of this article is to describe the insights gained from longer time series and the methodology underpinning these new estimates.[3]

The article is divided into four main sections. Section 1 describes the conceptual framework that underpins the full set of statistics. Section 2 describes the source data and methodologies used to prepare the data for the period prior to 1997. Section 3 describes the results. Section 4 concludes.

## Conceptual Framework

To prepare these statistics, we assume a generic production function relating industry gross output to five factor inputs using the function Q = F(K, L, E, M, S, t). Assuming constant returns to scale, perfect competition, and factor payments equal to marginal product, the gross-output growth model can be written as:

$$\frac{d\ln Q}{dt} = (\frac{\partial \ln Q}{\partial \ln K} \cdot \frac{d\ln K}{d\ln t}) + (\frac{\partial \ln Q}{\partial \ln L} \cdot \frac{d\ln L}{d\ln t}) + (\frac{\partial \ln Q}{\partial \ln E} \cdot \frac{d\ln E}{d\ln t}) + (\frac{\partial \ln Q}{\partial \ln M} \cdot \frac{d\ln M}{d\ln t}) + (\frac{\partial \ln Q}{\partial \ln S} \cdot \frac{d\ln S}{d\ln t}) + (\frac{\partial \ln Q}{\partial \ln t})$$

| | | | |
|---|---|---|---|
| Q | = | Gross Output | (1) |
| K | = | Capital Input | |
| L | = | Labour Input | |
| E | = | Intermediate Energy Inputs | |
| M | = | Intermediate Material Inputs | |
| M | = | Intermediate Purchased Services Inputs | |
| t | = | time | |

which can be rearranged to measure

3 See Fleck *et al.* (2014) for a more detailed discussion of the methodologies and source data that underpin the statistics for the more recent period.

(unobserved) multifactor productivity growth as follows:

$$\frac{d\ln Q}{dt} = \frac{\partial \ln Q}{\partial \ln t} - (\frac{\partial \ln Q}{\partial \ln K} \cdot \frac{d\ln K}{d\ln t}) - (\frac{\partial \ln Q}{\partial \ln L} \cdot \frac{d\ln L}{d\ln t}) - (\frac{\partial \ln Q}{\partial \ln E} \cdot \frac{d\ln E}{d\ln t}) - (\frac{\partial \ln Q}{\partial \ln M} \cdot \frac{d\ln M}{d\ln t}) - (\frac{\partial \ln Q}{\partial \ln S} \cdot \frac{d\ln S}{d\ln t}) \quad (2)$$

With the above assumptions, the unknown elasticities can be replaced with the observable factor share, $v_i$, for each input. Shown below is the factor share for capital input:

$$\frac{\partial \ln Q}{\partial K} = \frac{P_K K}{P_K K + P_L L + P_E E + P_M M + P_S S} \quad (3)$$

where

| | | |
|---|---|---|
| $P_K$ | = | Price of Capital |
| $P_L$ | = | Price of Labour |
| $P_E$ | = | Price of Intermediate Energy Inputs |
| $P_M$ | = | Price of Intermediate Materials Inputs |
| $P_S$ | = | Price of Intermediate Purchased Services Inputs |

The assumption of constant returns to scale ensures that the factor shares for all inputs sum to one:

$$V_K + V_L + V_E + V_M + V_S = 1 \quad (4)$$

In discrete time, the input weights are two-year averages of the cost shares for each input in years t and t - 1, where $\tilde{v} = \frac{1}{2}v_{\text{i,t}} + \frac{1}{2}v_{\text{i,t-1}}$. All of this information can be combined to rewrite MFP growth for an industry as the residual difference between growth in output and growth in the combined inputs:

$$\triangle MFP = \triangle \ln Q - \tilde{v}_K \triangle \ln K - \tilde{v}_L \triangle \ln L - \tilde{v}_E \triangle \ln E - \tilde{v}_M \triangle \ln M - \tilde{v}_S \triangle \ln S \quad (5)$$

Finally, it is worth noting that the above production function applies at the level of each industry. That is, individual industries face industry-specific output and input prices and these are reflected in the growth accounting model.

The MFP index is computed by dividing an index of real gross output by an index of combined real inputs. The combined index of real inputs is computed using a Tornqvist index number formula to aggregate real intermediate inputs by industry for energy, materials, and purchased services, real labour input, and real capital input weighted by average cost shares.

The above framework describes the approach to measuring the industry-level sources of growth, but an important objective of this article is to construct aggregate measures from the bottom up. To aggregate the sources of growth by industry to economy-wide totals we use the "direct aggregation" approach discussed in (Jorgenson, Ho, and Stiroh, 2005). The details of the direct aggregation approach are beyond the scope of this article, but the basic idea is to weight the industry-level input and MFP contributions by "Domar" weights. Direct aggregation across industries can be expressed with the following formula:

$$\begin{aligned}\triangle\ln V = \Sigma_j(\frac{\tilde{y}_j}{\tilde{w}_v j})\tilde{w}_K j\triangle\ln K_j \\ +\Sigma_j(\frac{\tilde{y}_j}{\tilde{w}_v})\tilde{w}_L\triangle\ln L_j \\ +\Sigma_j(\frac{\tilde{y}_j}{\tilde{w}_v})\triangle\ln MFP_j\end{aligned} \quad (6)$$

where $\triangle\ln V$ is aggregate value-added growth. The right-hand side decomposes this to the weighted sum of the contributions of capital, labour, and MFP growth by industry. For completeness: $\tilde{y}_{\mathrm{j}}$ is nominal value added in industry j as a share of aggregate value added and $\tilde{w}_{\mathrm{vj}}$ is the value added share in gross output in industry j. The other terms are defined as in Equation 5; and the tilde indicates average share in period t and t-1. All of the equations are implemented for each individual year in the time series.[4]

## Data

A main objective of this article is to implement the above framework in a way that is consistent with the U.S. national accounts. That is, the sources of growth from the bottom up across industries and factors of production should be consistent with the GDP accounts. In this section, we briefly describe the basic data sources and how we make them internally consistent so that components "add up" to the official GDP estimates. The growth accounting framework requires industry-level data on gross output, intermediate inputs, capital, and labour in current and constant prices. Details on the data construction and the new estimates constructed are given in the Appendix.[5]

Data on industry gross output and intermediate inputs by industry are drawn from BEA's GDP by Industry statistics, thus are consistent with the GDP accounts by construction. That is, in equation (5), $\triangle\ln V$ comes directly from the official GDP by industry statistics. Only total intermediate is published in the industry ac-

4 That is, for each t from 1987 to 2016. This can be contrasted to obtaining a growth rate from 1987 to 2016 using only these two years of data.

5 Available at: http://www.csls.ca/ipm/36/Garner_etal_appendix.pdf).

counts. The Appendix describes work to split total intermediate into energy, materials, and services such that they add back up to the published total intermediate inputs. Because the output and intermediate input data that we use to implement equation (5) is consistent with the GDP accounts, industry value added, which is constructed by double deflation, is also consistent with the industry accounts; and when we sum (appropriately weighted) value added contributions across industries, we obtain aggregate value added growth that is consistent with the official U.S. accounts.

Capital inputs by industry come primarily from the BLS Productivity Program. Capital services conceptually measure the service flow from capital assets. A central notion in the construction of capital measures is the concept of "productive" capital stock, or the stock measured as "efficiency units." Conceptually, productive stock represents the amount of new investment required to produce the same capital services actually produced by existing assets of all vintages. Thus, capital services are assumed to be proportional to productive stock at the asset level by industry. To construct industry-level measures of capital input, each asset is weighted by its share of capital compensation, i.e. share in capital income. These shares are estimated as the price of capital input by asset times its productive stock divided by the total capital income in the industry. The price of the capital input is estimated by the user cost method used by the BLS Productivity Program. To ensure consistency between the BLS capital input data, and the BEA GDP by industry data, the account constructed uses the quantity of capital input from the BLS productivity program for each industry, and the capital compensation underlying the integrated BEA-BLS production account.

Labour inputs combine hours data from the BLS and a labour composition adjustment from the BEA. In order to create a constant quality index of labour input, hours worked are weighted to account for substitution between heterogeneous types of labour. The need for this adjustment reflects the assumption that the marginal product of a skilled worker is higher than that of an unskilled worker, implying that replacing hours worked by an unskilled worker with an equal number of hours worked by a skilled worker will increase economic output without an increase in MFP. Given the framework described above, it is important to capture the change in the characteristics of the workforce as a change in labour input, or a change in the composition of labour input would manifest as an increase in MFP. This change in labour input due to shifts in worker characteristics is referred to as the labour composition effect.

In addition to the new historical data, this new dataset includes revised data for 1997-2015 and new estimates for 2016. Minor revisions throughout this period are due to the incorporation of updated data on capital and labour inputs from the BLS productivity program published on March 21, 2018. In addition, revisions in 2014 and 2015 reflect BEA's annual update to the industry accounts published on November 2, 2017.

Finally, it is worth noting why the data covers 1987-2016 when BEA's GDP by Industry accounts data covers 1947-2016. The primary reason for this is that a significant amount of additional detail is necessary to estimate the production account and this underlying data are not available at the time of writing. For example, labour and capital compensation controls are not available before 1987. The Current Population Survey (CPS) micro data that are used to estimate the labour composition are not available before 1964, and the sector detail available in the BEA GDP by Industry data is more limited before 1964 as well. Future work will examine extending the data before 1987.

## Results

The major advantage of the longer time series of integrated KLEMS (K-capital, L-labour, E-energy, M-materials, and S-purchased services) data is that it permits analysis of longer-term economic trends. The description of these trends is what we focus on in the presentation of our results.[6] Over the last three decades, this includes the information technology (IT) revolution and increased globalization of the production process. The dataset described above is an important tool for identifying the structural change that has taken place between 1987 and 2016, particularly at the industry level. This section describes industry-level sources of growth, including the industry-level contributions of capital, labour, and multifactor productivity to economic growth, as well as some aspects of structural change over this longer time period. To facilitate this discussion, results are mainly focused on nine sectors that reflect major industry groupings, rather than the 63 in-

6 The dataset that we use is posted here: https://www.bea.gov/data/special-topics/integrated-industry-level-production-account-klems so that alternative decompositions can be calculated with the publicly available data.

7 This is the same industry classification used by Jorgenson and Schreyer (2013).

## Table 1: Sources of Industry Output Growth in the United States, 1987-2016

| | Output Growth | Capital Contribution | Labor Contribution | Intermediate Contribution | MFP Growth |
|---|---|---|---|---|---|
| Farms | 1.69 | 0.09 | -0.18 | 0.37 | 1.42 |
| Forestry, fishing, and related activities | 0.11 | 0.42 | 0.99 | -0.49 | -0.81 |
| Oil and gas extraction | 1.29 | -0.08 | -0.08 | 0.06 | 1.40 |
| Mining, except oil and gas | 0.39 | 0.39 | -0.25 | -0.51 | 0.77 |
| Support activities for mining | 1.46 | 0.21 | 0.45 | -0.56 | 1.36 |
| Utilities | 0.31 | 0.74 | 0.03 | 0.05 | -0.50 |
| Construction | 0.39 | 0.21 | 0.52 | 0.34 | -0.68 |
| Wood products | 0.15 | 0.06 | -0.24 | 0.58 | -0.24 |
| Nonmetallic mineral products | 0.20 | 0.14 | -0.07 | 0.05 | 0.08 |
| Primary metals | 0.49 | -0.07 | -0.30 | 0.18 | 0.68 |
| Fabricated metal products | 1.18 | 0.18 | 0.05 | 0.99 | -0.04 |
| Machinery | 1.09 | 0.30 | -0.04 | 1.00 | -0.18 |
| Computer and electronic products | 6.56 | 0.56 | -0.49 | 0.53 | 5.96 |
| Electrical equipment, appliances, and components | 0.14 | 0.17 | -0.39 | 0.13 | 0.23 |
| Motor vehicles, bodies and trailers, and parts | 2.55 | 0.24 | 0.02 | 1.76 | 0.52 |
| Other transportation equipment | 1.04 | 0.23 | -0.28 | 1.37 | -0.28 |
| Furniture and related products | 0.16 | 0.16 | -0.33 | 0.33 | 0.00 |
| Miscellaneous manufacturing | 1.75 | 0.46 | 0.21 | 0.41 | 0.67 |
| Food and beverage and tobacco products | 1.10 | 0.25 | 0.09 | 0.93 | -0.17 |
| Textile mills and textile product mills | -1.90 | -0.10 | -0.85 | -1.44 | 0.49 |
| Apparel and leather and allied products | -2.95 | 0.00 | -1.74 | -1.75 | 0.54 |
| Paper products | -0.25 | 0.09 | -0.29 | 0.17 | -0.21 |
| Printing and related support activities | -0.77 | 0.01 | -0.53 | -0.75 | 0.51 |
| Petroleum and coal products | 0.85 | 0.10 | -0.07 | 0.00 | 0.81 |
| Chemical products | 1.29 | 1.12 | -0.01 | 0.71 | -0.53 |
| Plastics and rubber products | 1.37 | 0.29 | 0.02 | 0.71 | 0.35 |
| Wholesale trade | 3.31 | 1.12 | 0.43 | 0.82 | 0.94 |
| Retail trade | 2.93 | 0.86 | 0.37 | 0.78 | 0.91 |
| Air transportation | 0.99 | 0.40 | 0.05 | -0.03 | 0.57 |
| Rail transportation | 1.04 | 0.07 | -0.73 | 0.60 | 1.10 |
| Water transportation | 2.58 | 0.04 | 0.33 | 1.13 | 1.08 |
| Truck transportation | 2.89 | 0.35 | 0.49 | 1.73 | 0.31 |
| Transit and ground passenger transportation | 1.60 | 0.41 | 1.05 | 0.57 | -0.42 |
| Pipeline transportation | -0.44 | 1.12 | 0.03 | -2.43 | 0.84 |
| Other transportation and support activities | 2.85 | 0.02 | 1.35 | 2.04 | -0.56 |
| Warehousing and storage | 5.91 | 0.30 | 2.03 | 2.15 | 1.44 |
| Publishing industries, except internet (includes software) | 3.31 | 0.90 | 0.07 | 0.95 | 1.38 |
| Motion picture and sound recording industries | 2.45 | 1.40 | 0.57 | 0.68 | -0.19 |
| Broadcasting and telecommunications | 4.77 | 1.90 | 0.00 | 2.29 | 0.58 |
| Data processing, internet publishing, and other information services | 7.12 | 2.58 | 1.09 | 3.62 | -0.17 |
| Federal Reserve banks, credit intermediation, and related activities | 1.52 | 1.87 | 0.30 | 0.68 | -1.33 |
| Securities, commodity contracts, and investments | 6.49 | 0.15 | 1.06 | 3.19 | 2.10 |
| Insurance carriers and related activities | 2.77 | 1.27 | 0.49 | 0.64 | 0.37 |
| Funds, trusts, and other financial vehicles | 2.78 | 0.11 | 0.07 | 2.35 | 0.26 |
| Real estate | 2.72 | 1.39 | 0.06 | 0.94 | 0.33 |
| Rental and leasing services and lessors of intangible assets | 3.63 | 3.99 | 0.18 | 1.73 | -2.27 |
| Legal services | 0.92 | 0.68 | 0.68 | 0.78 | -1.22 |
| Computer systems design and related services | 7.98 | 0.18 | 4.53 | 2.51 | 0.77 |
| Miscellaneous professional, scientific, and technical services | 3.69 | 0.80 | 1.38 | 1.64 | -0.13 |
| Management of companies and enterprises | 3.06 | 0.29 | 1.57 | 2.27 | -1.07 |
| Administrative and support services | 4.66 | 0.76 | 1.77 | 2.01 | 0.12 |
| Waste management and remediation services | 2.67 | 0.32 | 1.00 | 1.75 | -0.41 |
| Educational services | 2.96 | 0.22 | 1.45 | 1.53 | -0.23 |
| Ambulatory health care services | 3.35 | 0.22 | 1.79 | 1.58 | -0.24 |
| Hospitals and Nursing and residential care | 2.77 | 0.26 | 1.15 | 1.86 | -0.51 |
| Social assistance | 3.69 | 0.10 | 2.53 | 1.60 | -0.54 |
| Performing arts, spectator sports, museums, and related activities | 3.73 | 0.08 | 1.19 | 1.86 | 0.61 |
| Amusements, gambling, and recreation industries | 3.68 | 0.68 | 1.03 | 1.79 | 0.18 |
| Accommodation | 2.11 | 0.69 | 0.28 | 0.84 | 0.30 |
| Food services and drinking places | 2.28 | 0.18 | 0.62 | 1.23 | 0.25 |
| Other services, except government | 1.74 | 0.43 | 0.51 | 1.10 | -0.29 |
| Federal | 0.72 | 0.37 | -0.17 | 0.46 | 0.07 |
| State and local | 1.90 | 0.45 | 0.64 | 0.73 | 0.08 |

Notes: Average annual log growth rate in percentage points. A contribution is a share-weighted log growth rate. Aggregate value added growth is the aggregate of share weighed industry value added growth. Sector aggregates are the sum of contributions over the underlying industries. A contribution in individual year t uses the log growth rate in period t and the average of the nominal shares in year t and t-1, and these contributions are then averaged over the sample periods presented in this table.
Source: Authors' calculations.

dustries described above.[7]

Industry-level sources of output growth for the entire 1987-2016 are shown in Table 1. Over this period, the three fastest growing industries were IT: computer systems design; data processing, internet publishing, and other information services; and computer and electronic products manufacturing, reflecting not only the importance of IT hardware, but also the related systems development and the shift towards cloud computing. The textile and paper manufacturing industries contracted over the period.

Since the Great Recession, imports in these industries have shown robust growth, likely reflecting increased competition from foreign products and other shifts in demand toward cheaper substitutes. Relatively strong growth in rental and leasing; broadcasting and telecommunications; and data processing was driven by capital investments, while growth in computer systems design; social assistance; and warehousing and storage was driven by growth in labour inputs, reinforcing the importance of looking at the input side when analyzing the sources of growth. Between 1987 and 2016, the computer and electronic products; securities, commodity contracts, and investments; and warehousing and storage had the largest growth in MFP.

Table 2 presents sector contributions to aggregate value-added growth and shows many familiar facets of economic growth over the last 30 years. Between 1987 and 2016, manufacturing contributed 0.34 percentage point to aggregate value-added growth of 2.38 per cent per year on average. The importance of including the new historical data is evident in this table because this contribution was skewed heavily towards the first part of the period; manufacturing contributed 0.45 percentage point to growth between 1987-95 and 0.84 percentage point during the IT-Investment boom of 1995-2000 and has fallen off since.

Between 2000 and 2007 manufacturing contributed 0.32 percentage point to aggregate growth and −0.01 between 2007 and 2016. Importantly, the manufacturing sector includes the relatively rapidly growing computer and electronic industry; excluding this industry the contribution of manufacturing to aggregate growth was 0.20 percentage point in 1987-95 and -0.08 percentage point in 2007-2016. Over the same period, value added generated by services industries increased in importance. In particular, the information industries; finance, insurance, real estate, rental and leasing; and other services accounted for about 46 per cent of real economic growth in the 1987-1995 period and 74 per cent of real growth in

**Table 2: Sector Contributions to Aggregate Value-Added Growth in the United States**

| | 1987-2016 | 1987-1995 | 1995-2000 | 2000-2007 | 2007-2016 | 2007-2009 | 2009-2016 |
|---|---|---|---|---|---|---|---|
| | | | Contributions | | | | |
| Value-Added | 2.38 | 2.65 | 4.22 | 2.34 | 1.14 | -1.56 | 1.91 |
| Agriculture, Forestry, Fishing, Hunting, Mining | 0.08 | 0.04 | 0.05 | 0.06 | 0.14 | 0.25 | 0.11 |
| Transportation, Warehousing, Utilities | 0.07 | 0.16 | 0.10 | 0.02 | 0.02 | -0.17 | 0.08 |
| Construction | 0.00 | 0.03 | 0.13 | -0.04 | -0.06 | -0.48 | 0.06 |
| Manufacturing | 0.34 | 0.45 | 0.84 | 0.32 | -0.01 | -0.64 | 0.18 |
| Computer and electronic products | 0.24 | 0.25 | 0.62 | 0.17 | 0.07 | 0.09 | 0.06 |
| Trade | 0.41 | 0.54 | 0.90 | 0.33 | 0.09 | -0.61 | 0.29 |
| Information | 0.20 | 0.17 | 0.20 | 0.30 | 0.14 | 0.03 | 0.17 |
| Finance, Insurance, Real Estate, Rental and Leasing | 0.50 | 0.46 | 0.89 | 0.57 | 0.27 | 0.02 | 0.34 |
| Other Services | 0.57 | 0.60 | 0.89 | 0.49 | 0.44 | -0.12 | 0.60 |
| Government | 0.19 | 0.20 | 0.21 | 0.28 | 0.11 | 0.17 | 0.09 |
| | | | Shares | | | | |
| Shares in Nominal Value-Added | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Agriculture, Forestry, Fishing, Hunting, Mining | 2.7 | 2.6 | 2.1 | 2.4 | 3.3 | 3.2 | 3.3 |
| Transportation, Warehousing, Utilities | 4.7 | 5.3 | 4.8 | 4.3 | 4.3 | 4.3 | 4.4 |
| Construction | 4.0 | 3.9 | 4.1 | 4.6 | 3.7 | 4.0 | 3.6 |
| Manufacturing | 13.9 | 16.7 | 15.4 | 12.7 | 11.6 | 11.6 | 11.6 |
| Computer and electronic products | 1.7 | 1.9 | 2.1 | 1.5 | 1.5 | 1.5 | 1.5 |
| Trade | 11.9 | 12.5 | 12.7 | 11.8 | 11.2 | 11.1 | 11.2 |
| Information | 4.6 | 4.5 | 4.7 | 4.7 | 4.5 | 4.7 | 4.5 |
| Finance, Insurance, Real Estate, Rental and Leasing | 18.6 | 17.5 | 18.5 | 19.3 | 19.0 | 18.6 | 19.1 |
| Other Services | 23.0 | 20.8 | 22.5 | 23.4 | 24.8 | 24.6 | 24.8 |
| Government | 16.7 | 16.2 | 15.3 | 16.9 | 17.6 | 17.8 | 17.5 |

Notes: Average annual log growth rate in percentage points. A contribution is a share-weighted log growth rate. Aggregate value added growth is the aggregate of share weighed industry value added growth. Sector aggregates are the sum of contributions over the underlying industries. A contribution in individual year t uses the log growth rate in period t and the average of the nominal shares in year t and t-1, and these contributions are then averaged over the sample periods presented in this table.
Source: Authors' calculations.

the 2007-2016 period.

The bottom portion of table 2 includes the nominal value-added shares of each of the major sectors and conveys a similar story. The nominal value-added share encompasses payments to labour and capital services and shows how income is distributed throughout the economy. Factors of production in the manufacturing sectors earned 16.7 per cent of aggregate income in 1987-1995, but only 11.6 per cent of income in 2009-2016, reflecting the overall decline in the share of manufacturing in the economy. Other services produced 20.8 per cent of income between 1987 and 1995, but this increased to 24.8 per cent over the 2009-2016 period. The value-added share in finance, insurance, real estate, rental and leasing also increased, from 17.5 per cent in the early periods to about 19.0 per cent in the later period.

**Table 3: Contributions of Capital and Labour Input and Multifactor Productivity by Sector to Aggregate Value-Added Growth in the United States**

| | 1987-2016 | 1987-1995 | 1995-2000 | 2000-2007 | 2007-2016 | 2007-2009 | 2009-2016 |
|---|---|---|---|---|---|---|---|
| | | | Capital Input | | | | |
| Aggregate | 1.19 | 1.25 | 1.91 | 1.35 | 0.62 | 0.64 | 0.61 |
| Agriculture,Forestry,Fishing, Hunting,Mining | 0.01 | 0.00 | 0.00 | 0.00 | 0.03 | 0.01 | 0.04 |
| Transportation, Warehousing, Utilities | 0.04 | 0.04 | 0.05 | 0.03 | 0.04 | 0.03 | 0.04 |
| Construction | 0.02 | 0.01 | 0.05 | 0.05 | -0.01 | -0.02 | -0.01 |
| Manufacturing | 0.14 | 0.17 | 0.26 | 0.07 | 0.11 | 0.13 | 0.10 |
| Trade | 0.17 | 0.17 | 0.31 | 0.22 | 0.08 | -0.02 | 0.10 |
| Information | 0.14 | 0.13 | 0.22 | 0.13 | 0.09 | 0.10 | 0.09 |
| Finance, Insurance, Real Estate, Rental and Leasing | 0.42 | 0.49 | 0.70 | 0.52 | 0.11 | 0.12 | 0.11 |
| Other Services | 0.16 | 0.16 | 0.24 | 0.20 | 0.09 | 0.15 | 0.07 |
| Government | 0.10 | 0.09 | 0.08 | 0.13 | 0.09 | 0.15 | 0.07 |
| | | | Labour Input | | | | |
| Aggregate | 0.76 | 1.09 | 1.33 | 0.43 | 0.40 | -1.30 | 0.88 |
| Agriculture, Forestry, Fishing, Hunting, Mining | 0.00 | -0.01 | -0.01 | 0.02 | 0.01 | -0.03 | 0.02 |
| Transportation, Warehousing, Utilities | 0.03 | 0.07 | 0.04 | 0.00 | 0.03 | -0.07 | 0.06 |
| Construction | 0.04 | 0.04 | 0.16 | 0.07 | -0.04 | -0.40 | 0.06 |
| Manufacturing | -0.04 | 0.07 | 0.03 | -0.21 | -0.04 | -0.41 | 0.06 |
| Trade | 0.07 | 0.13 | 0.12 | 0.04 | 0.02 | -0.20 | 0.08 |
| Information | 0.01 | 0.04 | 0.11 | -0.05 | -0.01 | -0.08 | 0.01 |
| Finance, Insurance, Real Estate, Rental and Leasing | 0.07 | 0.07 | 0.16 | 0.08 | 0.02 | -0.15 | 0.07 |
| Other Services | 0.48 | 0.60 | 0.61 | 0.39 | 0.39 | -0.06 | 0.52 |
| Government | 0.08 | 0.09 | 0.11 | 0.10 | 0.03 | 0.11 | 0.01 |
| | | | MFP | | | | |
| Aggregate | 0.43 | 0.31 | 0.98 | 0.55 | 0.13 | -0.90 | 0.42 |
| Agriculture, Forestry, Fishing, Hunting, Mining | 0.07 | 0.06 | 0.07 | 0.04 | 0.10 | 0.27 | 0.05 |
| Transportation, Warehousing, Utilities | 0.00 | 0.05 | 0.01 | 0.00 | -0.04 | -0.13 | -0.02 |
| Construction | -0.06 | -0.02 | -0.09 | -0.15 | -0.01 | -0.06 | 0.01 |
| Manufacturing | 0.24 | 0.21 | 0.55 | 0.46 | -0.07 | -0.36 | 0.01 |
| Trade | 0.17 | 0.24 | 0.47 | 0.08 | 0.00 | -0.39 | 0.11 |
| Information | 0.05 | 0.00 | -0.13 | 0.22 | 0.06 | 0.02 | 0.08 |
| Finance, Insurance, Real Estate, Rental and Leasing | 0.01 | -0.10 | 0.03 | -0.03 | 0.14 | 0.05 | 0.16 |
| Other Services | -0.07 | -0.16 | 0.04 | -0.10 | -0.04 | -0.21 | 0.01 |
| Government | 0.02 | 0.02 | 0.02 | 0.04 | -0.01 | -0.10 | 0.01 |
| Aggregate Value Added Growth | 2.38 | 2.65 | 4.22 | 2.34 | 1.14 | -1.56 | 1.91 |

Notes: Average annual log growth rate in percentage points. A contribution is a share-weighted log growth rate. Aggregate value added growth is the aggregate of share weighed industry value added growth. Sector aggregates are the sum of contributions over the underlying industries. A contribution in individual year t uses the log growth rate in period t and the average of the nominal shares in year t and t-1, and these contributions are then averaged over the sample periods presented in this table.
Source: Authors' calculations.

Table 3 shows the sector-level sources of growth. Over the entire period, growth in capital input was the predominant source of economic growth, followed by growth of labour input and then growth in MFP. Growth in capital input in the finance and trade industries accounted for about half of the total contribution of capital input. However, breaking down the contributions of capital growth across the time periods reveals important differences between the sources of growth in the later period (2009-2016) in relation to the earlier period (1987-1995). The choice of periods to compare is somewhat arbitrary, but comparisons of the 2009--2016 period to the 1987-1995 period reveal the extent and sources of the slow recovery after the financial crisis, even in comparison to the slow growth period before the IT investment boom. The most striking difference is in the contribution from the finance, insurance, real estate, rental and leasing which fell from 0.49 percentage point between 1987-1995 to 0.11 percentage point in 2009-2016; this mostly reflects the lingering effects of the housing crisis in the real estate sector. The only sector to have a larger contribution of capital input in the 2009-2016 period was the agriculture, forestry, fishing, hunting, mining sector, emphasizing the overall slowdown in capital investment in the recovery period.

More than half of the contribution of labour input over the entire period was accounted for by growth in labour input in the other services industries. Comparing the contribution of labour input by sector in the later period to the earlier period is not particularly illuminating, but we will see below that the industry data reveal significant shifts in the distribution of labour income by sector.

Finally, growth in MFP was dominated by MFP growth in manufacturing (mostly computers and electronic products) and the trade sectors over the 1987-2016 time period. MFP growth in manufacturing was much faster in the 1987-1995 period than in the 2009-2016 period. In contrast, the MFP contributions of the finance, insurance, real estate, rental and leasing and the other services industry were significantly higher in the later period.

It is worth summarizing a few of the main trends that the 1987-2016 KLEMS data reveal. Over this period, output growth shifted from manufacturing to services, and income shares shifted as well. Economic growth during the period of the ongoing recovery from 2009-2016 was significantly slower than the 1987-1995 period before the IT boom; this was driven mostly by slower capital and labour input growth. MFP growth was actually faster in the 2009-2016 period in comparison with the 1987--1995 period. The growth in other services was driven mostly by labour input growth and a recovery of MFP from negative early in the period to slightly positive towards the end of the period.

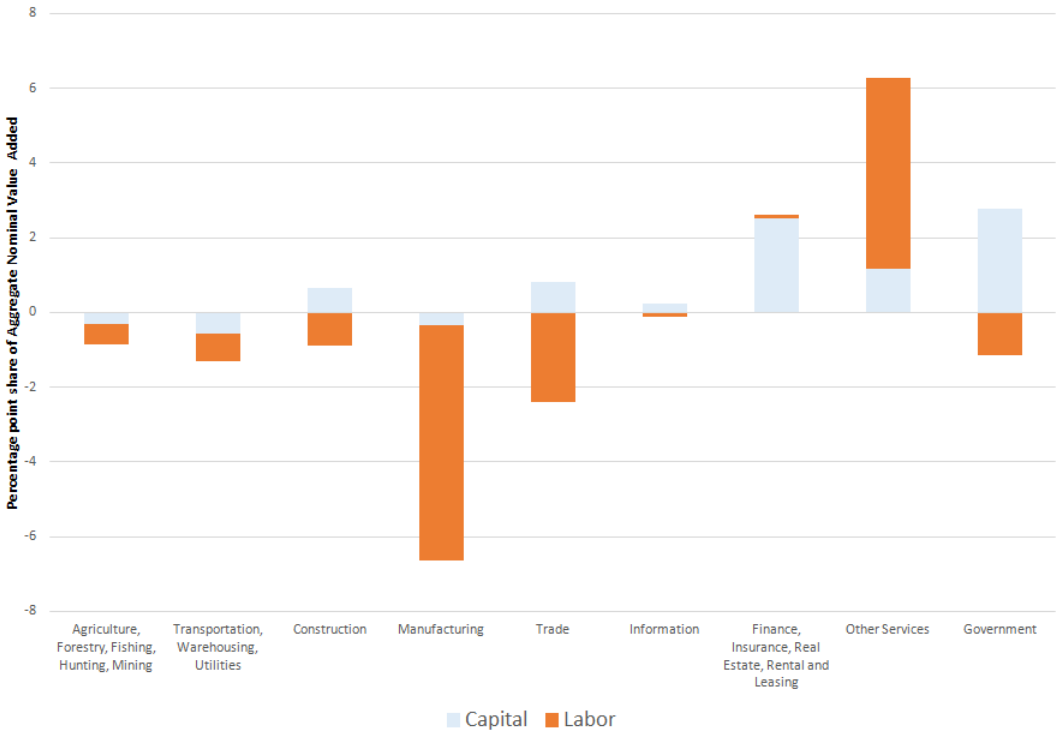
We now focus on one particular component of structural change over the last 30 years: the industry sources of the change in the distribution of income. It is relatively well known that the share of value added accruing to labour has been in decline. We present new information on the industry sources of this decline with the charts. Each component of income (whether it is total labour income, or college-educated labour, for example) is presented as a share of nominal aggregate value added.

Chart 1 shows the change in the share of capital and labour by sector in nominal aggregate value added. To reinforce the concepts, for this and the subsequent figures, the shares are defined as compensation to the factor of production in each sector divided by aggregate nominal value added. Over the 1987-2016 period, the aggregate total economy capital share increased from 38.6 per cent of income in 1987 to 45.5 per cent of income in 2016. Chart 1 indicates that this shift was not proportionate across sectors. For example, while the income share paid to labour generated in the manufacturing sector fell by a significant margin, it increased by almost as much in the other services sector. Thus, the shift in output from manufacturing to other services actually counterbalanced the aggregate trend of a falling labour share. In the trade sector, the share of aggregate income accruing to capital increased while that accruing to labour fell, providing evidence that an industry's expansion does not necessarily produce proportional gains for labour and the owners of capital.

Charts 2 and 3 provide more information on the changes in the share of aggregate income accruing to labour by sector. Chart 2 shows that even though the aggregate labour share fell over the period, the share of income accruing to college-educated labour (those with a Bachelor of Arts degree and above) increased significantly over the period, so that the decline in the aggregate labour share was entirely due to a decline in the share of income paid to workers without a college degree.

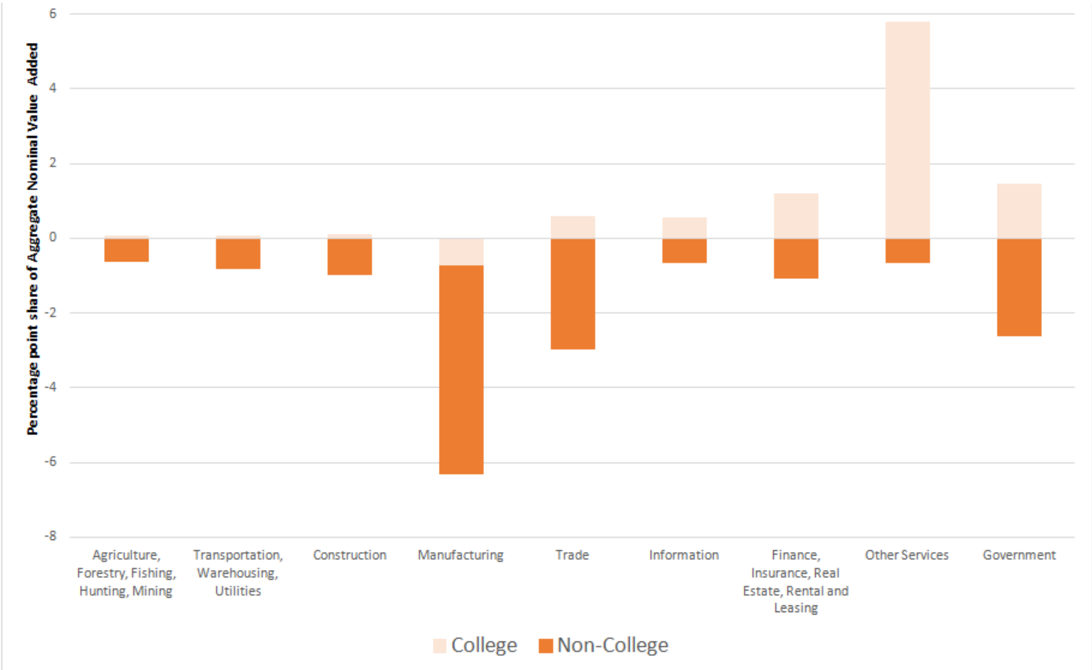
Chart 3 presents the decomposition by gender. Over the period, the share of income accruing to men fell from 44.2 per cent to 36.6 per cent between 1987 and 2016. This was driven mainly by large declines (relative to women) in the manufacturing, trade, and government sectors. With the shift towards services, the shares of in-

**Chart 1: Changes in the Input Shares of Aggregate Value Added in the United States, 1987-2016**




Source: Authors' calculations.

**Chart 2: Changes in the Labour Shares of Aggregate Value Added in the United States, 1987-2016**




Source: Authors' calculations.

**Chart 3: Changes in the Labour Shares of Aggregate Value Added in the United States, 1987-2016**

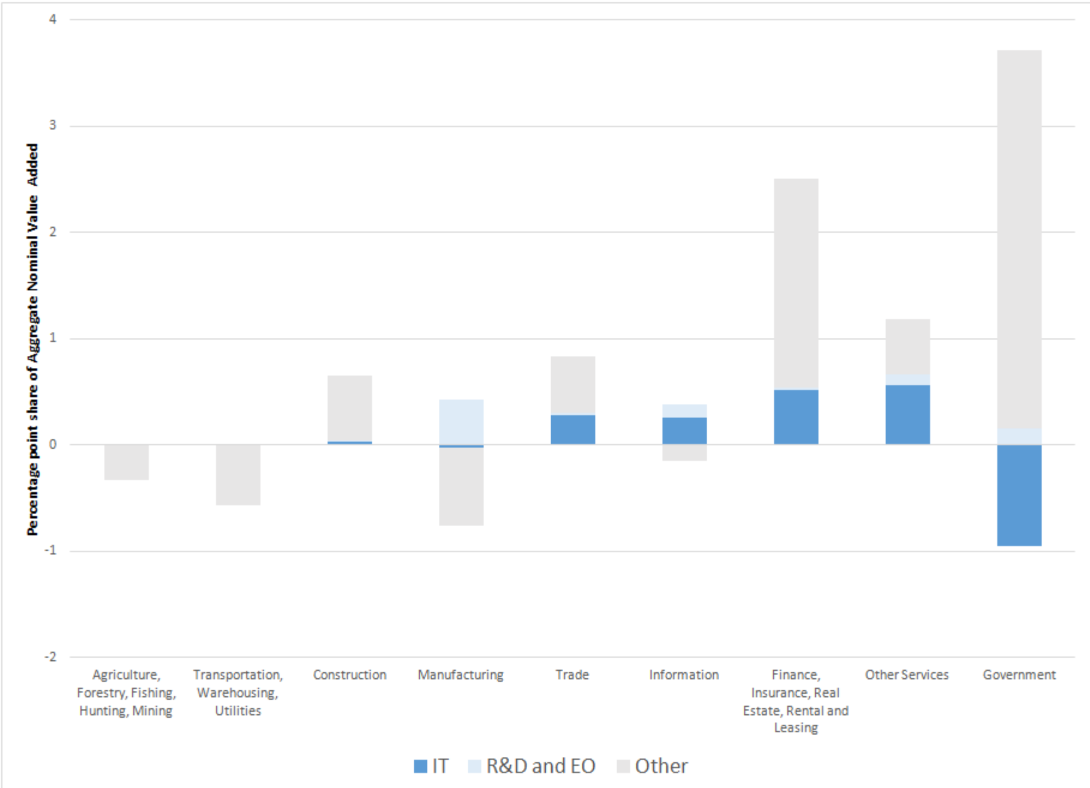

Source: Authors' calculations.

come paid to both men and women in the services sector increased, and the service sector was the largest driver of increase in the aggregate share of income paid to female workers. This is interesting in light of the findings in Ngai and Petrongolo (2017) that the shift to services has narrowed the gender pay gap.[8]

The change in the capital share was not proportionate across industries and types of capital. For example, chart 4 shows significant increases to the share of income paid to capital in the finance, insurance, real estate, rental and leasing well as in the other services sectors. Within these sectors, a significant portion of the increase was attributed to the share of IT capital. In contrast, in the construction and manufacturing sectors, there was little change in the share of aggregate income paid to IT capital. In the manufacturing sector, the share of capital income attributed to research and development actually increased, thus the decline in the overall capital income share in manufacturing

8 The finding of Ngai and Petrongolo (2017) focuses on wage rates, while the information that presented here is about aggregate income shares. While they are not directly comparable, both suggest that shift to services is an important component in how wages and income have evolved.

**Chart 4: Changes in the Capital Shares of Aggregate Value Added in the United States, 1987-2016**




Source: Authors' calculations.

was driven by a decrease in the share of income accruing to other types of capital.

## Conclusion

The purpose of this article was to present an extended time series of integrated KLEMS-based production accounts for the United States. The longer time series yields important data on the evolution of U.S. economic growth over the last three decades. The account shows the shift from manufacturing towards services and the importance of isolating the effects of the computer and electronics product industry when studying the overall manufacturing sector (Houseman, 2018). The KLEMS approach shows not only which industries are contributing to growth, but the industry-level sources of growth. The most important source of economic growth over the period was the accumulation of capital input. Of the 1.19 percentage point that capital input contributed to growth over the period, the services industries account for 0.89 percentage point. Aggregate labour input accounted for another 0.76 percentage point of economic growth between 1987 and 2016. Of this, the other services industries sector alone accounted for 0.48 percentage point, demonstrating the relative importance of labour in service producing industries. Finally, MFP growth accounted for 0.43 percentage point of aggregate economic growth. Almost all of this was accounted for by MFP growth in the manufacturing and trade sectors; within manufacturing almost all of the MFP growth was due to growth in MFP of the computer electronic products industry.

The account demonstrates the importance of structural change at the industry level in the evolution of the allocation of income between capital and labour. The share of aggregate income accruing to labour in the manufacturing sector shrank substantially over the period, while the share of income accruing to labour increased substantially in the services industries. In the manufacturing sector, this was mostly due to a decline in the share of income paid to workers without a college degree, while workers with a college degree accounted for the large majority of the increase in the income paid to labour in the service sectors.

The new estimates presented in this article are an important milestone because extending the account to cover 1987-1997 involved overcoming significant obstacles including the change in industrial classification between NAICS and SIC and changes in the reporting of educational attainment from years of school to attainment measures. However, this is not the final step in the development of the account. Important next steps could include extending the account even further back in time to span the entire period covered by BEA's GDP by industry accounts starting in 1947 and resolving existing difference in the measures of labour composition produced by BLS for the official MFP estimates and those produced by BEA for this set of accounts.

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# Online Appendix: Data Construction of New BEA-BLS Estimates of Industry-level Sources of U.S. Economic Growth between 1987 and 2016

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This appendix provides additional details on the data construction.

## Gross Output and Intermediate Inputs

BEA's GDP by Industry statistics provide a time series of nominal and real gross output, intermediate inputs (including a decomposition of energy, materials, and purchased services inputs), and value added by industry, prepared based on the 2007 North American Industry Classification System (NAICS). These data are fully integrated with expenditure-based GDP estimates from the National Income and Product Accounts (NIPAs). In addition, the data are prepared within a balanced supply-use framework that allows for simultaneous and consistent analysis of industry output, inputs, value added, and final demand. These fully integrated GDP by industry accounts were first released in January 2014,

1 The main article is available at http://www.csls.ca/ipm/36/Garner.pdf.

and covered the period 1997-2012. They have subsequently been updated annually and extended to cover the period 1947-2016 (Kim, Strassner and Wasshausen, 2017 and Barefoot, Gilmore and Nelson, 2017).

While certain series in the GDP by Industry dataset extended further back in time, the full suite of integrated make-use tables and GDP by industry statistics extended back only to 1998 prior to the release in early 2014. As a result, the initial version of the industry-level production account was also limited to the time period beginning in 1998. However, in February 2016, BEA released integrated make-use tables and GDP by Industry statistics extending back to 1947, adding a half century of historical data to this time series. The availability of these new historical data opened the possibility of extending the industry-level production account back in time as well (Lyndaker *et al.* 2016).

### Gross Output and Intermediate Inputs: Backcasting

Preparation of the historical make-use tables and GDP by Industry statistics relied heavily on a series of benchmark input-output tables prepared by BEA from 1947 to 1992.[2] These tables provide valuable information about the structure of the U.S. economy at various points in history; however, the tables as initially published were designed as standalone snapshots of the economy and could not be treated as a time series. Among other things, earlier tables were not updated to incorporate definitional and conceptual changes introduced in later tables, and the tables were not prepared using a consistent industry classification structure. Transformation of these disconnected benchmark tables into a consistent annual time series took place in four major steps.

First, the tables were updated to incorporate major definitional changes introduced into the NIPAs since the initial publication of each table. Major changes incorporated as part of this step include statistical revisions to autos and trucks, housing and housing services, and non-profits; changes to the treatment of output for insurance and banking; introduction of the "government as producer" treatment; and capitalization of software.

Second, the tables were updated to reflect the 2002 NAICS structure, consistent with data available as of May 2010. Benchmark tables

2 Benchmark tables in this period were prepared for the following years: 1947, 1958, 1963, 1967, 1972, 1977, 1982, 1987, and 1992.

in the historical period were initially published using whichever version of the Standard Industrial Classification (SIC) system was current at the time of preparation. The SIC-to-NAICS concordance that was used for the initial conversion of these tables to NAICS was based on fixed weights from 1997. This 1997 fixed-weight concordance was updated by aggregating SIC-based benchmark data up to roughly a 3-digit NAICS level of detail. The resulting concordance was used to convert both make and use tables to a 2002 NAICS basis. The converted tables were then re-balanced using a RAS balancing technique.

Third, annual tables were prepared for the inter-benchmark periods. To begin, make tables and unbalanced use tables were prepared by interpolating between benchmark tables. A variety of data were used as indicators for the interpolation process, including Census survey data, annual make-use tables and gross output by industry statistics published by BEA, and personal consumption and private investment data from the National Income and Product Accounts(NIPA). Each of these tables was then controlled to be consistent with historical GDP data using RAS balancing.

Fourth, the time series was updated to reflect the 2007 NAICS structure, and definitional and statistical improvements from BEA's 2013 comprehensive update were incorporated into the dataset. Major changes incorporated at this stage include the capitalization of R&D expenditures, own account entertainment originals, and residential housing transfer costs as well as the adjustment of defined pension plans from a cash-accounting basis to an accrual-accounting basis.

For the industry-level production account, intermediate inputs in the historical time series also needed to be decomposed into energy, materials, and purchased services (EMS) components. The time series of make-use tables for 1963-1996 includes a decomposition of intermediate inputs into 75 commodities; however, this level of detail was not sufficient to allow a one-to-one assignment of each commodity to an EMS category. We addressed this using unpublished data from the 1997 use table. The working level of detail for tables beginning in 1997 includes about 5,000 goods and services and about 800 industries. At this level of detail, it is possible to make a direct EMS assignment to each cell in the use matrix. By aggregating these data up to the same level of detail as the historical use tables (about 75 goods and services and 65 industries), we were able to calculate EMS ratios for each cell in the matrix. These fixed ratios were applied to the historical use tables to generate estimates of EMS inputs for each industry for 1987-1996.

With the nominal data available in the make-use framework, estimates of real GDP by industry were prepared using a double deflation methodology in which gross output and intermediate inputs are deflated separately and real value added is computed as the residual, as is standard in the published GDP by industry statistics. Real gross output by industry was derived by deflating the commodities produced by each industry as reflected in the make table.[3] Similarly, real intermediate inputs were derived by deflating the commodities consumed by each industry as reflected in the use table. Prices used for deflation were developed by Dale W. Jorgenson, Mun Ho, and Jon D. Samuels and are described in more detail in the article that accompanied the initial publication of the historical GDP by industry statistics (Lyndaker, *et al.* 2016).

As in the post-1996 period, the domestic and imported portions of intermediate inputs are deflated separately to account for potential differences in price between commodities purchased from domestic versus foreign sources. Intermediate inputs are disaggregated into domestic and imported components based on the proportionality assumption. More specifically, for each detailed commodity used by an industry, the portion attributable to imports is calculated as the ratio of total imports of the commodity over total domestic supply of the commodity.

## Gross Output and Intermediate Inputs: Revisions

This 2017 annual update to BEA's GDP by industry statistics incorporated the Census Bureau's latest Service Annual Survey (SAS) tabulations, which revised statistics for 2014 and 2015. In addition, newly available data for 2016 from SAS replaced estimates based on the Census Bureau's Quarterly Services Survey (QSS). Similarly, revised and newly available data from the Department of Treasury's Statistics of Income (SOI) Division led to revisions to underlying components of the current-dollar estimates of value added by industry, including corporate profits, nonfarm proprietors' income, and net interest for 2014 and 2015. Finally, the annual update incorporated newly available Census Bureau data from the 2015 Annual Survey of Manufactures, the 2015 Annual Retail Trade Survey, and the 2015 Annual Wholesale Trade Survey.

3 This differs from the BLS Productivity Program's use of a sectoral output measure which removes the double counting of the intrasectoral sales between establishments within the same sector.

## Capital Services Inputs

### Capital Input: Backcasting

By definition, a capital asset is one that lasts more than a year. Therefore, the service flows received from a producing industry or firm are employed over a longer period than the original investment conveys. As a practical matter, real stocks are constructed as vintage aggregates of real historical investments in accordance with an "efficiency" or service flow concept using the perpetual inventory method outlined in the initial release of the BEA-BLS production account. This implies that the hard work of backcasting historical stocks had, in effect, already been accomplished by the BLS with the original release of the BEA-BLS account.

The current-dollar value added components by industry needed to calculate rental prices used to construct capital services were the missing link that BEA's release of historical make-use tables was able to bridge. These new historical measures allowed the BLS to incorporate capital services estimates back to 1987. With the release of the 2016 Multifactor Productivity Trends[4] news release, BLS incorporated these integrated and improved data into their official measures. Thus, this release makes use of all the available historical data from the most recent BLS multifactor productivity update to produce its capital service measure back to 1987 to be consistent with the national accounts.[5]

### Capital Input: Revisions

With this update of the account, the capital measures for the finance and insurance industries were revised to more fully integrate the BEA-BLS production account into the national accounts. Previously, in the finance and insurance sectors, controls for capital compensation were not constrained to BEA income estimates because of concerns for some of the features of the more detailed estimates.

More recently, BEA has made a number of improvements to the finance and insurance sectors that made constraining the BLS construction of capital measures to the income pieces available from BEA beneficial from both a consistency standpoint as well as a methodological standpoint. Specifically, BEA improved the insurance and banking es-

4 See https://www.bls.gov/news.release/archives/prod3_03302017.pdf.

5 See https://www.bls.gov/mfp/mprdload.htm.

6 See March 2013 Survey of Current Business "Preview of the 2013 Comprehensive Revision of the National Income and Product Accounts."

timates with the 2013 Comprehensive Revision (Survey of Current Business, 2013).[6] These improvements have made constraining to BEA, as is done with all other industries in the BEA-BLS production accounts, a logical next step.[7] This change follows publication of the BLS Multifactor Productivity Trends 2017[8] release in which this consistent treatment was also adopted by BLS in the finance and insurance sectors. On a real basis, the revisions to the capital input measures were small.

The final revision to the methods for capital service estimates involves an update to how inventories are distributed among most non-manufacturing industries. For all non-manufacturing industries except mining, utilities, and construction, BEA inventories are grouped into an "other" category. BLS uses IRS book value data to distribute "other" inventories to the remaining non-manufacturing industries after moving the data from a company to an establishment basis via establishment-company ratios. Additionally, BLS employed a three-year smoothing of the IRS book values for the data processing, internet publishing industry. Previously BLS had only smoothed the data for the years 1999-2008. BLS now smooths the data from 1999 through the last year available. Because the IRS data are used to determine the share of "other" inventories allocated to each non-manufacturing industry, this change affected the inventory values of all of the other non-manufacturing industries as well.

## Labour Services Inputs

### Labour Hours

As in the previous set of accounts, BLS prepares a time series of labour hours reflecting annual hours worked aggregated from estimates of more detailed industries. BLS estimates labour hours using payroll employment and hours from the Current Employment Statistics (CES) survey and are supplemented with data for the self-employed and average weekly hours for nonproduction and supervisory workers from the Current Population Survey (CPS).[9] The BLS National Compensation Survey is also used to convert the hours of payrolled workers from a paid to a worked basis when constructing the initial set of employment and hours estimates

7 See https://www.bea.gov/scb/pdf/2013/06%20June/0613_preview_comprehensive_iea_revision.pdf also https://www.bea.gov/scb/pdf/2013/02%20February/0213_nipa-rev.pdf.

8 See https://www.bls.gov/news.release/archives/prod3_03212018.pdf

9 See http://www.nber.org/chapters/c13005.

for the BEA-BLS production account.[10] Sources for industries that are not covered by CES or where data are missing include the Department of Agriculture, BLS Quarterly Census of Employment and Wages (QCEW), and Mine Safety and Health Administration.[11] These estimates are subsequently controlled to BEA National Accounts estimates of hours worked at a more aggregate level before being distributed to demographic groups as outlined in the labour composition section.

## Labour Hours: Backcasting

In 2003, the BLS CES program released historical employment and average weekly hours data for detailed industries on a North American Industrial Classification system back to 1990. In addition to the historical data, the BLS CES program made available the bridge ratios used in converting the measures. These data serve as the basis for the estimates of the BEA-BLS Production account prior to 1997 and are consistent with the data after 1997. For the period prior to 1990, the BLS CES provides reconstructed historical measures for two-digit NAICS sectors back to 1939. Reconstructed historical measures for years before 1990 are also available for selected three, four, five, and six-digit NAICS industries.

Where available, complete NAICS-based payrolled employment and hours from the BLS CES series were used in the BEA-BLS production account. For the industries that were not available from BLS CES, employment estimates were developed using historical Standard Industrial Classification (SIC)-based measures and conversion factors published by the BLS CES program to reconstruct NAICS-based series back to 1987. This conversion was carried out at the most detailed industry level for which conversion factors were available by the BLS, that is, using a four-digit SIC to six-digit NAICS-CES bridge. The resulting converted employment estimates were historically linked to the published CES employment data series in 1990. Hours for 1987-89 were derived using an approach similar to that used to develop the employment estimates. Total hours residuals were constructed from the available NAICS-based aggregates and the available NAICS-based detail from BLS CES program. The residual total hours were then distributed to the detail using proportions derived from the initially converted set of NAICS-based employ-

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10 See https://www.bea.gov/scb/pdf/2014/08%20August/0814_industry-level_production_account.pdf.

11 See https://www.bea.gov/scb/pdf/2014/08%20August/0814_industry-level_production_account.pdf.

ment estimates, to create total payrolled hours estimates for the remaining component industries at all levels of industry detail.

The CPS assigns respondents to industries using the Census Bureau's Industry Classification System (ICS). There are two different classification systems across the time period of 1987-1996. For the years 1987-1991, the ICS is based on the 1980 Census codes, which uses the 1972 SIC classification, as modified in 1977. The ICS for the 1992-2002 interval is based on the 1990 Census which uses the 1987 SIC classification. The CPS data from 2000-2002 were dual-coded on both an SIC and a NAICS basis.

To estimate consistent historical NAICS-based self-employed and supervisory average weekly hour estimates back to 1987, a multi-step process was followed to convert the historical CPS data from an SIC-based code to a NAICS-based industry code used in the BEA-BLS production account. First, a three-year average SIC-to-NAICS conversion bridge was derived from the dual coded CPS data from 2000-2002. Adjustments to the initial conversion ratios were later made based on a comparison of the NAICS industry employment levels for 2000-2002 generated by applying the bridge with the employment estimates from the CPS data provided on a NAICS basis. NAICS final employment and hours estimates for 1987-2002 were derived by applying the adjusted conversion ratios to the historical SIC-based employment and hours series.

With the annual release of the 2016 data, the BLS instituted an improvement to the hours worked to hours paid ratios necessary to convert the BLS CES data for payrolled workers to the theoretically preferred hours worked basis.[12] From 2005-onward, fourth-quarter NCS data at the three-digit NAICS level are used as a proxy for each annual ratio value. During these years, more than 98 per cent of the sample rotation is isolated to the fourth quarter of each year. These new observations, which represent around 20 per cent of the overall respondents in this quarter, provide a refreshed source of response relative to the three prior quarters of the year, in which carried-over responses are generally held the same as the initial survey response.

From 1996 through 2004, however, an average of the four quarterly NCS ratios is used as the NCS sample rotation was intermittent throughout the year and was not regularly scheduled as the 2005-onward period had been. In order to estimate three-digit ratios

12 See https://www.bls.gov/lpc/hwhpnew.htm.

for 1990-1996, the 1996 NCS ratio values are carried backwards using the BLS Hours At Work Survey (HWS) as an extrapolator series. For 1987-1989, ratios for 14 super sectors from the HWS are utilized to move more detailed industry hour worked to hours paid data backwards.

## Labour Hours: Revisions

This update of the BEA-BLS production accounts uses the same source for labour hours as the original release, but includes a number of improvements. The BLS CES made an improvement in educational services, health care and social assistance that has been incorporated into this update the BEA-BLS production accounts.[13] In addition, there has been a revision to incorporate the all-employee hours measure for couriers and messengers within other transportation and support activities which revises the series across the time period.

## Labour Composition

For this set of accounts, workers are disaggregated by sex, eight age groups, six education groups, and employment class (payrolled vs. self-employed) for a total of 192 demographic categories. In addition, workers are categorized into one of 63 industries resulting in a total of 12,096 cells in the labour composition matrices for each period.

The estimation process begins by filling out information on employment, hours, and compensation for each cell in these matrices. For 1990 and 2000, the matrices are initialized using the U.S. Census 1990 and 2000 1-per cent Public Use Microdata Sample (PUMS) files. Initial estimates are generated for 1991-1999 by linear interpolation at the cell level. These initial estimates are iteratively adjusted using the RAS balancing technique to match a series of marginal controls developed from the March supplement to the CPS. For years before 1990 the t+1 balanced matrices are used as the initial cell estimates, and for years after 2000 the t-1 balanced matrices are used. As with the periods 1990-2000, these initial matrices are iteratively adjusted to match controls from the CPS.[14]

After balancing, the matrices are scaled in sequence (1) to employment controls from BEA's National Income and Product Accounts (NIPAs) for 63 industries by employment class, (2) to BLS hours for 63 industries by em-

13 https://www.bls.gov/ces/cesbmart13.pdf.

14 Labour composition estimates for the published BLS MFP data are constructed using the Basic Monthly CPS data. BLS and BEA are collaborating to reconcile the labour composition measures produced by BLS for the official MFP estimates and those produced by BEA for the account presented in this article.

ployment class, (3) to NIPA hours for payrolled workers by 17 aggregate industries, and (4) to NIPA compensation for payrolled workers by 63 industries. In the final step, the hourly compensation of self-employed workers is replaced by the rate for payrolled workers in the same cell. This step is taken because reported compensation of self-employed workers cannot be disentangled from compensation accruing to their capital assets. Additional methodological information is described in Fleck, *et al* (2014) with updates in Rosenthal, et al (2014).

### Labour Composition: Backcasting

Previous publications of these accounts made use of an SIC-to-NAICS bridge from the BLS CES program to convert SIC-based labour measures beginning in 2003 to NAICS industries. In preparing the new historical period covered by these accounts, a modified SIC-to-NAICS bridge was constructed to incorporate time-varying weights for manufacturing industries. These dynamic, employment-based weights were supplied by the Federal Reserve Board based on research from Bayard and Klimek (2004) which made use of establishment-level microdata from the Census of Manufacturing and the Annual Survey of Manufactures spanning the period from 1963 to 1997. The time-varying weights replaced static weights where available, but were scaled to leave unchanged any weights linking portions of SIC manufacturing industries to NAICS nonmanufacturing industries. For the period between 1997 and 2000, all updated manufacturing weights were interpolated to the static weights from the previous bridge.

The modified SIC-to-NAICS bridge was applied to the U.S. Census 1990 PUMS files to develop the initial 1990 labour composition matrix as well as to the 1987-2002 CPS marginal controls. The bridge was also applied to the SIC-based NIPA employment, hours, and compensation scaling controls for 1987-1997; however, these converted results were not used directly. In order to mitigate the possibility of time series breaks, the converted series were used as indicators to backcast a time series beginning with the 1998 levels in the published NAICS-based NIPA tables. Finally, these new NAICS-based employment, hours, and compensation levels were scaled to the SIC-based totals for all industries to ensure that this conversion process left totals unchanged.

In addition to the modified bridge, the 1987-1991 March Supplement of the CPS required special handling for the reported level of educational attainment. The current questionnaire allows respondents to select their highest degree attained, which aligns well with the education categories chosen for these accounts. However, prior to 1992, respondents were instead asked for the number of years of schooling as well as whether the last year of schooling was completed. This inconsistency was addressed by converting the number of years of schooling to an estimated highest degree attained via a frequency matrix described in Jaeger (1997). That work matched CPS respondents who had reported educational attainment under both versions of the questionnaire, and cross tabulated pairs of responses to create conversion weights.

### Labour Composition: Revisions

Revisions to the period 1998-2000 are a result of the interpolated Census PUMs matrices. The process of controlling to the CPS redistributed the marginal matrices based on the shares that resulted from the iterative proportional scaling procedure. Beyond that, revisions reflect updates to incorporate the latest data with hours and compensation estimates and are typically confined to the 2014 forward period.

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# Knowledge Intensity in a Set of Latin American Countries: Implications for Productivity

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Abstract

This article proposes to measure the knowledge intensity of economies with an alternative approach to those based on the aggregation of industries according to their R&D expenditure or the qualification of the workforce. The proposed metric is based on the economic valuation of productive services provided by a set of assets that incorporate knowledge, specifically human capital and information and communication technologies (ICT). Rather than using a single indicator to measure knowledge intensity, we follow an economic approach rooted in a growth accounting methodology, determining the contribution of each individual asset according to the prices of the services they provide. This methodology is applied to four Latin-American (LA) countries, namely Brazil, Chile, Colombia and Mexico, taking the United States and Spain as benchmarks for the period 2000-2016.

*Knowledge economy* is the term applied to describe an economy where a considerable share of production is based on accumulated knowledge. Despite this term being frequently used, there is no metric that accurately measures how much economic value stems from knowledge. The most widely-used approach classifies productive activities into several categories according to technological intensity, usually on the basis of R&D

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expenditure or high-skilled labour.[2] Calculations are then made on the percentage that these activities represent in total employment or production.

It is clear that knowledge is generated and disseminated by educated and intelligent individuals. However, it is not only our discoveries of today that matter but the knowledge accumulated by humanity over time. Thus, when measuring the weight of knowledge in the production of goods or services we should concentrate, not only on current discoveries, but on all human capital used in the process, both directly and indirectly, i.e., including that which has been incorporated into capital goods and intermediate products.

There are three important limitations regarding conventional measures of knowledge intensity. The first is that it focuses on the current creation of knowledge rather than how the productive system uses it, which is crucial to analysing certain problems.

The second is that it uses classifications of knowledge intensity in activities based on a single factor: R&D expenditure in the case of manufacturing, and human capital with higher education in services industries. Knowledge, however, is incorporated into production through various channels: qualified labour in general, some capital assets and intermediate inputs. The weight that each of these carries in industries is different, and, therefore, classifying activities based on a single criterion could bias the results.

The third major limitation is that the incorporation of knowledge varies from one country to another within the same industry. The reality is that knowledge is (more or less) present in all industries and not only in those defined as high or medium technology in the usual classifications, which in turn have different degrees of knowledge intensity by country.

In Latin America several studies analyse the growth of trade in knowledge-intensive services. López *et al.* (2014) in their analysis of Latin American competitiveness use this approach in combination with the deployment of ICT. They use segments of information on knowledge-intensive services based on the available data on trade in the following segments: business and professional services, software and informa-

2 See, for example, the definition of KIS (Knowledge Intensive Services) and HTech (High Technology Manufacturing) or KIA classification (Knowledge Intensive Activities), which are used by Eurostat in its "Science, technology, digital society statistics," available at: http://ec.europa.eu/eurostat/data/database. OECD (2015) uses these classifications as well. See also the Tradecan (Trade Competitive Analysis of Nations) methodology, which was developed in 1990 by the Economic Commission for Latin America and the Caribbean (ECLAC).

tion services, and audiovisual, cultural and personal services. Others draw upon the available evidence in the theoretical and empirical literature to assess the position occupied by Latin America in the various areas that have an impact on its competitiveness in those sectors (López and Ramos, 2013).

Other studies examine the knowledge economy through a set of indicators which includes several approaches to measuring the presence of knowledge in productive activities and societies. In addition, in recent years it has become more common to focus on the so-called digital economy and thus, on the analysis of indicators related to the development and diffusion of new technologies. However, these measures are partial as they only take into account a part of what we call the knowledge economy, a broader concept that not only focuses on the use of digital computing technologies, but on the different kinds of productive inputs with a particular degree of knowledge-intensity. In some cases, synthetic indices of the development of knowledge or digitalization—both in the economic system and society—are elaborated, including multiple variables which are aggregated according to statistical criteria or ad hoc weights. However, as stated above, many of these indices are usually partial[3] and have an ambiguous meaning, given that they are not derived from a metric based on clear definitions and evaluation criteria, nor on a precise structure of relationships between variables. In this sense, business accounting and the system of national accounts have advantages for the aggregation, which is based on the relative prices of goods or factors.

This article explores whether it is possible to assess the intensity with which knowledge is used—not its generation or creation—within economies by means of a methodology that is integrated into the conceptual schema, measurement criteria and information systems of national accounts. To answer this question, we can take two different approaches: the development of knowledge satellite accounts and the development of knowledge accounting.

Regarding the first option, the complexity and data requirements of satellite accounts are considerable, given that they aspire to build an in-

3 Some examples are the KEI and KAM indicators published by the World Bank (see Chen and Dahlman (2006) and World Bank (2008a, 2008b) for more details) or the Digital Economy and Society Index (DESI) developed by the European Commission (see more details at: https://ec.europa.eu/digital-single-market/en/desi). All of them take into account different economic and social dimensions to measure the development of the knowledge economy, but exclude some important areas, such as physical capital endowments, institutional characteristics of the labour markets, etc., which may be relevant.

tegrated system that quantifies all dimensions and elements present in the dynamics of a knowledge-based economy. Because of that, although some official statistics institutes have taken preliminary steps in developing such knowledge satellite accounts,[4] they are not available for the majority of countries.

The second alternative takes advantage of the important theoretical and empirical advances achieved in the measurement of physical and human capital (Jorgenson *et al.*, 1987). We have chosen to go in this direction, proposing to measure the weight of knowledge in GDP by calculating the market value of a set of knowledge-based inputs which are incorporated in the production processes. The cornerstone of this approach is the analytical structure of modern growth accounting, which allows us to differentiate the value of various types of physical and human capital service inputs. This methodology was initially proposed by Pérez and Benages (2012) and applied to all the European countries included in the EU KLEMS database. Maudos, Benages and Hernández (2017) updated and expanded this methodology applying it to the Spanish regions for which KLEMS-type data is available.

The proposed methodology can be applied today to those economies whose national accounts systems offer industry data on various types of labour and capital services and their corresponding compensation. Databases that allow these estimates to be carried out have been created and harmonized by projects developed within the framework of WORLD KLEMS, devoted to examining total factor productivity and sources of economic growth.[5] In our case, we will make use of the recently released LAKLEMS database containing information for four Latin-American countries: Brazil, Chile, Colombia and Mexico.

There are many questions we are interested in answering in this study. Is the value added generated by the factors of production incorporating knowledge high enough to speak of knowledge economies? What differences can we observe in the weight of knowledge among industries and among countries? What is the time evolution of knowledge intensity by industry and by economy? Do activities and countries converge in knowledge intensity? How important are knowledge-based factors to the growth of economies and their levels of labour productivity?

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4 See Haan and van Rooijen-Horsten (2003) and van Rooijen-Horsten *et al.* (2008).

5 See http://www.worldklems.net/.

To address these issues, the article is structured as follows. Section 1 explores the methodological approach adopted in the context of related economic literature, while section 2 reviews the statistical data, its sources and coverage. Section 3 presents the results both at the aggregate level and for the nine industries for which information is available. Finally, section 4 sets out the main conclusions.

## Calculating Knowledge Intensity: Methodological Approach

The most widely-used approach for measuring knowledge intensity in economies is based on classifying manufacturing industries according to technology intensity—measured by the weight of R&D expenditure in relation to GDP—and services industries according to the use of human capital—measured by the percentage of staff with higher education (OECD, 2015; Eurostat, 2013). The first one, the weight of R&D, responds better to the objective of analysing the intensity in which knowledge is created rather than how much knowledge is used. In fact, the classification of manufacturing according to technological intensity was conceived for another purpose: to assess the origin of exogenous technological progress and its role in growth and competitiveness. The focus on R&D activities is justified since technology-intensive companies and industries show a high innovative and commercial dynamism and are especially productive (Hatzichoronoglou, 1997).

It is clear that R&D activities play a key role in generating knowledge. This knowledge is incorporated in the capital assets used in the production process. Machinery and other capital goods are the key vehicles for the use of knowledge. These capital goods are previously produced incorporating the knowledge used in their own production process, and are almost always intensive in human capital and in the use of other machinery. The same can be said of some intermediate products, although the degree in which they incorporate knowledge varies to a greater extent than in the case of machinery.

Since our objective is to measure the weight of knowledge used in current production, we should not concentrate solely on the discoveries of today but rather on all the knowledge accumulated in capital assets throughout time. It is not a question of measuring knowledge but rather which part of the economic value of production remunerates the knowledge accumulated in the used inputs.

The refinement provided by the concept of productive capital offers a greater precision for measuring capital services and allows us to approximate the accounting of knowledge incorporated in the capital stock. Other analytical and statistical improvements in the methodology for measuring assets and their productive services are a consequence of a greater accuracy in aggregation procedures, using Tornqvist indices (OECD, 2001, 2009; Jorgenson *et al.*, 1987). On account of these developments, an improved analysis is now available using sources of growth as well as key variables to estimate the value of production of assets incorporating knowledge. Developments currently underway extend the capital assets to take into account the contribution of intangible assets, many of which are also the result of knowledge accumulated by companies and their organizations.[6] A more accurate measurement of physical and human capital services better assesses the knowledge incorporated in the factors and reduces the weight of the Solow residual (Solow, 1956, 1957). These advances in growth accounting illustrate that, when the contributions of productive factors are measured more precisely, incorporated knowledge is more relevant than total factor productivity (TFP) when explaining improvements in labour productivity.[7]

The methodological and statistical framework of advanced versions of *growth accounting* offers an appropriate scheme to build an *accounting of the use of knowledge in production.* We can consider that knowledge is incorporated into production through the use of different kinds of labour, capital, and intermediate inputs. However, to simplify the presentation of the methodology and relate it to subsequent empirical findings, we only show the case in which the measurement of the product is gross domestic product (GDP) or gross value added (GVA), although the approach will be replicable in similar terms to the case of total production. Thus, we do not consider knowledge incorporated into intermediate inputs, but only content in primary inputs, namely labour and capital. Taking this into account, to assess the contribution of productive factors based on knowledge, first we have to identify which factors contain knowledge,

6 See Corrado, Hulten and Sichel (2006), Marrano and Haskel (2006), Van Ark and Hulten (2007), Fukao *et al.* (2007), Marrano, Haskel and Wallis (2007), Hulten (2008), Corrado *et al.* (2013) and Corrado, Haskel and Jona-Lasinio (2017). From our work's perspective, the services of intangible assets increase the value added generated but the income they yield could be allocated to the heart of the organizations, both to the owners of capital and labour. It is because these assets, by their nature, do not have an external market that determines their price. Therefore, their contribution can be considered to be accounted through the remuneration of other factors.

7 See Aravena, Hofman and Escobar (2018), Coremberg and Pérez (2010), Oulton (2016) and Pérez and Benages (2017) on how a more accurate measurement of productive factors impact TFP.

measure the amount used in different activities, and value their services with appropriate prices.

From this point of view, knowledge intensity in an industry is defined as the value of the knowledge services used in relation to the value of its production. Thus, it can take any value in the interval $[0, 1]$. Industries are therefore not classified into categories of greater or lesser intensity, avoiding the discontinuity caused by thresholds which arbitrarily separate some groups from others. However, a certain arbitrariness is unavoidable when considering which assets include knowledge and which do not. Pérez and Benages (2012) take a broader view, considering high- and medium-skilled workers (higher and upper secondary education) as well as machinery and equipment as knowledge-based factors. Workers with basic studies and real estate capital are not considered to incorporate significant knowledge, and are consequently excluded.

An alternative view would be to consider a narrower definition for both inputs. From the capital side, the alternative is to exclude machinery and equipment assets, considering ICT and other intangible assets, besides software, already recognized by the 2008 System of National Accounts (SNA 2008): R&D, mineral explorations and entertainment, literary and artistic originals. From the labour side, a more restrictive view would adapt to the traditional approach of considering only workers with the highest level of tertiary education.

As already mentioned, the knowledge intensity of an industry can take any value in the interval $[0, 1]$. One of the implications of this is that, unlike the conventional approach, knowledge intensity in an industry is not constant over time or among countries. Another implication is that the knowledge intensity of an economy is obtained from the knowledge intensity in each of its industries, as well as from the weight of value added of each branch of activity in the aggregate GVA.

Assuming that there are $m$ types of labour and $n$ types of capital and some of these provide knowledge services and others do not, let $L_{ij}$ be the amount of labour of type $i$ used in sector $j$; $K_{hj}$ the amount of capital of type $h$ used in the same sector $j$; $P_{ij}^{L}$ is the unitary wage paid for the labour of type $i$ in sector $j$; and $P_{hj}^{K}$ is the user cost of type $h$ capital in sector $j$. Defining the value added in real terms produced by sector $j$ as $V_j$ and being $P_j^V$ its price, the value added of sector $j$ in nominal terms $(V_j P_j^V)$ is distributed between the different inputs included in the production process so that,

$$V_j P_j^V = \sum_{i=1}^{m} L_{ij} * P_{ij}^L + \sum_{h=1}^{n} K_{hj} * P_{hj}^K \quad (1)$$

Let us assume that the price of the amount used for each type of labour depends on its productivity and that the basis for differences in productivity is the human capital that each type contains. Under these hypotheses, wages can approximate the economic value of the amount of knowledge per unit of each type of labour. According to this criterion, we can consider that the type of labour that offers a lower wage (for workers with lower education levels) does not incorporate knowledge. While the other types of labour do incorporate knowledge, though at different rates according to the number of years or level of education. Alternatively, it can be considered that only workers with tertiary education incorporate knowledge. If we generalize to allow $f$ type of low-skilled labour, the value of labour is decomposed into two parts, the second of which measures the value of human capital services:

$$\sum_{i=1}^{m} L_{ij} * P_{ij}^L = \sum_{i=1}^{f} L_{ij} * P_{ij}^L + \sum_{i=f+1}^{m} L_{ij} * P_{ij}^L \quad (2)$$

Thus, the value of knowledge incorporated through labour (knowledge-intensive labour, KIL) would be given by:

$$KIL_j = \sum_{i=f+1}^{m} L_{ij} * P_{ij}^L \quad (3)$$

The unit value of productive services providing different kinds of labour that incorporate knowledge is not the same. For example, the production services of workers with higher education are more intensive in knowledge than in the case of workers with upper secondary education. By multiplying the amount of each type of labour by its wages, knowledge intensity can be accurately calculated when the wages are a reflection of this intensity. This criterion implies that the value of knowledge that qualified workers have does not depend on education per se but rather on their experience and how it is used by the productive system in general, which is reflected in their wages.

In terms of capital, we assume that the productivity of each asset is reflected in its user cost, which is taken into account in the calculation of the productive capital. The differences in the user cost have become more relevant due to the growing importance of ICT investment, which was a key driving force behind the disaggregation of assets and the distinction between net and productive capital (OECD, 2001, 2009).

The capital user cost has three components: the financial opportunity cost or rate of return, the depreciation rate resulting from the service life of the corresponding asset, and earnings or losses of capital arising from variations in its price. In the long-term, i.e., in the absence of price changes associated with the business cycle (Schreyer, 2009), the component of the user cost that most differentiates certain assets from others is the depreciation rate, which depends on the average service life of the assets. The service life of machinery is shorter than housing or infrastructure, while that of ICT assets is shorter than the majority of machinery and transport equipment. The materials that make up the assets and, in particular, the complexity and vulnerability to obsolescence (i.e., the technology incorporated) makes the economic life shorter (and depreciation faster). Assets that contain more knowledge tend to have a shorter economic life and a more intense depreciation, although there can be exceptions to this rule. In the language of capital theory, more depreciation means greater user cost that should be offset by a greater flow per unit of time of the asset's productive services, because otherwise the decision to invest in it would not be justified.

We assume that the content of knowledge in assets increases proportionately with its user cost. We use as a starting point the hypothesis that assets with a lower user cost —produced by the construction sector— do not incorporate knowledge in a significant way. On the other hand, we can assume that machinery and equipment do, although with the relative intensity reflected by their user cost (e.g. much higher in ICT assets). As before, a more restrictive view for capital would consider that only ICT and intangible assets incorporate knowledge in the production process.

The value added generated by physical capital is broken down into two broad categories: those that do not incorporate knowledge significantly (g assets) and those that do (n-g assets):

$$\sum_{h=1}^{n} K_{hj} * P_{hj}^{K} = \sum_{h=1}^{g} K_{hj} * P_{hj}^{K} + \sum_{h=g+1}^{n} K_{hj} * P_{hj}^{K} \tag{4}$$

Then, the value of knowledge incorporated through physical assets (*knowledge intensive capital, KIK*) would be given by:

$$KIK_j = \sum_{h=g+1}^{n} K_{hj} * P_{hj}^K \quad (5)$$

And the value of knowledge-intensive factors or value added based on knowledge (*knowledge intensive value, KIV*) of activity *j* will therefore be:

$$KIV_j = KIL_j + KIK_j \quad (6)$$

The relative knowledge intensity ($\%KIV_j$) of activity *j* is defined as

$$\%KIV_j = \frac{KIL_j + KIK_j}{V_j P_j^V} \quad (7)$$

Given the knowledge content of each industry, the knowledge intensity of an economy depends on the weight of the various branches in the aggregate. If *q* industries exist, the knowledge intensity of the economy as a whole ($\%KIV$) is defined as,

$$\%KIV = \sum_{j=1}^{q} \%KIV_j * \frac{V_j P_j^V}{\sum_{j=1}^{q} V_j P_j^V} \quad (8)$$

The exercises presented later in the article adopt the most restrictive version for measuring the knowledge economy presented in this section. That is, for labour it considers only tertiary-educated workers as knowledge intensive, and for capital only ICT capital following the spirit of the KLEMS project. It would have been interesting to include other intangible assets, besides software, that are already included in the 2008 System of National Accounts, such as R&D, but, so far, only two LAKLEMS countries, Chile and Mexico, have released the required information. The next section describes the data and presents some basic descriptive statistics.

## Statistical Data: Sources and Coverage

The estimates of knowledge intensity following the methodology described previously and presented in the next section are based on data from the LAKLEMS database.[8] This database contains information by industry on variables related to labour, capital and total factor productivity and economic growth—value added, output, employment and qualification, gross capital formation by assets and accumulated capital, capital and labour compensation, etc. At the moment, data are available for four Latin-American countries, Brazil, Chile, Colombia and Mex-

8 The LAKLEMS project includes eight countries of Latin America (Chile, Colombia, Costa Rica, Dominican Republic, El Salvador, Honduras, Mexico and Peru) and Argentina and Brazil also form part of the project. LAKLEMS is financed and executed by the Inter-American Development Bank (IADB). A team at the University of Santiago de Chile is responsible for the substantive implementation.

ico, for the period comprised between 1990 and 2016, although the time coverage varies across countries (1995-2013 for Brazil, 1995-2015 for Chile, 1990-2014 for Colombia and 1990-2016 for Mexico). Here, we focus on the period 2000-2016.

Thus, the LAKLEMS database offers all the variables needed to apply the methodology outlined in section 1: value added, capital compensation by asset and labour compensation[9] by educational attainment level.

Labour data are classified by educational attainment distinguishing among three levels: high, medium and low. For our purposes, we consider that workers with high education levels contribute knowledge to the production process, whereas the remaining do not. In the case of physical capital, the LAKLEMS database distinguishes seven capital assets: three ICT assets and four non-ICT assets (Table 1). As stated before, when considering the narrower definition of knowledge intensity, only ICT assets are classified as knowledge-based capital. Thus, according to this, knowledge-based GVA includes the remuneration of high-educated workers and ICT capital.

As explained in section 1, the measure of knowledge intensity is carried out at the sectoral level. Although a greater industry detail is available for some countries, e.g. Mexico, only nine individual industries are considered here, in order to have a common industry classification for all the countries analysed. Table 1 shows a list of these industries.

In addition to the aforementioned countries, two other developed countries are included in the analysis for the purpose of comparison. As this methodology has already been applied to Spain and its regions (Maudos, Benages and Hernández, 2017) and considering that Spain has close historical and economic ties with Latin America, information on this country is also presented in this analysis. The main information sources used are: EU KLEMS database, National Accounts (NA), Labour Force Survey (LFS) and Structure of Earnings Survey (SES), published by the INE (Spanish National Statistical Office), and BBVA Foundation-Ivie database on capital stock. Educational attainment classification, assets' classification and industry detail have been adapted to those offered by LAKLEMS database to obtain comparable results.

On the other hand, and as the benchmark country in terms of pro-

9 In the case of Mexico, there is no information on hours worked by self-employed workers. Thus, labour compensation figures only include labour compensation remunerating employees. For the remaining countries, these figures include both the compensation that remunerates employees and self-employed workers.

**Table 1: LAKLEMS Database: Capital Assets and Industry Classification**

| Available Capital Assets in LAKLEMS Database | LAKLEMS Industry Classification |
|---|---|
| **ICT assets** | Agriculture, forestry and fishing |
| Software | Mining and quarrying |
| Computing equipment | Manufacturing |
| Communication equipment | Electricity, gas and water supply |
| **Non ICT assets** | Construction |
| Transport equipment | Wholesale & retail trade; accommodation and food service |
| Machinery & Equipment (excluding ICT) | Transportation and communications |
| Non-residential structures | Financial, real state and business services |
| Residential structures | Other services |

Source: Own elaboration.

ductivity and ICT development, the United States is also included in the analysis. In this case, the main data sources are USA KLEMS database[10] and the Integrated Industry-Level Production Accounts, elaborated and updated by BEA (Bureau of Economic Analysis) and BLS (Bureau of Labour Statistics). Again data from these sources have been adapted to LA KLEMS' characteristics.

Table 2 provides an overview of the two sets of variables involved in the methodology presented in section 1: capital and labour inputs classified by capital assets, and types of labour according to the level of educational attainment.

Regarding capital inputs, Table 2 shows the composition of gross fixed capital formation (capital flows) in the four LA countries plus Spain and the United States. As expected, ICT assets have a lower weight in the Latin American economies considered, around 6 per cent on average, this weight being more than double in Spain and the United States. However, there are important differences among the four LA countries. Chile presents the highest share of ICT investment (8.2 per cent) in the last year with available information, and Brazil, the lowest (4.6 per cent), almost half that of Chile. In addition, this share has decreased since 2000 in Brazil, and also in Colombia. In all the countries analysed, residential and non-residential structures are, by far, the main assets, reaching in Brazil and Colombia a high of more than 95 per cent of total investment, over 10 percentage points more than in Spain and the United States.

As expected, due to its initial low base level, ICT capital has experienced a higher rate of growth than non-ICT capital in all countries. According to their lower initial levels, these growth rates are higher in the LA countries, with the only exception of Mexico. The analysis of this struc-

10 See http://www.worldklems.net/data.htm.

**Table 2: Descriptive Statistics: Capital and Labour Data. LAKLEMS Countries, Spain and the United States, 2000 and the Latest Available Year**

*a) Gross Fixed Capital Formation: Structure by assets (%)*

| | Brazil | | Chile | | Colombia | | Mexico | | Spain | | United States | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2013 | 2000 | 2015 | 2000 | 2014 | 2000 | 2015 | 2000 | 2015 | 2000 | 2015 |
| ICT | 9.34 | 4.59 | 5.43 | 8.17 | 8.76 | 4.67 | 5.35 | 5.88 | 10.57 | 15.1 | 21.9 | 18.41 |
| Software | 4.11 | 1.64 | 1.75 | 3.68 | 1.35 | 0.53 | 0.13 | 0.17 | 3.18 | 7.83 | 10.36 | 12.16 |
| Computing equipment | 1.94 | 0.76 | 1.97 | 2.16 | 2.37 | 1.02 | 1.66 | 1.29 | 3.11 | 2.46 | 5.44 | 2.85 |
| Communication equipment | 3.29 | 2.19 | 1.71 | 2.33 | 5.03 | 3.11 | 3.55 | 4.42 | 4.28 | 4.81 | 6.11 | 3.4 |
| Non ICT | 90.66 | 95.41 | 94.57 | 91.83 | 91.24 | 95.33 | 94.65 | 94.12 | 89.43 | 84.9 | 78.1 | 81.59 |
| Transport equipment | 7.67 | 13.34 | - | - | 6.82 | 6.93 | 9.93 | 10.72 | 10.26 | 11.45 | 8.61 | 10.61 |
| Machinery & Equipment (exclu. ICT) | 23.33 | 12.49 | 12.65 | 32.26 | 16.04 | 9.44 | 24.06 | 29.8 | 14.88 | 18.69 | 21.38 | 23.37 |
| Non residential structures | 32.32 | 38.86 | 50.54 | 43.66 | 48.93 | 49.31 | 32.06 | 28.19 | 29.43 | 30.12 | 24.42 | 26.17 |
| Residential structures | 27.34 | 30.72 | 31.38 | 15.9 | 19.44 | 29.65 | 28.61 | 25.42 | 34.87 | 24.63 | 23.68 | 21.44 |
| Total | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |

*b) Gross Fixed Capital Formation: Average annual growth*

| | Brazil | Chile | Colombia | Mexico | Spain | United States |
|---|---|---|---|---|---|---|
| | 2000-2013 | 2000-2015 | 2000-2014 | 2000-2015 | 2000-2015 | 2000-2015 |
| ICT | 6.63 | 10.30 | 10.85 | 4.94 | 5.64 | 3.80 |
| Software | 7.76 | 14.30 | 13.58 | 3.99 | 5.02 | 4.12 |
| Computing equipment | 7.63 | 8.06 | 14.25 | 4.10 | 6.53 | 5.24 |
| Communication equipment | 4.09 | 7.78 | 9.52 | 5.29 | 6.09 | 1.89 |
| Non ICT | 4.41 | 4.98 | 9.74 | 2.18 | -0.81 | 0.33 |
| Transport equipment | 7.91 | 0.00 | 11.98 | 4.18 | 1.42 | 3.13 |
| Machinery & Equipment (exclu. ICT) | 5.19 | 7.74 | 11.27 | 4.25 | 0.22 | 1.98 |
| Non residential structures | 3.70 | 5.04 | 8.39 | 0.40 | -0.65 | -0.88 |
| Residential structures | 3.18 | 1.48 | 11.35 | 1.82 | -2.19 | -0.85 |
| Total | 4.65 | 5.36 | 9.26 | 2.31 | -0.14 | 0.91 |

*c) Labour (hours worked): Share by level of education (%)*

| | Brazil | | Chile | | Colombia | | Mexico | | Spain | | United States | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2015 | 2000 | 2015 | 2000 | 2015 | 2000 | 2016 | 2000 | 2015 | 2000 | 2015 |
| High | 8.66 | 18.41 | 22.88 | 35.2 | 14.23 | 21.73 | 14.04 | 13.37 | 26.6 | 40.74 | 28.89 | 37.95 |
| Medium | 34.51 | 42.48 | 57.63 | 45.93 | 40.58 | 42.34 | 38.69 | 46.52 | 19.56 | 24 | 60.72 | 54.24 |
| Low | 56.84 | 39.12 | 19.49 | 18.87 | 45.19 | 35.93 | 47.28 | 40.1 | 53.83 | 35.26 | 10.39 | 7.81 |
| Total | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |

*d) Labour (hours worked): Average annual growth rates*

| | Brazil | Chile | Colombia | Mexico | Spain | United States |
|---|---|---|---|---|---|---|
| | 2000-2015 | 2000-2015 | 2000-2015 | 2000-2016 | 2000-2015 | 2000-2015 |
| High | 7.55 | 4.52 | 4.77 | 1.03 | 3.32 | 2.11 |
| Medium | 3.98 | 0.13 | 2.20 | 2.49 | 1.84 | -0.46 |
| Low | 0.03 | 1.43 | 0.29 | 0.31 | -2.34 | -1.61 |
| Total | 2.48 | 1.65 | 1.88 | 1.33 | 0.48 | 0.30 |

Note: In the case of Chile, Transport equipment is included in Machinery & Equipment (excluding ICT).
Source: BEA, BLS, EU KLEMS database, LAKLEMS database, BBVA Foundation-Ivie, INE, World KLEMS and own elaboration.

ture and its evolution is important because capital stock stems from the accumulation of GFCF flows. Therefore, it also affects the distribution by asset of the capital compensation, the magnitude that is going to be used to estimate part of the knowledge-based GVA.

The information for labour qualification, according to the level of education attained, appears in the lower part of Table 2. Since 2000, the general pattern has been, as expected, the reduction of the weight of the lower levels, in favour of the other two. Only in Chile, the less qualified workers have kept constant their share, but at a very low level. In the majority of countries in general, job creation is concentrated mainly among the group of workers with higher educational levels, whereas the growth rate of low-skilled labour is very low, or even negative in the case of Spain and the United States. In this latter country, only high-skilled labour shows a positive growth in the period considered.

## Knowledge Intensity Estimates

This section presents the main results of the exercises proposed earlier in the article for measuring the knowledge economy. The first part shows the aggregated results while the second focuses on detail by industries.

### Aggregated Results

Chart 1 provides an overview of the share of knowledge economy over total GVA—as given by equation (8)—for the four Latin America countries, Spain and the United States over the period covering the year 2000 to the latest year available. Spain and the United States are included as benchmark, the first representing a large, middle income European country, and the second being the world leader in terms of productivity and in producing and using new technologies. Both countries share very close historical and economic ties with Latin America.

The share of knowledge-based gross value added in total gross value added in the most recent year ranges from a low of 10 per cent in Mexico to a high of 38 per cent in the United States, followed by Spain (37 per cent) and Chile (35 per cent). Colombia (19 per cent) and Brazil (23 per cent) are in an intermediate position. Mexico has kept the share of the knowledge economy rather constant, while Colombia and Chile show an upward trend, more pronounced in the second than the first. Brazil presents a different profile, with a fall from 2000 to 2010 and a slight recovery from then on, although its knowledge intensity in the last year available is below its level in 2000. It is the only country that shows this behaviour: a reduction of knowledge share in the economy. Even in Mexico knowledge share was more than 1 percentage point higher in 2016 than in 2000.

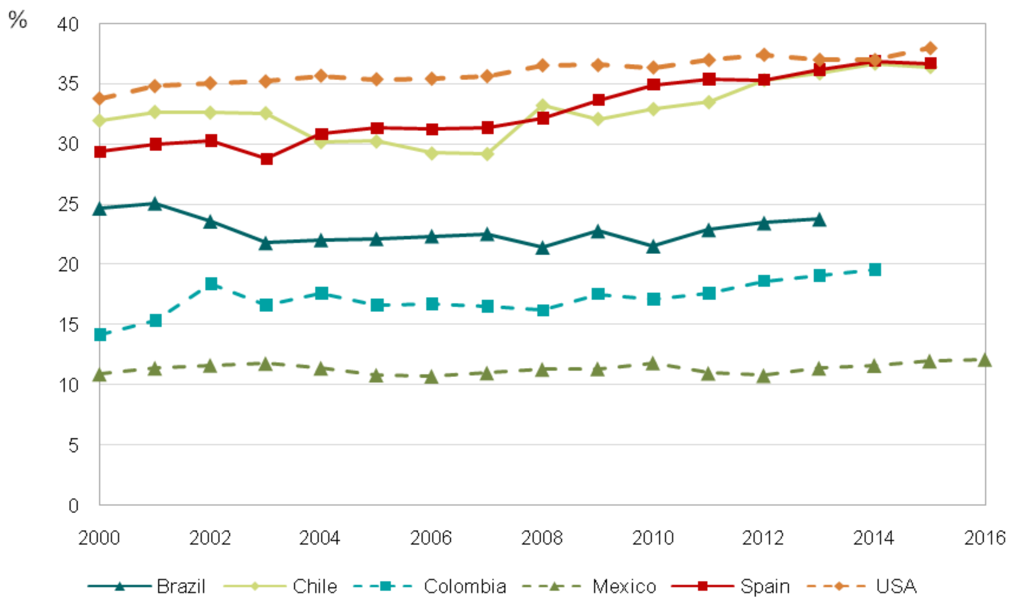
Chart 2 presents the annual growth rates of both knowledge and non knowledge based GVA. For all the countries considered, with the only exception of Brazil, the growth of knowledge-based inputs has been higher during the period analysed. Colombia presents the highest growth rate (6.5 per cent), followed by Chile (4.4 per cent), whereas the United States (2.3 per cent) has the lowest. Among the LA countries, Mexico shows the lowest growth rate (2.6 per cent).

When compared with American countries, it is worth highlighting Spain's rather strong slowdown in non-knowledge based GVA as a consequence of the economic crisis that began in 2008, which basically affected the building industry and the assets it produces, such as dwelling and all type of constructions. It also suffered a sharp increase of unemployment which mainly affected low-skill workers (Table 2). The LA countries do not seem to have been hit in such a strong way.

Chart 3 offers a complementary view summarizing the contributions of both types of inputs to GVA growth. In general, for the Latin American countries the contribution of non-knowledge factors is markedly higher than that of its knowledge counterpart. This is especially noticeable for Mexico, Brazil, and also Colombia. What explains this result, the higher contribution to GVA growth of non-knowledge factors, is the capital accumulation in non-knowledge-based assets, such as dwellings and other non-residential structures, during this period. This is a common feature of all these countries, especially relevant in the case of Colombia and Mexico. Again, Chile shows a more balanced pattern of growth, more similar to that of Spain and the United States. In both countries, knowledge is the main contributor to GVA growth.

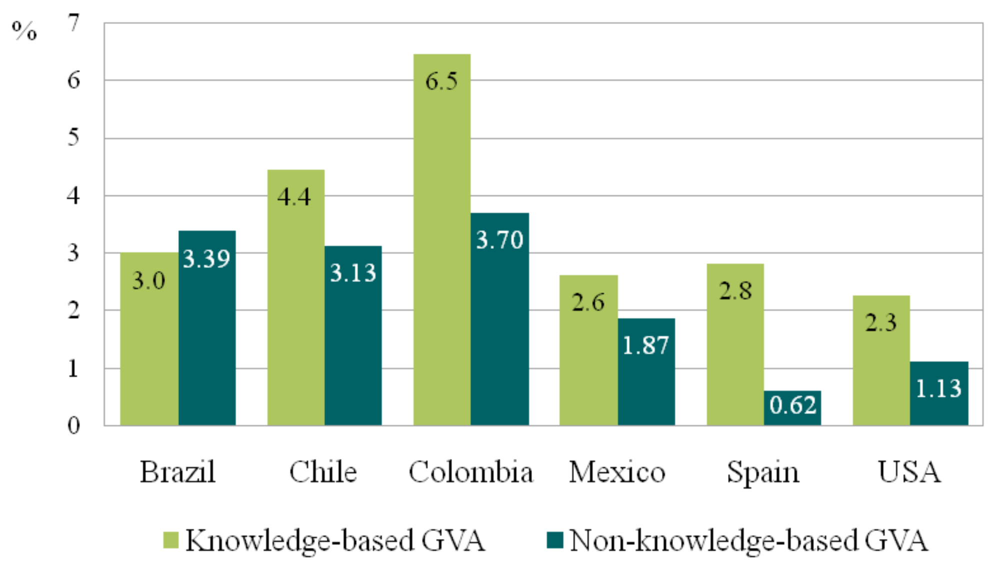
Chart 4 gives a more detailed decomposition of the share of knowledge and non-knowledge inputs of production over total GVA for the year 2000 and the last year available. As expected, te ICT capital compensation share is very small for all countries. The largest contribution corresponds to the United States, Mexico and Spain, close to 4 per cent, and the lowest to Colombia (2.3 per cent). The contribution of knowledge intensive labour, corresponding to workers with the highest level of education, is greater in the United States, Chile and Spain, around 33 per cent in the

**Chart 1: Knowledge-Based Gross Value Added (GVA), LAKLEMS countries, Spain and the United States, 2000-2016 (Share of Total GVA)**



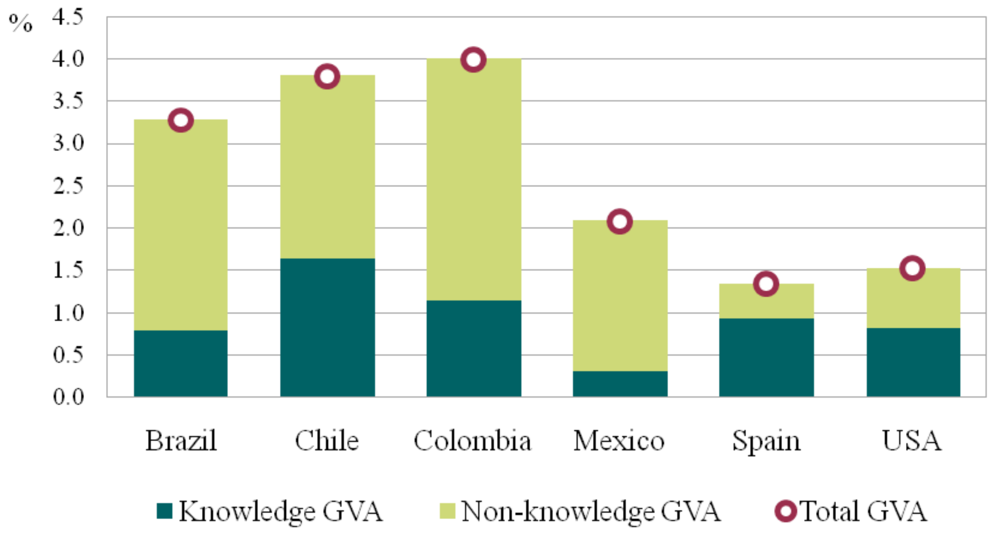

Source: BEA, BLS, EU KLEMS database, LAKLEMS database, BBVA Foundation-Ivie, INE, World KLEMS and own elaboration.

**Chart 2: Annual Growth Rate of Knowledge and Non-Knowledge-Based Gross Value Added (GVA), LAKLEMS Countries, Spain and the United States, 2000-2016***




* 2000-2013 for Brazil, 2000-2014 for Colombia and 2000-2015 for Chile, Spain and the United States.
Source: BEA, BLS, EU KLEMS database, LAKLEMS database, BBVA Foundation-Ivie, INE, World KLEMS and own elaboration.

**Chart 3: Knowledge and Non-Knowledge Contribution to Annual Gross Value Added (GVA) Growth Rate, LAKLEMS Countries, Spain and the United States, 2000-2016***



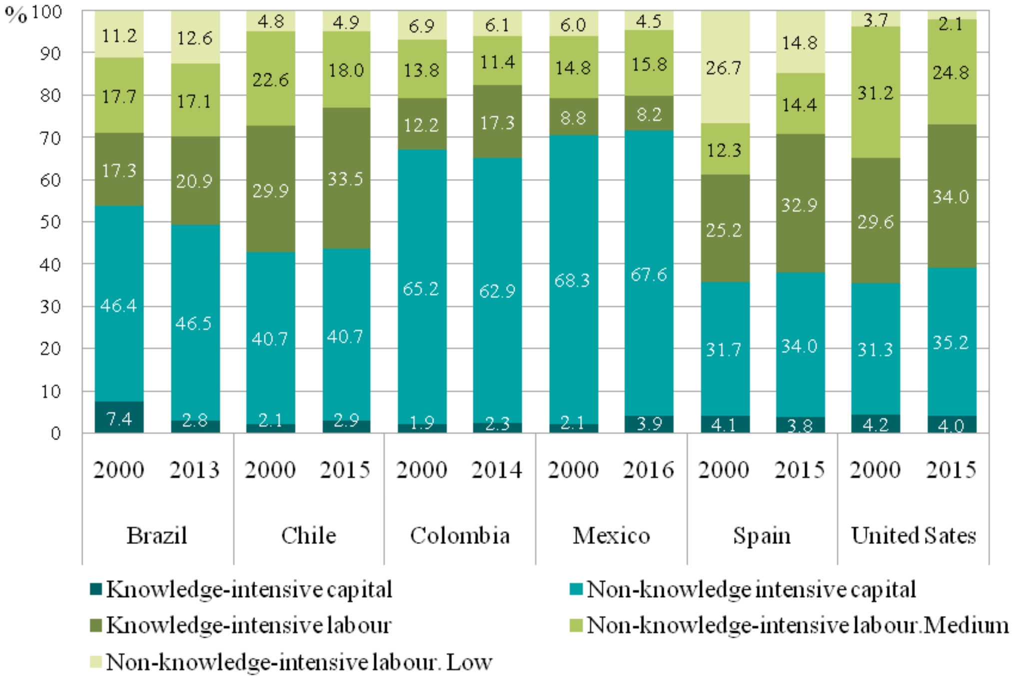

* 2000-2013 for Brazil, 2000-2014 for Colombia and 2000-2015 for Chile, Spain and the United States.
Source: BEA, BLS, EU KLEMS database, LAKLEMS database, BBVA Foundation-Ivie, INE, World KLEMS and own elaboration.

last year available, while in Mexico it is the lowest, 8.2 per cent. These results are the combination of the weight of high-educated workers and the wages they receive. As shown by Table 2, the United States, Chile and Spain are also the two countries with the highest shares of high-educated workers (37.9 per cent, 35.2 per cent and 40.7 per cent, respectively).

The share of non-knowledge-intensive capital is very high in Mexico and Colombia (around 65 per cent), and relatively low in Chile (40.7 per cent), but still higher than in Spain (34 per cent) and the United States (35.2 per cent). Within non-knowledge labour, Chart 4 distinguishes between medium and low levels of qualification. In the four Latin American countries, medium levels have a larger contribution, as in the United States, while in Spain low qualified workers have a higher one. This result is consistent with the weights for each type of labour shown in Table 2. Also worth noting are the low contributions of both knowledge and non-knowledge labour in Mexico and Colombia. Since according to our approach these contributions are computed taking wages as reference, the more general conclusion is that for those two countries the capital share amounts to almost 70 per cent of total GVA and labour the remaining 30 per cent, an income distribution that is more biased toward capital than in the rest of the countries.

Chart 5 complements the informa-

Chart 4: **Knowledge and Non-Knowledge Compensation over Gross Value Added (GVA), LAKLEMS Countries, Spain and the United States, 2000-2016* (%)**



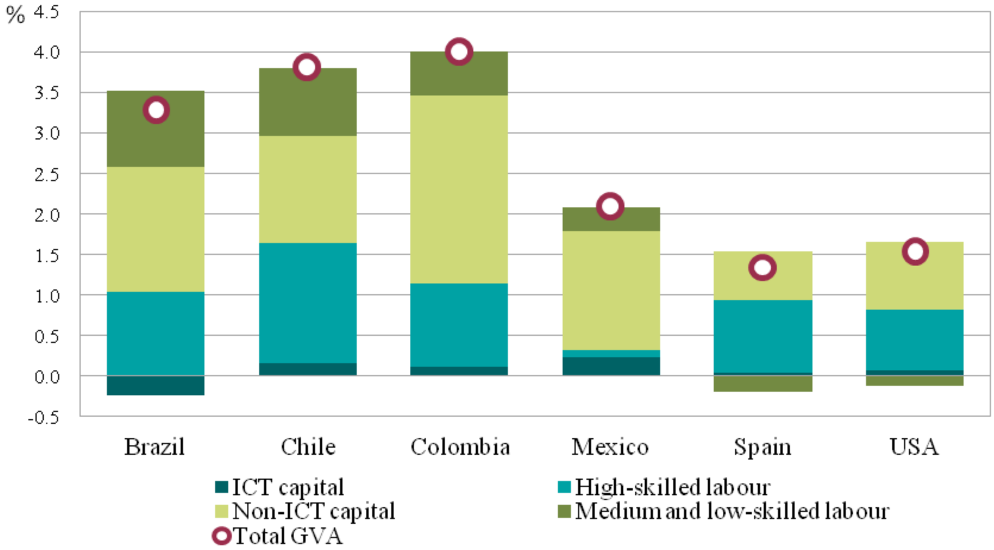

* 2000-2013 for Brazil, 2000-2014 for Colombia and 2000-2015 for Chile, Spain and the United States.
Source: BEA, BLS, EU KLEMS database, LAKLEMS database, BBVA Foundation-Ivie, INE, World KLEMS and own elaboration.

tion provided in Chart 4 offering the contribution of the four types of inputs to GVA growth. Starting with knowledge-intense capital, that is, ICT capital, Mexico shows the largest contribution, while Brazil presents a negative one.[11] Knowledge intensive labour contribution (high-skilled labour) is remarkably high in Chile, and also in Brazil and Colombia, but very low in Mexico. Colombia and Mexico stand out with the highest contributions of non-knowledge intensive capital, and Brazil, Chile and again Colombia with non-knowledge intensive labour. The contribution of the latter is negative in the case of Spain and the United States, whose main driver of growth is high-skilled labour.

In terms of GVA per capita , Chart 6 shows the United States as the country with the highest level, close to $50,000 (2010 US dollar PPP), followed by Spain with around $30,000. Chile is, by far, the Latin Ameri-

11 This may explain why the growth rates of knowledge-based GVA in Brazil are lower than those of non-knowledge GVA (Chart 2).

**Chart 5: Knowledge and Non-Knowledge Inputs' Contribution to Annual GVA Growth Rate, LAKLEMS Countries, Spain and the United States, 2000-2016***




* 2000-2013 for Brazil, 2000-2014 for Colombia and 2000-2015 for Chile, Spain and the United States.
Source: BEA, BLS, EU KLEMS database, LAKLEMS database, BBVA Foundation-Ivie, INE, World KLEMS and own elaboration.

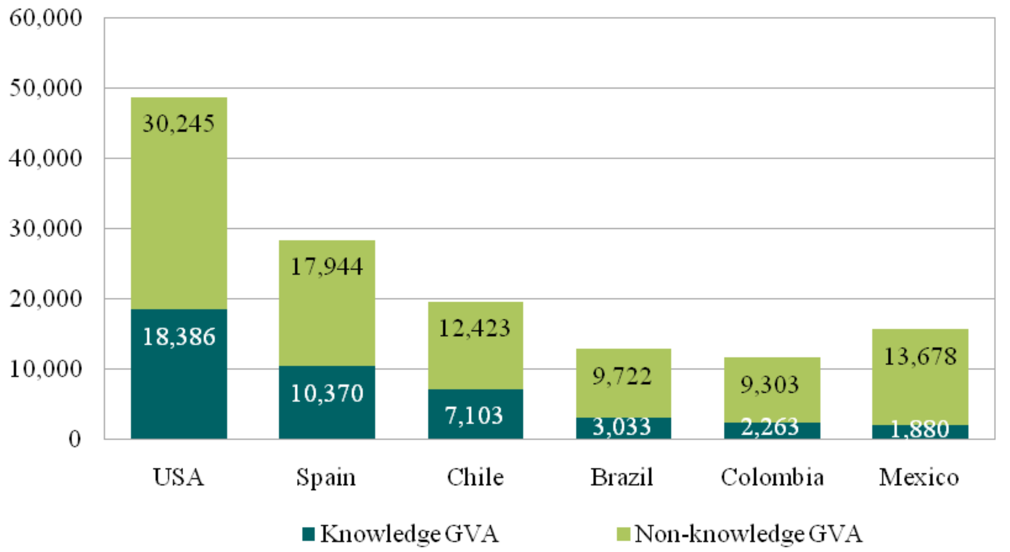
can country with the highest GVA per capita and also with the highest knowledge economy per capita, while for the other three countries it is much lower, especially for Mexico. However, despite having the lower knowledge economy level, Mexico ranks fourth in GVA per capita, after Chile. For the remaining countries, the higher the knowledge-based economy share, the higher the GVA per capita.

Finally, Chart 7 shows the changes in the knowledge-based economy per capita in 2000 and the most recent year available. All countries have benefited from the increase in knowledge-based GVA. But, while Colombia and Chile have almost doubled, the gains reached by Mexico and Brazil are very minor. Even Spain, a more developed country, shows a higher increase than these two countries.

Panel A of Chart 8 shows the relationship between knowledge-based GVA growth and labour productivity performance in each country. As can be observed, it is possible to establish a positive relationship between both variables, as the countries where the use of knowledge-based factors have grown faster are also the countries showing further productivity improvements. Panel B of Chart 8 confirms this result showing that in general the industries that have increased their knowledge-intensity at a faster pace are those that also perform better in terms of labour productivity.

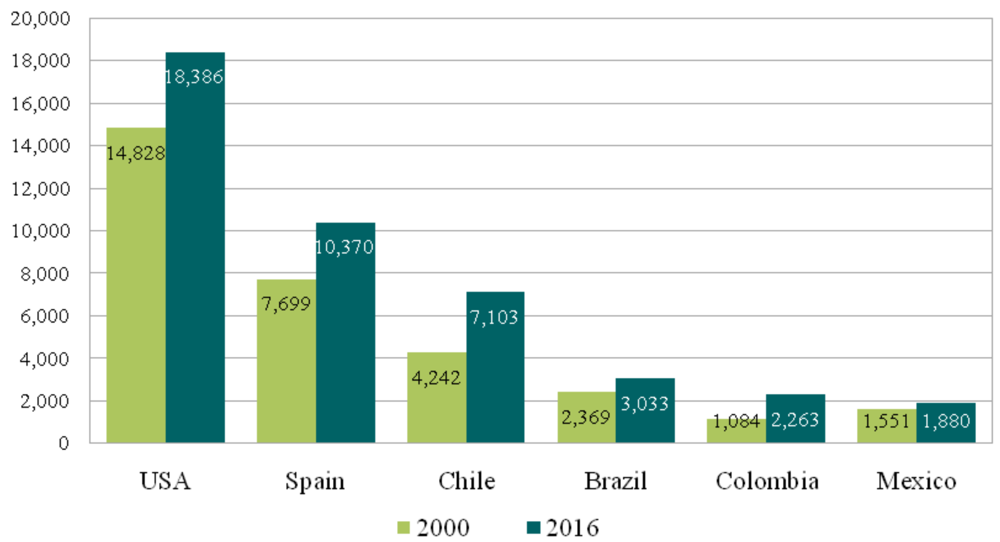
Putting all the pieces of evidence

**Chart 6: Real GVA per Capita: Knowledge and Non-Knowledge, LAKLEMS Countries, Spain and the United States, 2016* (2010 US Dollar PPP per Person)**



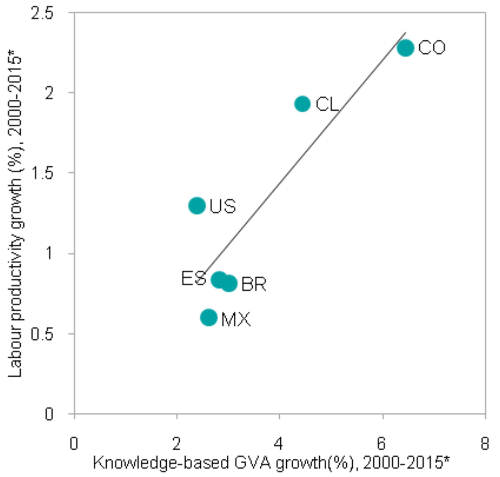

* 2013 for Brazil, 2014 for Colombia and 2015 for Chile, Spain and the United States. Note: Countries are ranked according to knowledge-based GVA. Source: BEA, BLS, EU KLEMS database, LAKLEMS database, BBVA Foundation-Ivie, INE, OECD, World KLEMS and own elaboration.

**Chart 7: Real Knowledge-Based GVA per Capita, LAKLEMS Countries, Spain and the United Sates, 2000 and 2016* (2010 US Dollars PPP per Person)**

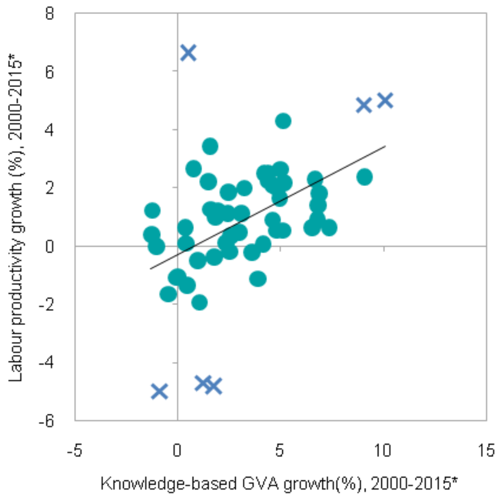



* 2013 for Brazil, 2014 for Colombia and 2015 for Chile, Spain and the United States. Note: Countries are ranked according to knowledge-based GVA. Source: BEA, BLS, EU KLEMS database, LAKLEMS database, BBVA Foundation-Ivie, INE, OECD, World KLEMS and own elaboration.

**Chart 8: Labour Productivity and Knowledge-Based GVA Growth, LAKLEMS Countries, Spain and the United States, 2000-2015***




**(a) Labour Productivity and Knowledge-Based GVA Growth by Country**




**(b) Labour Productivity and Knowledge-Based GVA Growth by Country and Industry**

* 2000-2013 for Brazil and 2000-2014 for Colombia. Note: Outliers (marked with an x) in panel b correspond to the sectors Mining and quarrying and Agriculture, forestry and fishing in the case of some LA countries. Source: BEA, BLS, EU KLEMS database, LAKLEMS database, BBVA Foundation-Ivie, INE, OECD, World KLEMS and own elaboration.

together, the picture that emerges is one with sharp differences among the four Latin American countries. Chile stands out for its higher weight of knowledge economy, its dynamic behaviour which in turn translates into a higher contribution to GVA growth. It is the Latin American country which follows a pattern of growth similar to Spain, a European medium range country for developed countries standards. This conclusion is especially true regarding the distribution between capital and labour income shares in total GVA, and also regarding the more similar contribution of the different types of inputs, knowledge and non-knowledge capital and labour. Its per capita income is the closest also to the Spanish one and the split between knowledge and non-knowledge is also the most balanced in per capita terms of the four LA countries.

On the opposite side, Mexico has the lowest share of the knowledge-based economy, presenting a very high share of non-knowledge capital. In fact, it is the country with the largest concentration of this source of growth in its economy. Of the two remaining countries, Colombia shows the most dynamic behaviour from a knowledge-based economy standpoint: the rate of growth of knowledge intense inputs has been the highest of the four Latin American countries, but it has not been, at least not yet, enough to reach the share over the total of Chile, Spain and the United States, the reference countries. Brazil, on the other side, started the period with a higher share of knowledge economy over GVA but has experienced a continuous fall in recent years.

### Industry Results

A distinctive characteristic of KLEMS methodology is the emphasis it puts on the importance of industry disaggregation. In fact, the results presented earlier come from the aggregation of industry data as described in section 1 (see equation 8). The available level of industry disaggregation is not homogenous for all countries. As explained earlier in the article, in the case of the LAKLEMS project, information is available for the nine industries listed in Table 1.

Chart 9 depicts knowledge-based GDP by industry for the year 2000 and the last year available. The industry labelled other services, which includes public administration, health and education, is the one with the highest knowledge intensity in all the countries. The only exception being Colombia, for which transportation and communication occupies the first position, and other services the fourth. However, it is this industry that shows the largest increase in the 2000-2014 period.

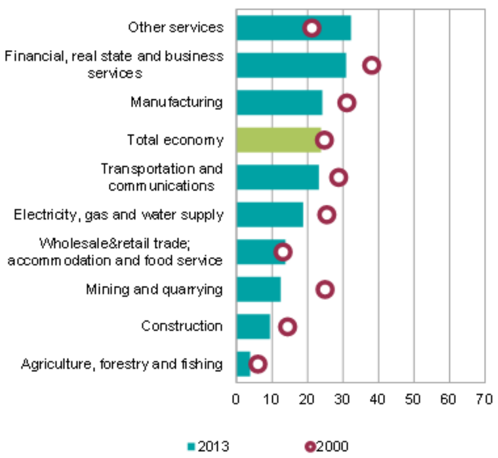
The second most knowledge-intensive industry in almost all the countries analysed is financial, real estate and business services, with the exception of Mexico in which construction takes the second position. For the rest of the countries, this is a more laggard industry in this respect. For instance, in Brazil and Spain it occupies the 8th position, the United States and Colombia 6th, and Chile 4th.

The industries presenting the lowest knowledge intensity are mining and quarrying (9th in Chile and the United States, 8th in Mexico and Colombia, 7th in Brazil and 5th in Spain), and agriculture, forestry and fishing (9th in Brazil, Mexico and Spain, 7th in Chile and the United States, and 5th in Colombia). Electricity, gas and water supply is the less knowledge-intensive industry in Colombia, and occupies the 8th position in Chile and the United States and the 7th in Spain, while in the other two countries it takes a more intermediate position.

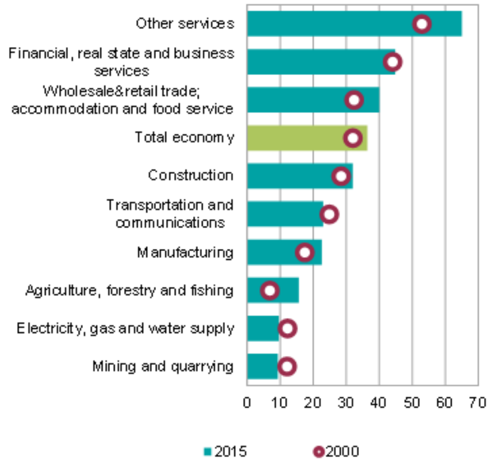
It is also interesting to note that manufacturing, which is more R&D intensive, is not the most knowledge-intensive according to our approach. In all the countries it takes an intermediate position: 3rd in Brazil and the United States, 4th in Spain, 6th in Chile and Mexico, and 7th in Colombia.

It is also worth highlighting that,

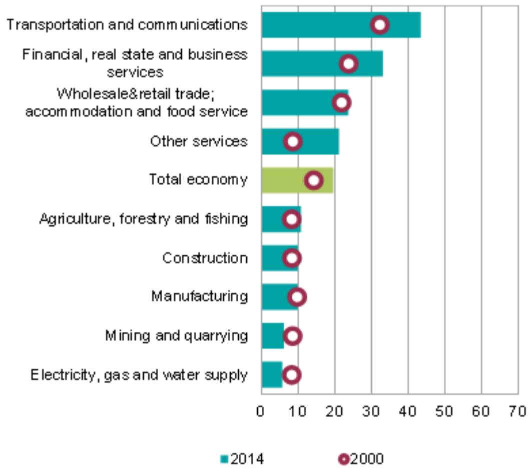
**Chart 9: Knowledge-Based GVA by Industry, LAKLEMS Countries, Spain and the United States, 2000 and 2016* (Percentage of each Industry's GVA)**



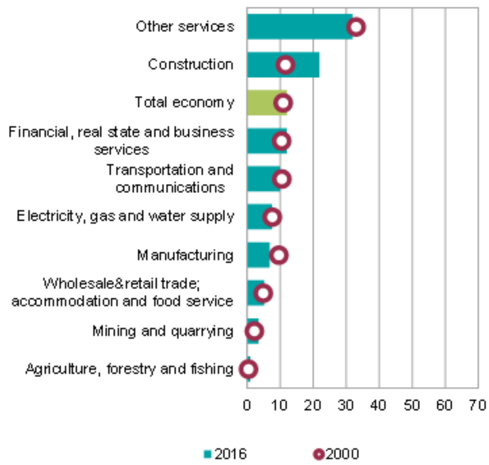

(a) **Brazil**



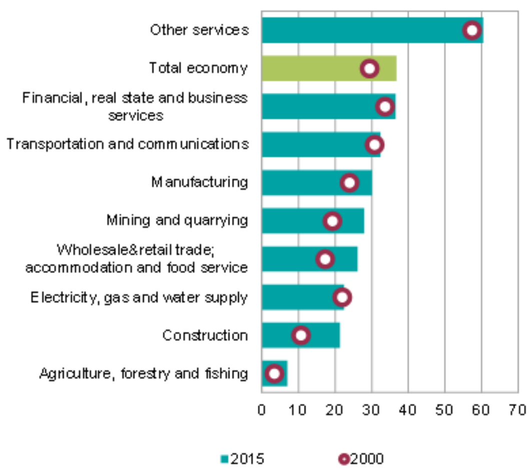

(b) **Chile**



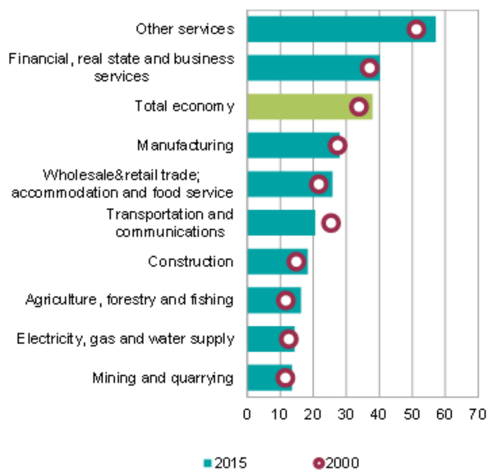

(c) **Colombia**




(d) **Mexico**




(e) **Spain**




(f) **United States**

* 2013 for Brazil, 2014 for Colombia and 2015 for Chile, Spain and the United States. Source: BEA, BLS, EU KLEMS database, LAKLEMS database, BBVA Foundation-Ivie, INE, World KLEMS and own elaboration.

in the case of Spain and the United States, almost all the industries have increased their knowledge intensity, whereas this result does not hold for all the Latin American countries and industries, especially Brazil.

Chart 10 shows the contributions of the two inputs, labour and capital, distinguishing between knowledge intensive—that is, ICT assets for capital and tertiary education for labour—and the rest, which is considered non-knowledge intensive (non-ICT capital and medium- and low-skilled workers), for the last year for which information is available. This information complements the one offered in Chart 4, which presents similar information but related to the total economy.

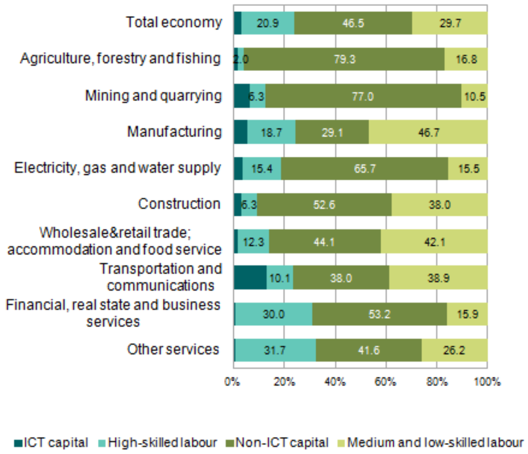
The following observations are of note. First, for all countries, the high knowledge intensity in other services is basically due to the labour component, especially in Chile, Spain and the United States. This is not surprising when we recall that it includes public administration, health and education, activities requiring the presence of high-skilled workers. However, in the case of Brazil and Colombia, non-knowledge-based capital also plays an important role regarding this sector. ICT capital has an important contribution in the transportation and communication industry, mainly for the communication component. This high contribution is especially relevant in Brazil, Colombia and Spain. ICT contribution is also important in the construction industry in Mexico, electricity, gas and water supply in Chile, and manufacturing in Chile and Brazil and financial, real state and business services in Spain and the United States.

Besides other services, labour-knowledge intensity has a very relevant role in financial, real estate and business services in all countries, except Mexico; also in transportation and equipment, and in wholesale & retail trade; accommodation and food service in Chile, Colombia and Spain.

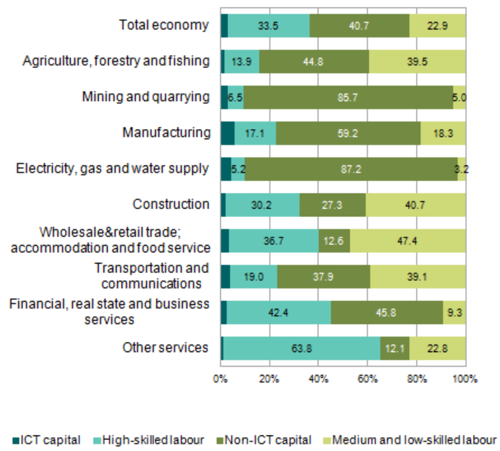
The contributions of the non-knowledge inputs, capital and labour, vary among countries but follow the same pattern for certain sectors. For instance, the contribution of non-ICT capital is very high in all the countries in electricity, gas and water and mining and quarrying (the latter not in Spain). For the remaining industries, the contribution of non-knowledge-intensive labour is higher in Brazil and Chile, and also in Spain and the United States, than in Colombia or Mexico.

As can be seen, there are important differences in terms of knowledge intensity by industry, and also by countries within the same industries. Regarding the first differences, a way to verify how different the contribu-

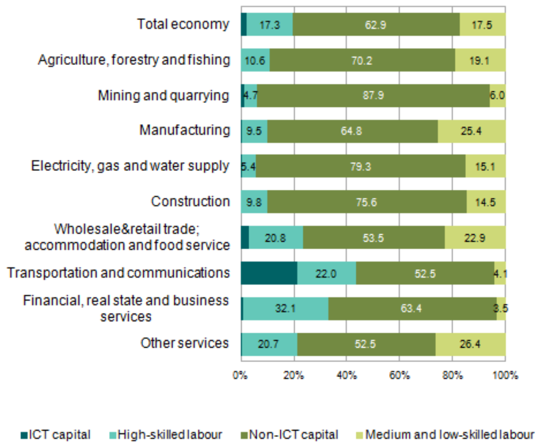
**Chart 10: Knowledge and Non-Knowledge Compensation over GVA by Industry, LAKLEMS Countries, Spain and United States, 2016* (%)**



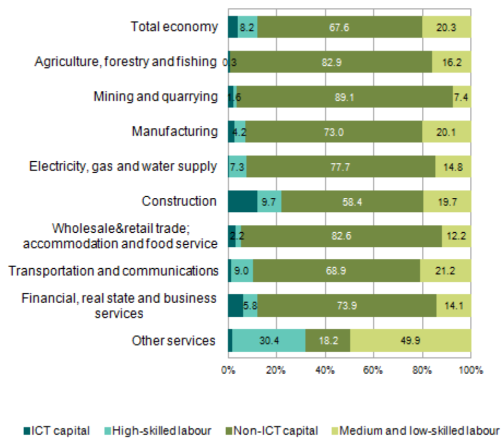

(a) **Brazil**



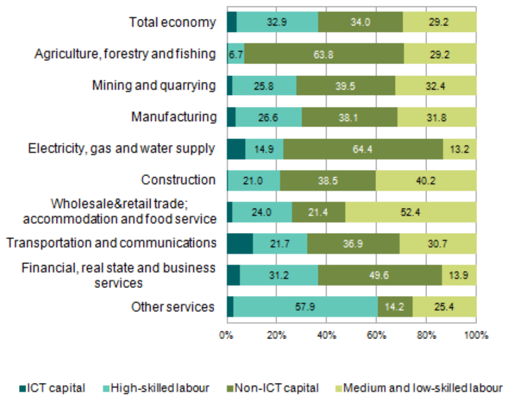

(b) **Chile**



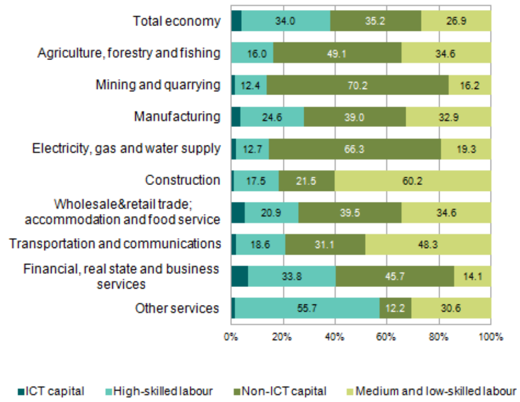

(c) **Colombia**




(d) **Mexico**



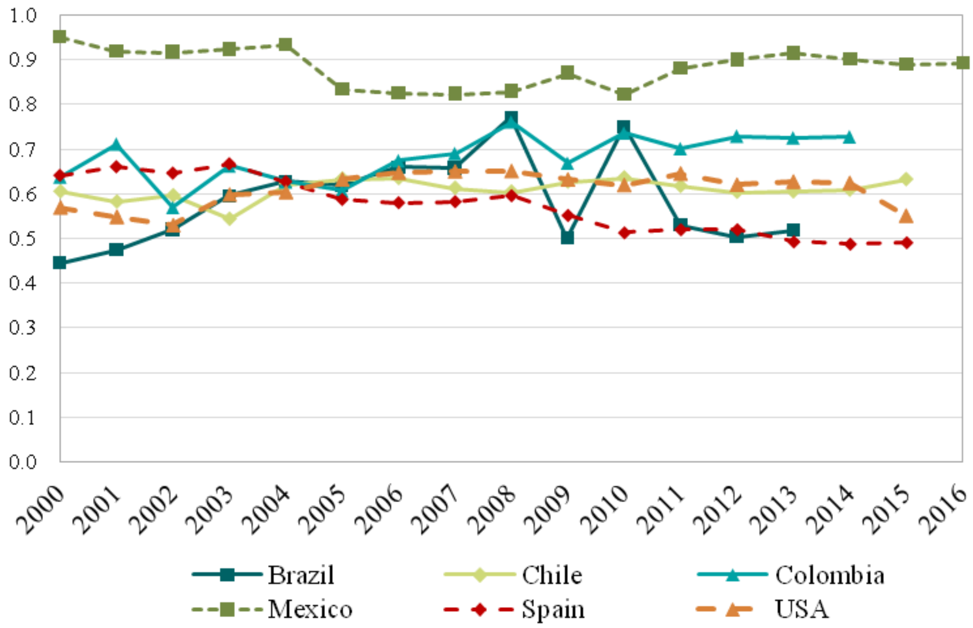

(e) **Spain**




(f) **United States**

* 2013 for Brazil, 2014 for Colombia and 2015 for Chile, Spain and the United States. Source: BEA, BLS, EU KLEMS database, LAKLEMS database, BBVA Foundation-Ivie, INE, World KLEMS and own elaboration.

**Chart 11: Dispersion of the Knowledge-Based GVA Share Among Sectors, LAKLEMS Countries, Spain and the United States, 2000-2016 (Coefficient of Variation)**




Note: Dispersion level is measured with the coefficient of variation. Source: BEA, BLS, EU KLEMS database, LAKLEMS database, BBVA Foundation-Ivie, INE, World KLEMS and own elaboration.

tions of the knowledge-based inputs are within each country's industries is by computing the dispersion (as measured by the coefficient of variation) of their shares over GVA among sectors.

Chart 11 provides this information and identifies Mexico as the country with the highest dispersion, probably due to the high contribution it has in other services and construction industries, as compared with other sectors. Colombia occupies the second position, possibly originated, in this case, by the very high contribution of the transport and communication industry. Brazil follows a rather erratic path, which suggests taking a more in-depth look at the data. Finally, Chile is the Latin American country presenting the lowest dispersion, which means that the production process of the different industries is more homogeneous than in the other three countries.

In this respect, it is interesting to highlight, again, that this characteristic is shared with the United States and Spain, the latter the country with the lowest dispersion. In addition, dispersion has decreased in Spain, the United States and Mexico since 2000, but has increased in Brazil, Colombia and slightly in Chile. In these countries the differences in terms of the use of knowledge-intensive inputs among sectors is increasing. Further research is needed on these results in order to explain the differences in GVA composition by industries and in its performance across Latin American countries.

## Conclusion

The proposed metric calculates the knowledge content of the economy based on more accurate and disaggregated measurements of human and physical capital services by sector, provided by LAKLEMS database. In order to compute the size, and composition, of the knowledge economy, we have used a rather restrictive definition of knowledge-based inputs, which considers only ICT assets for capital input, and the highest level of educational attainment in the case of labour. Nine industries in four Latin American economies, plus the United States and Spain, were analysed over the period 2000-2016 or last year available. The United States and Spain are introduced in the analysis as benchmark countries with strong historical, cultural and economic ties with Latin America.

The study confirms that developing economies are moving towards a more knowledge-based pattern of production, even though considerable differences exist among them. In addition, the speed in which they approach the existing standards of more developed countries varies considerably. The share of the knowledge-based economy ranges from around 10 per cent in Mexico, 20-25 per cent in Colombia and Brazil, and a larger weight, around 35 per cent in Chile, similar to that of Spain or the United States. The share of the knowledge economy has remained almost constant in Mexico over the period, while it fell slightly in Brazil, and increased in Colombia, Chile, Spain and the United States.

On a per capita basis, Chile is the Latin American country with the highest knowledge-based GVA, more than double that of Brazil, the second country in the ranking, but still at a great distance from more advanced countries. Mexico is the country that comes last in per capita terms and, in addition, it shows a less dynamic path during the 2000-2016 period.

In three of the Latin American countries, the rate of growth of knowledge-based GVA has been much higher than the non-knowledge counterpart. Colombia showed the most dynamic behaviour, followed by Chile and Mexico. Brazil is the only country experiencing the opposite trend. Chile is the country showing the most balanced split between knowledge and non-knowledge sources of growth.

ICT capital has a low share in total capital in all economies, but it tends to increase with the level of development. Chile and Brazil are the countries which incorporate more ICT into the production process, and Colombia the one with the lowest presence. However, the contribution of ICT capital to GVA growth in all countries exceeds its weight in the economy. From the labour side, skilled labour is the factor contributing the most to the knowledge economy but, again, with important differences among countries. Chile is, by far, the country with the largest contribution of high-educated workers, followed by Colombia and Brazil. However, non-intensive knowledge capital is the main driver of GVA growth in Colombia and Mexico, while Brazil and Chile show a more balanced distribution among the four drivers of growth: knowledge-based and non-knowledge-based capital and labour.

The disaggregation by industries provides further insights on the composition of the knowledge economy. Generally speaking, other services—which basically refer to public administration, health and education—and financial, real estate and business services are, in almost all countries, the industries with the largest contribution of knowledge-based assets. This result originates mainly from the contribution of workers with higher levels of educational attainment. On the contrary, agriculture, forestry and fishing, and mining and quarrying are, broadly speaking, non-knowledge activities, splitting the responsibility between labour and capital depending on the country analysed.

A positive relationship can be established between the increase of knowledge-based GVA and labour productivity performance in each country and sector, as the countries and industries that have increased their use of knowledge-based factors at a faster rate also show further labour productivity improvements.

Overall, we can say that there are important differences among the Latin American countries in terms of knowledge-based economy. In addition, there are also differences in terms of knowledge intensity among different industries within the same country and, with the exception of Mexico, these differences have increased in the Latin American countries during the most recent period. In this sense, further research is needed to provide more insight on the role played by each industry in the knowledge intensity of each country and to identify different sectoral patterns of growth of knowledge-based GVA among Latin-American countries. In addition, comparing the results with those of Spain and the United States, two countries with a more intense use of knowledge-based factors and a higher GDP per capita, provides new research lines that focus on the effects of using knowledge-based factors on productivity and economic performance.

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