Editor's Overview

THE 31ST ISSUE OF THE *International Productivity Monitor* contains articles on the following topics: the productivity paradox in the New Digital Economy; the industry origins of Canada's weaker productivity growth; the factors behind the gap between productivity and median wage growth in Canada; a review of Robert J. Gordon's new book, *The Rise and Fall of American Growth*, with a response by the author; and a symposium on issues related to total factor productivity growth, including its sources, industry decompositions, and relationship to partial productivity measures.

The rise of the New Digital Economy is unquestionably altering the dynamics of economic growth. Yet despite the productivity-enhancing potential of many of these new technologies, productivity growth throughout the world has slowed down since the mid-2000s. In the lead article in this issue, **Bart van Ark** from The Conference Board and the University of Groningen addresses this paradoxical situation. He makes the case that we are currently in an installation phase where the effects of the new digital economy are under the radar screen of aggregate productivity growth and are manifesting themselves in rapidly falling prices of ICT assets, increased spending on ICT services, and greater use of intangible assets. Once digital technologies are widely diffused, the deployment phase will see stronger productivity growth.

Labour productivity growth in Canada has fallen off considerably since 2000. In the second article, **John R. Baldwin and Michael Willox** from Statistics Canada examine the origins of this slower growth. They develop a methodology that decomposes labour productivity growth at the aggregate and industry level into within-industry effects and reallocation effects. They find that of the 0.81 percentage point fall-off in business sector output per hour growth in Canada between 1989-2000 and 2000-2014, 1.05 percentage points was due to direct or within-industry productivity effects. Favourable reallocation effects in labour input added to aggregate productivity growth after 2000 and reduced the slowdown between periods by 0.23 points. From an industry perspective, three industries - manufacturing, mining, oil and gas, and finance, insurance and real estate - accounted for all of the post-2000 productivity slowdown.

Many Canadians feel they are not sharing in the income gains from productivity growth. In the third article, **James Uguccioni** from the University of Toronto shows that this perception is based in reality. Between 1976 and 2014 median hourly real wages in Canada grew at a meagre 0.1 per cent per year, while output per hour advanced at a 1.1 per cent average annual rate. The author decomposes this 1.0 percentage point gap and finds that rising earnings inequality accounts for about one half, with labour's falling share of national income responsible for one third. Real wage growth has been fastest at the top and bottom of the earnings distribution, suggesting a hollowing out of the middle class.

One of the most important publishing events in 2016 for economists has been the release of *The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War* by Northwestern University economist **Robert J. Gordon**. The fourth article in this issue features of review of the book by **Daniel E. Sichel** of Wellesley College, with a response by the author himself.

Sichel points out that Gordon has actually written two books, the first on the dramatic change in U.S. living standards since 1870 and the second on the post-1970 period and the future where the drivers of strong productivity growth up to 1970 cannot be repeated. Sichel has high praise for the first book, calling it truly extraordinary in coverage and creativity. He is less enthusiastic about the second book. He finds it more speculative, downplaying the factors such as digital technologies that point to an improved productivity performance going forward.

Gordon takes issue with Sichel's optimism and points out that the United States has already experienced slower productivity growth for 35 out of 45 years since 1970 (the 1995-2004 period is the exception). He believes that the digital revolution will not alter economic life as profoundly, or along as many dimensions, as earlier great inventions, especially electricity. In addition, a number of headwinds including a plateau in educational attainment, the growth of inequality, and sociological decay have negative implications for median income growth.

For many if not most economists, total factor productivity (TFP) is the most important and fundamental productivity concept or measure. The last three articles in this issue comprise a symposium on the topic of TFP.

The first article in the symposium by **Nicholas Oulton** from the London School of Economics and the National Institute of Economic and Social Research provides a thorough examination of the sources of TFP growth, based on an empirical analysis of TFP trends in 15 EU countries, the United States, Japan and Australia over the 1970-2007 period. He finds that any attempt to eliminate TFP from the growth story and replace it with a wider or better measure of capital seems unlikely to succeed. He concludes that it is unfortunate that measurement error plays such a prominent role in the TFP discussion, and that until there is improved measurement, the mystery of TFP is likely to remain unresolved.

The second article in the symposium by **Matthew Calver** from Finance Canada and **Alexander Murray** from the Centre for the Study of Living Standards first discusses methodologies for the estimation of industry contributions to multifactor productivity growth. They then decompose MFP growth in Canada over the 1997-2014 period by industry and by province. Their results are methodology-dependent. The decomposition technique that includes relative price changes as contributing to aggregate MFP finds that the mining and oil and gas sector, and the provinces where this sector is concentrated, made by far the largest contribution to aggregate MFP growth because of the large increases in output prices over the period. In contrast, the technique that excludes relative price movements finds that manufacturing and Ontario (the province where manufacturing is concentrated) made the largest contribution.

The third article in the symposium by **Alexander Murray** from the Centre for the Study of Living Standards provides an assessment of the strengths and weakness of partial versus total factor productivity measures. He points out that partial productivity measures provide an incomplete picture of the efficiency with which all inputs are being employed. However, TFP suffers from a number of weaknesses, including burdensome data requirements, and complex methodological choices about which there is no expert consensus. This results in a lack of transparency and difficulty for non-experts to understand. He concludes that productivity analysts should adopt a balanced, context- appropriate approach that incorporates both types of productivity measure.

Table of Contents

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The Productivity Paradox of the New Digital Economy

Bart van Ark
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ABSTRACT

Despite a rapid increase in business spending on capital and services in Information and Communication Technology (ICT), the New Digital Economy (mobile technology, the internet, and cloud) has not yet generated any visible improvement in productivity growth. This article reviews the latest evidence for the United States, the United Kingdom and Germany. We find rapidly declining ICT prices, a shift from ICT investment to ICT services, and a continued increase in knowledge based-assets supporting ICT. However, the New Digital Economy is still in its "installation phase" and productivity effects may occur only once the technology enters the "deployment phase".

The rise of the New Digital Economy, defined as the combination of mobile technology, ubiquitous access to the internet, and the shift toward storage, analysis, and development of new applications in the cloud, is unquestionably altering the dynamics of economic growth. For example, over the past 15 years, business spending on digital services including cloud computing, data analysis, and other information services in major advanced economies (such as the United States, the United Kingdom, and Germany) rapidly increased. On the other hand, investment in digital assets (or ICT (Information and Communication Technology) capital), especially computers and peripherals, and communications equipment, has slowed significantly. Relative to average prices, prices of digital assets including computers and peripherals, communications equipment, and software have continued to decline rapidly, giving businesses large opportunities to operate at lower cost and higher efficiency and bring products and services to market at competitive prices.

Yet the New Digital Economy creates an important conundrum: as the economy is digitizing at such a rapid pace, why are we not seeing much faster productivity growth? Global productivity growth has been remarkably slow for almost a decade now, and there is little indication that the New Digital Economy has boosted productivity growth. Clearly there are multiple reasons for the slowdown in productivity since the mid-2000s, as discussed in the first section of this article.

In the second section, we argue however that the New Digital Economy is showing its effects under the radar screen of aggregate productivity growth. So far, the effects of the New Digital Economy are showing up most clearly in rapidly falling prices of ICT assets, increased spending

1 Bart van Ark is Executive Vice President, Chief Economist, and Chief Strategy Officer at The Conference Board in New York and Professor at the University of Groningen in the Netherlands. He thanks Carol Corrado and Abdul Erumban for comments and support. This article is based on a recent report by The Conference Board entitled *Navigating the Digital Economy: Driving Digital Growth and Productivity from Installation to Deployment* (Van Ark *et al.*, 2016). Email: Bart.VanArk@conference-board.org.

on ICT services rather than investment in ICT assets, and a critical shift towards the greater use of intangible assets, in particular ICT design and services, workforce training and organizational innovations. Despite the rapid diffusion of products and services based on the New Digital Economy among consumers, the business sector is finding it very hard to harvest the potential productivity gains as yet. The current evidence shows that only a limited number of firms have made a full transition to the New Digital Economy. Even fewer have already seen large benefits in terms of higher revenue, productivity, or profitability. As a result relatively few sectors and industries have seen visible productivity gains so far.

In the third section we make the case that the resolution of the rapid technological change-slow economic growth conundrum can be found in the fact that we are still in the "installation phase" of the New Digital Economy. This represents a period during which new technologies emerge and advance, driven by the creation of new infrastructure and new and superior ways of doing things, disrupting established practices and organizations. However, the productivity gains may not become visible until the "deployment phase" when the new technological paradigm will have been widely diffused and will have become common practice across organizations, enabling its full potential in terms of economic and business growth, productivity, and profitability. It is too early to say how large the productivity effects of the New Digital Economy will be during the deployment phase. But there is also no reason to be more pessimistic about future productivity effects compared to previous technology regimes.[2]

The Productivity Slowdown in the New Digital Economy

Since the mid-2000s, productivity growth has been showing a declining trend. This decline has been substantial, long-lasting, and across the board, and includes mature economies such as the United States, the Euro Area, and Japan as well as emerging markets such as China, India, Brazil, and Mexico. Globally, labour productivity growth (measured as output per worker) has only moderately slowed from 2.6 per cent per year, on average, in the 1996-2006 period to 2.4 per cent in the 2007-2014 period. The slowdown in global total factor productivity growth has been much more dramatic, downshifting from 1.3 per cent from 1999 to 2006 to only 0.3 per cent from 2007 to 2014.[3]

In earlier work at The Conference Board, we identified several reasons for the productivity slowdown, including the possible impact of the recent recessions (including the Great Recession in 2008-2009 and the Eurocrisis in 2011-2012) from which, in particular, the mature economies are still struggling to recover; the exhaustion of the potential for productivity growth in emerging markets; the intensification of regulatory and other policy measures that inhibit productivity growth; and the weaker translation of technology and innovation into productivity since the mid-2000s (van Ark *et al.*, 2015).

The slowdown in productivity growth in the past decade, especially in mature economies, is often attributed to the 2008-2009 recession and therefore considered temporary. However, in most countries, productivity growth already began to slow down before the recession and, except for a brief rebound, has not recovered to

2 See also the exchange between Sichel (2016) and Gordon (2016b) on Gordon (2016a) in this issue of the *International Productivity Monitor*.

3 See The Conference Board Total Economy Database (https://www.conference-board.org/data/economy-database/), November 2016. The periodization of the average growth rates refers to growth relative to the previous year, i.e. 1999-2006 refers to 1998 as the base year.

the growth rates of the 1990s and early 2000s. For example, between 2007 and 2014, growth in output per hour in the United States slowed to only 1.0 per cent per year on average, down from 2.4 per cent between 1999 and 2006 (Chart 1). In Germany, annual labour productivity growth slowed from 1.6 per cent per year to 0.8 per cent, and in the United Kingdom it weakened most dramatically from 1.9 per cent to 0.1 per cent. Even with an adjustment for faster declines in ICT prices (as described in the next section), and taking into account the shift toward purchased ICT services, these productivity declines remain.

Some economists are calling the current phase of economic growth one of long-term (or secular) stagnation, even though they may differ on the causes: either demand constraints due to disincentives to spend and invest, or supply constraints - such as slower labour force growth and weak productivity growth - that are restraining growth (Summers, 2016; Teulings and Baldwin, 2014; Gordon, 2016). Others are downplaying concerns of slow growth. They argue that while the effects of digitization and related technologies, such as nano- and bio-technologies and cognitive sciences, are becoming increasingly visible in the world around us, their impact on growth is not being well captured by current measurement techniques (Brynjolfsson and McAfee, 2011; Ford, 2015). While we are of the opinion that all of those factors are playing some role, it is also clear that without significant improvement in productivity growth, it is unlikely that stagnant growth in the coming decade can be avoided (van Ark, 2016). The need to prioritize productivity is underlined by the slowdown in growth of labour supply in the medium term, which could be up to one percentage point globally. To achieve similar GDP growth rates as during those times, labour productivity growth rates would therefore have to be higher by the same amount as the slowdown in labour supply in the next decade (van Ark *et al.*, 2015).

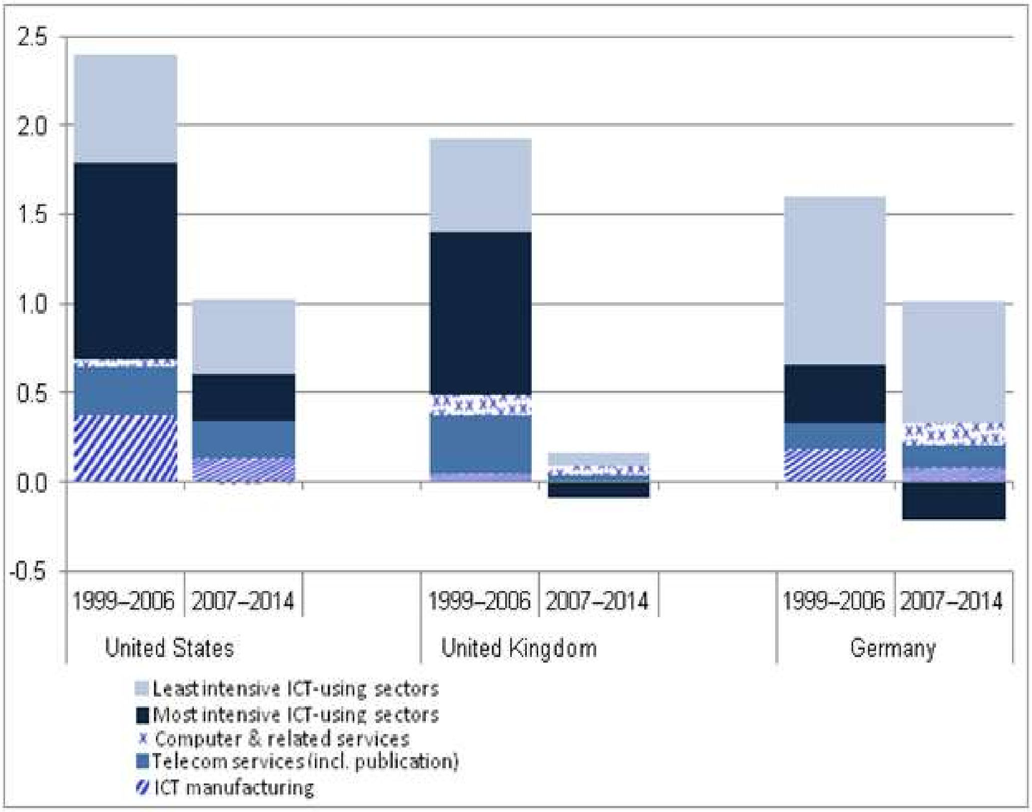
The productivity results at the sector level are even more startling when measuring the growth impact of the New Digital Economy (Chart 1). We find that the contribution of the ICT-producing sector - including ICT manufacturing (ICT hardware and telecommunication equipment), telecom services, and computer and information services - to aggregate productivity growth has weakened significantly in the United States, United Kingdom, and Germany since 2007, although it remained positive by a small margin.

What's more, we find that when looking at the top half of industries which represent the most intensive users of digital technology (measured by their purchases of ICT assets and services relative to GDP) have collectively accounted for the largest part of the slowdown in productivity growth in all three economies since 2007, namely for 60 per cent of the productivity slowdown in the United States, 66 per cent of the slowdown in Germany, and 54 per cent of the slowdown in the United Kingdom. In the United States the contribution of the most intensive ICT-using industries declined from 46 per cent to 26 per cent of aggregate productivity growth between both periods. The United Kingdom and Germany even registered negative productivity growth in the intensive ICT-using sector. The fact that ICT intensive users account for a larger part of the slowdown than less-intensive ICT users is another indication that the difficulty of absorbing the technology effectively is part of the explanation for the productivity slowdown.

A more detailed analysis of productivity performance in the United States shows that the productivity contributions of ICT-intensive and less-intensive industries are distributed rather randomly across the spectrum of fast- and slow-growing industries. Chart 2 presents a so-called

Chart 1

Contribution of ICT-Producing, Most Intensive ICT-Using and Least Intensive ICT-Using Industries to Total Economy Labour Productivity Growth, 1996–2006 and 2007–2014 (average percentage point change per year)



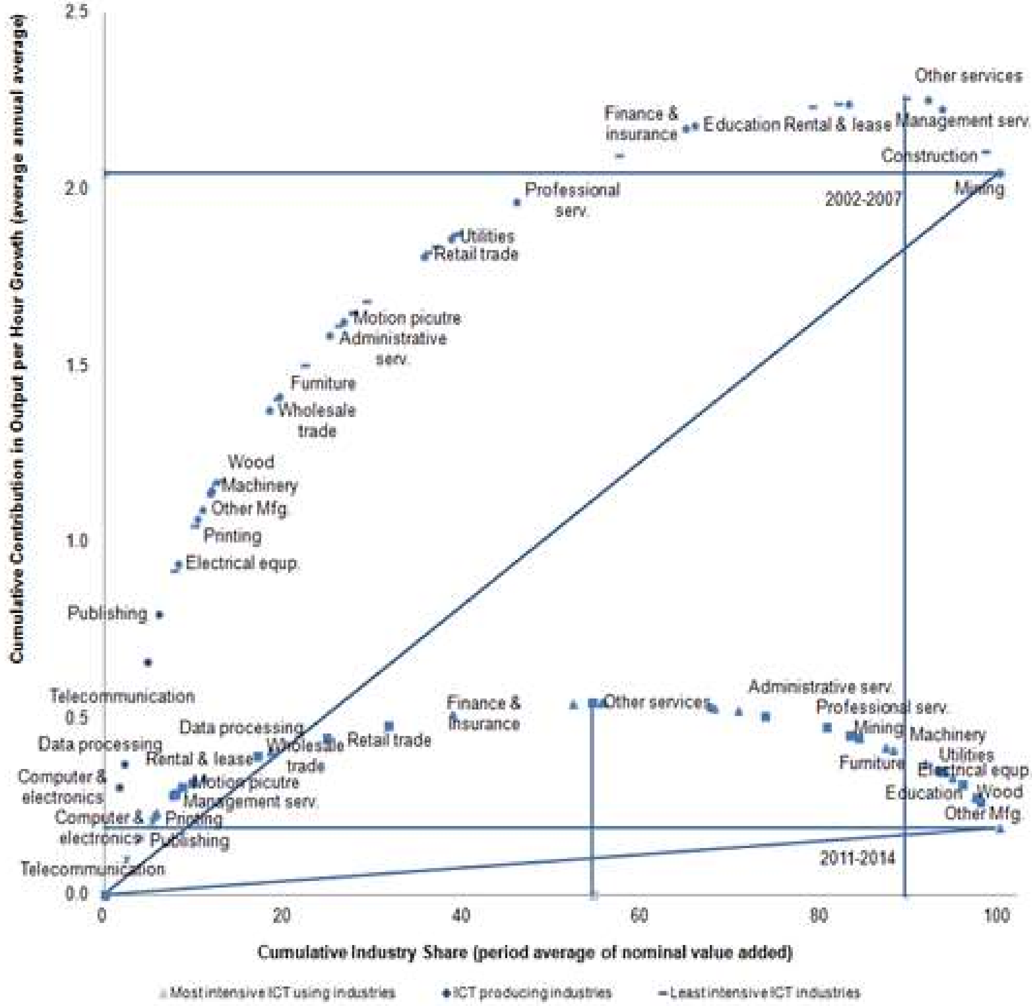
Note: "Most intensive ICT-using industries" refer to the top half of the industries with the highest share of value of ICT investment plus purchases of ICT services as a percentage of "synthetic output" (which is value added at industry level plus the intermediate use of ICT services) for each period. Least intensive ICT-using sectors refer to the bottom half of industries in terms of ICT intensity. The contribution of ICT-producing industries (which are also part of "most intensive ICT-using industries) to labour productivity growth are shown separately.
Source: van Ark *et al.* (2016)

Harberger diagram picturing the cumulative contributions of 30 industries to aggregate labour productivity growth ranked on the basis of the highest to the lowest contributions, weighted by the nominal GDP share of each sector (Harberger, 1998).

Chart 2 shows that aggregate labour productivity in the United States increased at an annual average rate of 2.1 per cent during 2002-2007 and only 0.2 per cent per year during 2011-2014. During the first period, industries account for 89.5 per cent of industry value added made positive contributions to productivity growth. Only four industries (other services, management services, construction, and mining) show negative productivity growth contributions, of which three were ICT intensive industries. During the period from 2011 to 2014 period only 55 per cent of industry value added was produced in industries with positive contributions to productivity growth. Among industries with negative productivity contributions, were ICT-intensive industries such as machinery, electrical equipment and several service industries. It seems the results are distributed randomly in terms of the positive and negative contributions

Chart 2

Cumulative Labour Productivity Growth Contributions by Industry in the United States, 2002-2007 and 2011-2014



Note: "Most intensive ICT-using industries" refer to the top half of the industries with the highest share of value of ICT investment plus purchases of ICT services as a percentage of "synthetic output" (which is value added at industry level plus the intermediate use of ICT services) for each period. Least intensive ICT industries sectors refer to the bottom half of industries in terms of ICT intensity. The contribution of ICT-producing industries (which are also part of "most intensive ICT-using industries) to labour productivity growth are shown separately.

Source: van Ark *et al.* (2016)

to productivity growth between the more and less intensive ICT-intensive industries, suggesting no impact of differences in ICT use.

ICT-producing industries, including computer and electronics, data processing and telecommunication services provided the largest positive contributions, but given the relatively small size of those industries, their impact on the aggregate is limited. However, even in ICT-producing industries, productivity growth from 2011 to 2014 was substantially below the rates of 2002-2007.

What the New Digital Economy Has Delivered So Far

Despite the disappointing productivity results from the New Digital Economy so far, there are at least three important reasons why it is premature to conclude that the New Digital Economy will not deliver on growth. We discuss these reasons in this section: 1) the ongoing rapid decline in ICT prices; 2) the rise of ICT services in business spending; and 3) the role of knowledge-based assets for ICT.

The Ongoing Rapid Decline of ICT Prices

Rapid price declines in ICT goods and services are an important manifestation of technological change and productivity growth. The dramatic acceleration in technological progress in ICT is underpinned by the strong acceleration of research and development (R&D) spending, mainly in software (Byrne and Corrado, 2016a). While the share of the digital producing sectors (ICT hardware, software and telecommunication and other ICT services) in nominal GDP of the United States has remained relatively small and stable at 6 per cent over the past two decades, the drop in prices of the assets and services (computers and peripherals, communications equipment and software) this sector produces (relative to average prices in the economy) has on average been about 7 per cent per year between the late 1980s and 2014 (Chart 3).

However, the pace by which ICT asset prices relative to aggregate prices have fallen every year, as measured by deflators from the U.S. National Income and Product Accounts, has slowed significantly over the past decade. According to calculations by Byrne and Corrado (2016a), prices for ICT assets relative to the average price decline of aggregate output (or GDP) have declined by less than 2 per cent per year from 2011 to 2015, down from 9 per cent per year from 1995 to 2005. Although improvements in cost-performance ratios in ICT have slowed since 2005, the softening price decline of ICT assets in the official statistics is not in line with the evidence from alternative estimates.

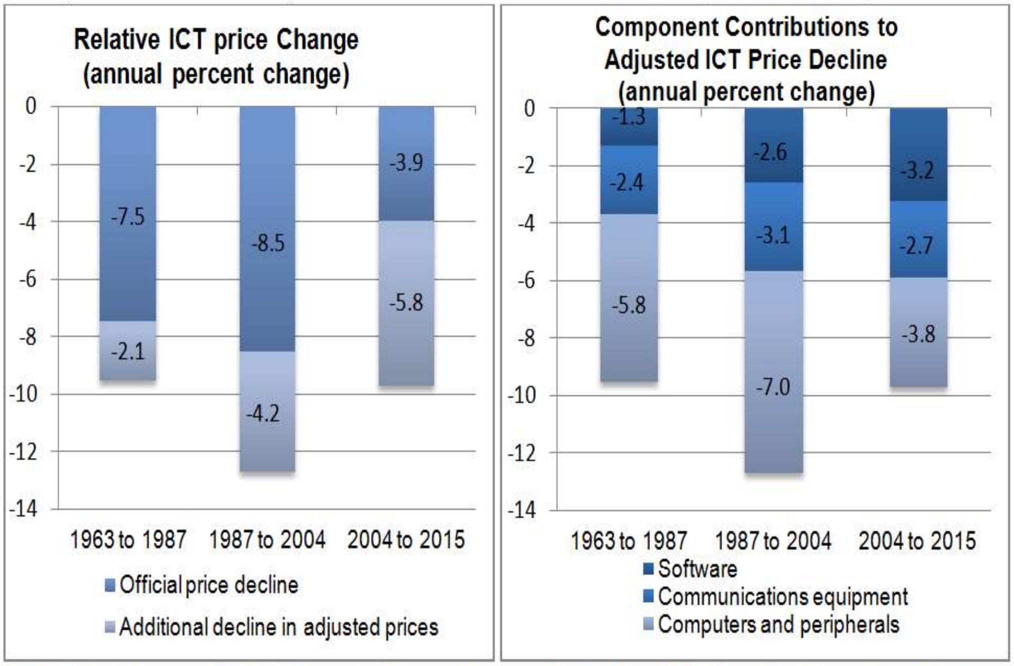
Byrne and Corrado (2016a and 2016b) have produced new price indexes for communications equipment, high-end computing equipment, and prepackaged enterprise software, which have constituted the lion's share of directly priced products in private ICT investment spending in the United States and are key enablers of technological change in the New Digital Economy. The new price series suggest that the official prices used by the US Bureau of Economic Analysis significantly understate the performance improvements of many ICT products and systems. While the pace of decline in ICT asset prices since 2004 was somewhat slower than it was in the prior two decades, it is at least on par with the experience prior to 1985 (that is, after correcting the ICT price indexes for overall inflation).

Price declines, communications equipment, and software are all faster overall than the official figures and have been well-maintained, generating a price decline of about 10 per cent per year since 2005, with a larger contribution from software and a smaller contribution from computers and peripherals (Chart 3). The new evidence suggests that the decline in prices due to the New Digital Economy has in fact continued to boost economic growth, and especially productivity growth. While the speed of these price declines is likely to peter out over time as technologies mature, improvements in cost-performance ratios for producers as well as users in the New Digital Economy will remain quite substantial for some time to come. Currently, the impact of the adjusted ICT price indexes by Byrne and Corrado on labour productivity and output growth in the United States is about 0.3 percentage points - but still not raising U.S. labour productivity much above 1 per cent on an annual basis.

Of course, these adjustments to productivity and GDP growth do not take account of the widely discussed and observed benefits the New

Chart 3

Changes in Official and Adjusted Price Indexes for ICT Investment, United States, 1963-2014



Note: Relative ICT price change is the change in the price index for ICT goods relative to the change in the price index for total GDP. Adjusted prices are official prices corrected for measurement issues. Growth rates are measured as compound growth rates.

Source: Byrne and Corrado (2016a)

Digital Economy provides to consumers. Many digital products and services can be produced at such low marginal cost that they can essentially be provided for free. For example, the benefits to the consumer from sharing spare capacity of cars (Uber) or homes (Airbnb) supported by platforms like Facebook or Google are not measured as part of GDP beyond what consumers pay for it. And the consumer utility of free content obtained from the internet is not measured at all. Hence the consumer is likely to be much better off as a result of the New Digital Economy than the statistics on GDP suggest (e.g. Aeppel (2015) and Hatzius and Dawsey (2015)).

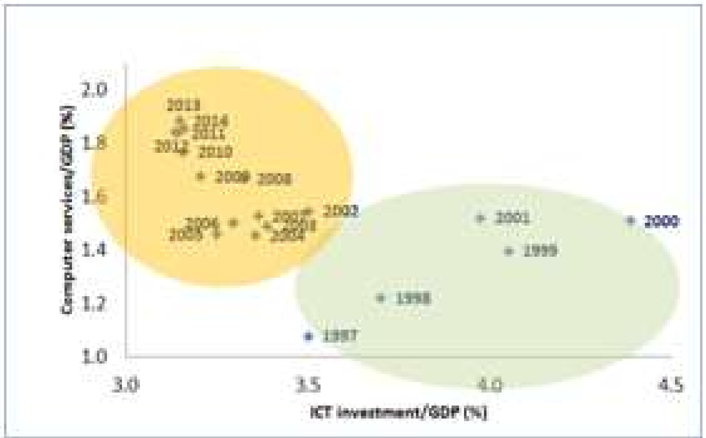
Even so some aspects of the sharing economy, such as the income consumers receive from sharing free capacity as well as the more efficient utilization of data centers by business, are already being captured in GDP through better productivity performance. But these effects add at most 0.1 percentage points to GDP growth.[4]

The statistical challenges in measuring the benefits of the New Digital Economy for the consumer are enormous - yet it should not be assumed beforehand that any adjustments will completely eliminate the slow productivity growth we are currently facing (Ahmad and Schreyer, 2016; Grömling, 2016). It should also be taken into account that some of the consumer benefits are offset by challenges for companies to be profitable. Many companies experience significant downward price pressure unless they add new unique features to their products that allow them to maintain their price margins, at least temporarily.

4 This estimate is based on Byrne, Fernald, and Reinsdorf (2016). See also Corrado and van Ark (2016), reporting a similar correction to price change for consumer internet access services.

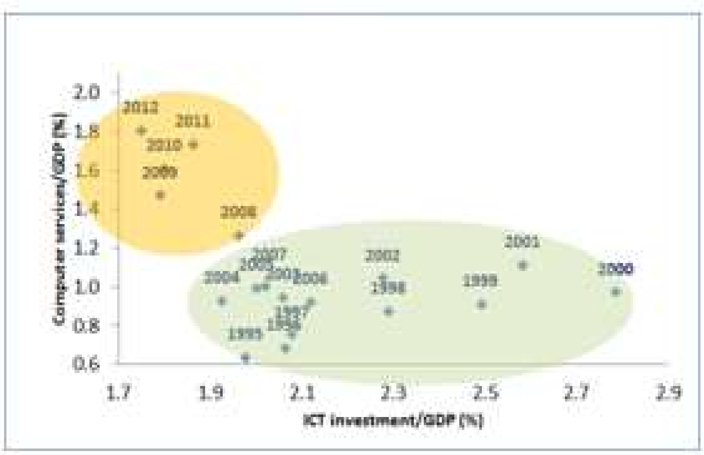
Chart 4: Producer Purchases of Computer Services and ICT Investment as a Percent of Nominal GDP (%)

United States, 1997-2014



United Kingdom, 1997-2012

Germany, 1995-2012



Sources: US Bureau of Economic Analysis; Eurostat; German Statistical Authority; EUKLEMS; The Conference Board

The Shift from Spending on Digital Assets to Digital Services

While declining ICT prices and improved quality of digital capital assets provide a primary channel for growth in the New Digital Economy, investment in ICT as a percentage of nominal GDP has fallen substantially (Chart 4). In the United States the decline started from a peak of 4.3 per cent of nominal GDP in 2000 and gradually slowed to around 3 per cent in 2014. In the United Kingdom, ICT investment peaked in 2001 at 2.8 per cent of GDP, and slowed until 2009 after which it modestly improved. Germany's ICT investment rate peaked at 2.8 per cent of GDP in 2000, and has consistently fallen since, reaching 1.7 per cent in 2012. Much of the observed decline in the ICT investment rate is a reflection of slower growth in computers and communication equipment investment relative to GDP. Meanwhile, the share of software in GDP has remained stable in Germany, and has shown modest increases in both the United Kingdom and the United States since 2010.

In contrast to the slowdown in business investment, there has been a major rise in spending on ICT services. The latter refers to data storage and information processing services (including cloud computing), computer systems design, and other information services (including internet publishing).[5] For example, business spending on digital services (including cloud computing and other information services) relative to output has increased from 1.5 per cent in 2000 to 1.9 per cent in 2014 in the United States, from 2.2 per cent in 2000 to 3.0 per cent in 2013 in the United Kingdom, and from 1.0 per cent in 2000 and 1.8 per cent in 2012 in Germany (Chart 4). This shift from ICT assets to ICT services is having a very large impact as companies move to external service providers for their ICT infrastructure. This can range from moving data into a "private cloud" (i.e. a company's internal cloud) to accessing public cloud services to store, access, and process data.

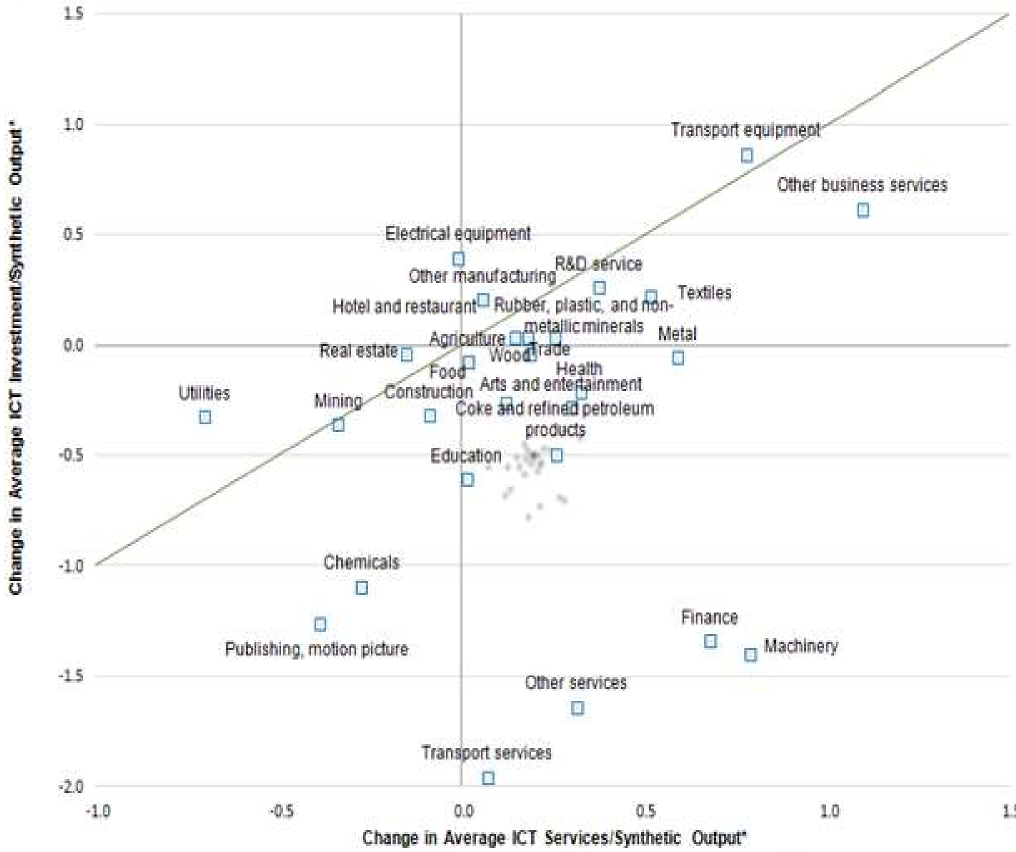
The shift from owning ICT assets to purchasing ICT services, which increases business flexibility, scalability, and utilization of data capabilities, is a widespread phenomenon across industries. Looking at data for the United States, business spending on ICT services increased much faster than spending on ICT investment in most industries, with many industries seeing a decline in the ICT investment ratio. Even industries that continued to see increased ICT investment (for example, transport equipment and other business services) have increased their ICT service use more rapidly (Chart 5). These changes allow firms to better utilize their digital data centers and to save directly on ICT expenses and on related costs such as energy, labour, and maintenance. The savings improve companies' resource allocation and efficiency, and can ultimately contribute to the economy's overall productivity performance.

While official measures are not available, some private sector estimates suggest that price declines for ICT services have been even more dramatic than for ICT investment. For example, one estimate suggests that the US bandwidth cost-performance ratio (dollar value of megabits per second) has fallen more than 25 per cent per year since 1999 - a pace near that of the historical cost-performance ratios commonly reported for computers (Hagel *et al.*, 2013). Cloud computing and storage prices have also been falling very rapidly in constant-quality terms. For example, one source suggests that Loudcloud,

5 More precisely, computer services refer to the following detailed industries in the North American Industry Classification System (NAICS): data processing, hosting, and related information services (NAICS 51820 and 51913) and computer systems design services and related computer services (NAICS 54152, 54153, and 54159).

Chart 5

Change in ICT Investment Intensity and ICT Services Intensity in US Industries Between 1999-2006 and 2007–2014



* Annual average for the period 2007–2014 minus the annual average for the period 1999–2006

Note: ICT investment consists of investment in software, hardware, and communication equipment; ICT services consist of computer systems design and related services as well as data processing, internet publishing, and other information services. Synthetic output is defined as the sum of industry value added and the intermediate use of ICT services. ICT-producing industries are excluded from this chart.

Sources: US Bureau of Economic Analysis; The Conference Board

which is claimed to be one of the first cloud computing companies, saw a decline in cost for a customer running a basic internet application from \$150,000 U.S. per month in 2000 to \$1,500 U.S. per month 10 years later (Andreessen, 2011). These figures imply a price drop of more than 30 per cent per year for cloud services during the 2000s, a pace of change that appears to have continued in recent years.[6]

Still, despite those impressive changes, the shift toward full usage of digital services is incomplete as yet. A recent survey of more than 550 companies in Europe and the United States suggests only a modest uptake on one major usage of digital services, which is "big data" analytics.[7] Only 28 per cent of companies in North America and 16 per cent in Europe had undertaken big data initiatives as part of their business

6 In March 2014 Google announced price cuts for its cloud computing services and storage by 30 per cent, only to be followed about one year later by further cuts in the 20 to 30 per cent range. See Lardinois (2014) and Yegulalp (2015) for reports on these changes.

processes in 2015. Another 25 per cent of companies in North America and 23 per cent in Europe had implemented a big data initiative as a pilot project. Hence about half of companies surveyed had not yet undertaken any big data initiative. Strikingly, the study also found that manufacturing companies were lagging in applying big data analytics projects in regular business processes by 14 percentage points relative to the retail sector (27 per cent versus 13 per cent of companies in each sector).

The Role of Knowledge-based Assets for ICT

There are various reasons why the rapid decline in ICT prices and the shift to ICT services is still facing impediments in terms of its impact on growth. Those range from external factors related to slower economic growth to factors internal to the firm. For example, there are multiple barriers to the use of big data analytics including IT capabilities, data privacy issues, analytical skills of the workforce, and companies' organizational adaptability.[8] Raising productivity by shifting inputs from ICT assets to ICT services strongly benefits from the use of critical knowledge-based assets (KBA) - often also referred to as intangible capital.

Knowledge-based capital consists of the intangible assets resulting from firms' investments in software, R&D, other innovative property (e.g. product and services design), and economic competencies (e.g. investments in firm-specific training and organizational change). In fact, a key takeaway from previous microeconomic studies of productivity change within firms is that these economic competencies investments are part of a complex link between firm-level IT adoption and productivity growth. In addition, increased collaboration and interaction within firms are having a large impact on several measures of firm performance, including R&D and sales (Brynjolfsson and Hitt, 2000; Brynjolfsson and Hitt, 2003).

During the Great Recession of 2008-2009, the pace of KBA accumulation somewhat weakened. This development may have reduced the impact of digital technology for productivity growth. However, since 2010 investment growth in most KBA has recovered strongly and has been faster than that of overall investment in machinery, equipment and structures. In the United States, the combined business spending on design, workforce training, and organizational innovations kept about the same pace as the rise in business R&D. In the United Kingdom, whose economy is strongly services-based with financial and business services absorbing large amounts of spending on business competencies, combined business spending on design far outstripped the R&D increase. Only in Germany, where manufacturing is more dominant, was R&D growth stronger than spending on KBA - and the growth gap between the two even increased somewhat (van Ark *et al.*, 2016: 33).

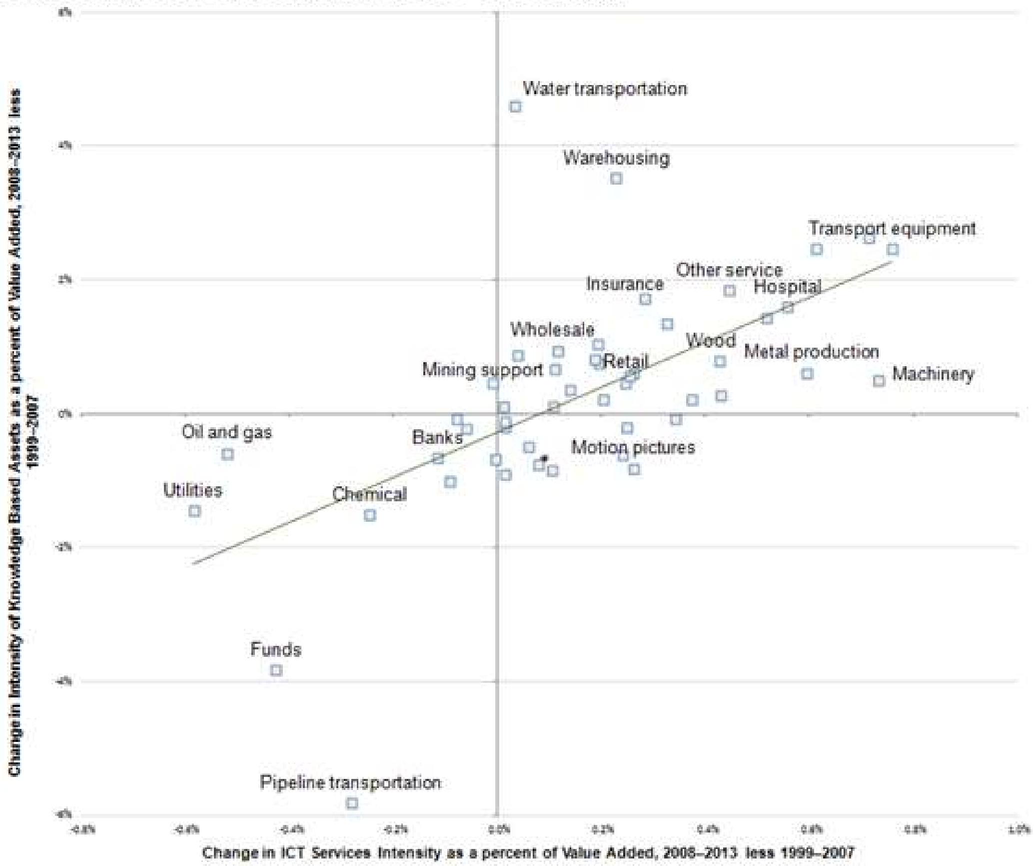
There is a strong complementarity between business spending on KBA and ICT services. For the United States both manufacturing (including transportation equipment, machinery, and metal products) and services sectors (such as transportation, retail, and insurance) have seen strong positive relationships in the

7 Bange *et al.* (2015:9) use the following definition of "big data": "Big data describes the methods and technologies for the highly scalable loading, storage and analysis of polystructured data. Big data technology can help companies to manage large data volumes, complex analysis, and real-time integration of data from a variety of data structures and sources."

8 For example, Bange *et al.* (2015) finds that 49 per cent of companies in North America and Europe report inadequate analytical know-how in the company to make better use of big data technologies and analysis, and 34 per cent responded that company processes are not mature enough for the use of big data technologies.

Chart 6

Changes in Knowledge-Based Assets and ICT Services Intensity by Industry
United States, 2008–2013 Relative to the 1997–2007 Average



Note: ICT services intensity is defined as spending on ICT services relative to GDP during the New Digital Economy period (2008–2013) compared to its rate in the prior period (1997–2007). Knowledge-based assets refer to design and economic competencies such as brand, organizational structure, and firm-specific employee training. ICT-producing industries and outlier industry pairs are not plotted. Outlier industries include apparel, leather and allied product manufacturing, securities, commodity contracts and investments, rental and leasing services and lessors of intangible assets, and management of companies.
Sources: The Conference Board for SPINTAN (EU FP7 project under grant agreement No. 612774); INTAN-Invest; and elaboration of data from the US Bureau of Economic Analysis

rise of KBA and ICT services intensities between 1997-2007 and 2008-2013 (Chart 6). While correlation is no proof of cause, it is plausible to assume that the increase in knowledge-based assets works in tandem with ICT services for producer innovation, as it repeats historical patterns that have been well documented for the Old Digital Economy in relation to ICT capital (Corrado *et al.*, 2014).

From the Installation Phase to the Deployment Phase of the New Digital Economy

This article argues that one paradox of the New Digital Economy as yet remains unresolved: as the economy seems to be digitizing at an unprecedented pace, why are we not seeing much faster economic growth and productivity increases? Why are many businesses not seeing a major impact from digital technology on revenue and profits, while some seem to be running ahead of everyone else? Why have not wages

Figure 1
Installation Phase versus Deployment Phase in the New Digital Economy

Source: Based on Carlota Perez, Technological Revolution and Financial Capital: The Dynamics of Bubbles and Golden Ages (Cheltenham, United Kingdom: Edward Elgar Publishing Limited), 2002.

gone up faster, especially for high-skilled workers who are in great demand?

Are we at the doorstep of a new transformative era for business that can lead to explosive growth due to the latest trends in digitization? Or could it be that the effects of the New Digital Economy will be less dramatic than expected and unable to reverse the current sluggish growth path?

Using a typical lifecycle model of innovation and based on historical experiences, one can distinguish between the "installation phase" and the "deployment phase" in any new general purpose technology, as shown in Figure 1.[9] The installation phase is characterized by a much greater interest in the new technology as early application cases emerge. Research and development and other innovation expenses are increasing as organizations access new ICT assets and services to develop product and service innovations. Typically first movers, whether these are particular companies, sectors, or industries, move ahead of their followers in terms of adoption of the technology and the speed with which they see results in the form of productivity gains or new products and services. The success cases during the installation phase often represent the so-called mushroom effects scattered around in a field with companies failing as well as many organizations and sectors that remain unaffected (Harberger, 1998). Toward the end of the installation phase, an economy often experiences a period of frenzy, with expectations overshooting the potential for growth, followed by a bubble burst. This frenzy period can often provide a cleanup of overinvestment, followed by the deployment phase. During this phase the technology will play out as a true General Pur-

9 For a detailed review of the concepts of installation and deployment phases in technology as well as how one period evolves into the other - often interrupted by a frenzy period and a crisis - including an historical review, see Perez (2002). For a recent application, see Neumann (2015).

pose Technology (GPT) in all its aspects: ubiquitous use and widespread adaptation of technology in multiple applications, and significant real cost reductions leading to lower prices as well as market scale for the new products and services.

This article has argued that there are good reasons to believe that the New Digital Economy is still in the installation phase producing only random and localized gains in productivity in certain industries and geographies. And while increases in knowledge-based assets in selected industries are positively related to the shift toward greater use of ICT services, there are no signs as yet that collectively they have contributed to productivity growth.

One can possibly draw an historical parallel between the current situation of weak productivity growth and rapid technological change and the first half of the 1990s, when these two phenomena were also observed. The term 'productivity paradox'was coined to describe this earlier situation, which resolved itself with a spurt of ICT-fueled productivity growth between 1995 and 2004 (van Ark *et al.*, 2003). History may repeat itself.

This raises the question as to where, when, and how the benefits of the New Digital Economy will play out. In other words, with regard to the rapid technological change-slow growth conundrum, ultimately something will have to give. One possibility is that the large efforts made through business investment and spending are not going to pay off in terms of much more revenue growth, especially if aggregate demand and investment remain weak sources of growth. While there will still be opportunities for growth from the New Digital Economy, they may be much narrower in scale or scope than often assumed and the returns on the aggregate investment may be lower. Also some of the gains may more likely arise from digitally-based improvements in business processes and higher productivity, leading to tangible cost reductions, rather than from higher revenue growth.

The other possibility is that economic growth, and especially productivity growth, will eventually become much stronger as businesses double down on making the technologies work better despite some headwinds, by focusing on the revenue opportunities that will likely arise. Some headwinds to digital transformation may arise from a non-conducive business environment, including unfavorable regulatory policies, a lack of skilled workers, or difficulties in obtaining funding for startups or small enterprises who aim to develop new innovations in the New Digital Economy. But they may also come from challenges within the firm, such as the ability to effectively combine new technologies with human capital and critical knowledge-based assets.

While we do not expect large aggregate growth effects from the New Digital Economy any time soon, our analysis suggests that even in a slow growth environment there are significant benefits in terms of productivity growth provided companies and economies focus on the following (van Ark *et al.* 2016):

- Take advantage of ongoing rapid price declines in information and communication technology (ICT) assets and services to obtain significant cost reductions;
- Leverage the shift from investment in ICT assets to purchased digital services to increase firms' flexibility in raising productivity and speeding up the bringing to market of new products and services;
- Create key knowledge-based assets (product and services design, workforce training, and organizational improvements) to strengthen innovative capabilities;
- Assess and manage different degrees of talent shortages among digital workers and tech-savvy workers;

- Utilize local innovation ecosystems by taking advantage of access to talent, partnerships, and shared services; and,
- Create agility and resiliency to anticipate and respond to the disruptive impact of new technology.

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The Industry Origins of Canada's Weaker Labour Productivity Performance and the Role of Structural Adjustment in the Post-2000 Period

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Abstract

This article examines how much of the slowdown in labour productivity growth observed in Canada's business sector after 2000 was due to weaker productivity growth within industries and how much was due to structural adjustment. The analysis makes use of a decomposition method that differs from many of the standard decomposition approaches commonly found in the literature and allows for the contributions of changes in the importance of individual industries to be calculated. The approach reveals that the post-2000 slowdown was attributable entirely to weaker productivity growth within industries and that structural adjustment had a slight mitigating effect on the slowdown. Lower productivity growth within three industries - manufacturing; finance, insurance and real estate; and mining, oil and gas - accounted for all of the slowdown in business sector labour productivity growth in the 2000s.

During the period from 2000 to 2014 (referred to hereinafter as "the 2000s"), Canada's business sector labour productivity growth slowed to a compound annual rate of 1.00 per cent, from 1.81 per cent in the 1990s (1989 to 2000). Canada's weaker productivity performance in the 2000s contrasts with the performance of the U.S. business sector. Business sector productivity growth in the United States fell slightly between the two periods, decreasing from a compound annual rate of 2.23 per cent in the 1990s to 1.98 per cent in the 2000s, a pace nearly two times faster than that observed in Canada.[2] Changes in productivity have an

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2 The use of the 2000-2014 period obscures the slowdown in U.S. productivity growth which began in the mid-2000s. After recording compound annual growth of 3.1 per cent from 1995 to 2005, U.S. business sector labour productivity growth slowed to 1.3 per cent from 2005 to 2014.

impact on the standard of living of Canadians. Average wages (after adjusting for inflation) typically grow at roughly the same pace as labour productivity (Baldwin *et al.*, 2014, Chart 2). While other factors, such as increased labour force participation and improved terms of trade, also contribute to growth in living standards, labour productivity is the key driver of real gross domestic income growth in the long run. [3]

To better understand the nature of Canada's productivity growth slowdown between the 1990s and the 2000s, the different ways in which industries contribute to the growth of labour productivity in Canada's business sector will be examined. Productivity growth for the business sector is separated into two distinct components: a direct productivity growth effect and the effect of the changing relative importance of different industries, referred to as structural adjustment.

The first component, the direct productivity growth effect (sometimes referred to as the 'pure,' or 'within-industry,' effect) captures the impact of changes in an industry's labour productivity (measured as real value added per hour worked) while holding constant the relative importance of all industries. This component captures the effect of the change in productivity occurring within each industry.

The second component, structural adjustment, captures the impact on aggregate productivity growth of the reallocation of labour across industries. Reallocation occurs as a result of many forces. In the 2000s, Canada faced an appreciation of its currency, particularly against the U.S. dollar, increasing competition from emerging economies, rising commodity prices, and relatively weak U.S. demand for Canadian exports. These forces benefited some industries while others were adversely affected. For example, the manufacturing sector saw its share of labour (measured as hours worked in the business sector) decline from 21.1 per cent in 1989 to 18.5 per cent in 2000. The sector's secular decline intensified in the 2000s as its labour share declined every year after 2000, reaching a low of 12.1 per cent in 2014. On the other hand, the share of labour in construction, which benefited from the natural-resource and housing boom as well as from low interest rates, increased from 8.1 per cent in 2000 to 12.3 per cent in 2014, after declining for most of the 1990s.

Separating aggregate productivity growth into these two components allows analysts to focus on each in isolation from the other. The examination of the sources of direct productivity growth permits an assessment of whether the productivity slowdown was widespread - and therefore perhaps endemic - or whether it came from specific sectors and therefore might be explained by specific circumstances. At the same time, the examination of the structural adjustment component allows a determination of the extent to which the overall slowdown in productivity growth came not from the performance of specific industries but from industrial restructuring.

To that end, the approach to decomposing aggregate labour productivity developed here reveals that measuring the impact of structural adjustment within one industry cannot be done without considering the effect of the structural adjustment in other industries. The interdependencies of structural adjustment across industries have typically been overlooked in studies that have attempted to assess industry contributions to aggregate labour productivity. In filling this gap, this study lays the groundwork for further debate on the nature of structural adjust-

3 Increases in the terms of trade in the 2000s offset the weakness in productivity growth during this period (Baldwin *et al.* 2014, Chart 12).

ment: how to better measure it and how to better understand its impact on aggregate labour productivity.

The article contains five sections. The first section provides the analytical framework for the decomposition of aggregate labour productivity growth into direct and structural adjustment effects. Section two presents the industry impacts of the direct labour productivity effect and section three presents the structural adjustment effects. In the fourth section, the combined impact of the direct and structural adjustment effects are given. The fifth and final section concludes.

Analytical Framework

Several studies, including those by Nordhaus (2001) and Stiroh (2002) for the United States, and Tang and Wang (2004) and Sharpe (2010) for Canada, have used different methodologies to decompose aggregate labour productivity growth into a direct productivity growth effect and a structural adjustment effect. As de Avillez (2012) pointed out, the variation between methods provides complementary, rather than competing, stories as they tend to produce similar results for most industries.[4] Stiroh's (2002) approach, represented in Equation (1), is chosen here to begin, for two reasons: it has been widely used in the literature; and it is relatively easy to interpret since it neatly decomposes aggregate labour productivity growth by industry into the direct productivity growth effect and structural adjustment.[5] By comparison, the approaches followed by Nordhaus (2001), Tang and Wang (2004) and de Avillez (2012) are made more complex by the fact that they have included an interaction term, the interpretation of which is seldom agreed upon (Balk, 2014 and Reinsdorf, 2015).

$$\Delta ln\left(\frac{Y_t}{H_t}\right) = \Sigma_{i=1}^{N}\left[\bar{S}_{i,t}^{VA}\ \Delta ln(Y_{i,t}/H_{i,t}) + \bar{S}_{i,t}^{VA}\ \Delta ln\left(\frac{H_{i,t}}{H_t}\right)\right] \quad (1)$$

The left-hand side of Equation (1) is the per cent change in aggregate labour productivity growth expressed as the change in the logarithmic value (Δln) of real value added (Y) per hour worked (H) for a given period of time (t). On the right-hand side, the first term in square brackets represents industry *i*'s contribution to aggregate productivity from the direct productivity growth effect, and the second term is a measure of industry *i*'s contribution that comes from structural adjustment. By construction, these two terms equal aggregate productivity growth when summed across all industries. The direct productivity growth effect for industry *i* is calculated by multiplying the industry's weight in terms of nominal value added ($\bar{S}_{i,t}^{VA}$) by the per cent change in its labour productivity ($\Delta ln(Y_t/H_t)$). The contribution from structural adjustment for industry *i* is calculated as the industry's weight multiplied by the per cent change in its labour share ($\Delta ln(H_{i,t}/H_t)$), which is expressed as the growth in the ratio of industry *i*'s hours worked to the hours worked in the aggregate sector. Stiroh (2002) calculated industry weights as the share of industry *i*'s nominal value added (VA) in the aggregate sector aver-

4 There are exceptions. Reinsdorf (2015) found large differences in the contributions to Canadian aggregate business sector labour productivity growth from mining, oil and gas, construction and manufacturing in a comparison of the Tang and Wang (2004) method-referred to as the generalized exactly additive decomposition or GEAD-and the CSLS method from Sharpe (2010). These differences were due to the role of price effects in the GEAD methodology. Total contributions from other industries were similar.

5 This equation provides an approximation, which results from the use of logarithmic differences to approximate the growth rates in question.

aged over the current and previous periods, *t* and *t-1*, respectively, as represented in Equation (2).

$$\bar{S}_{i,t}^{VA} = \frac{(VA_{i,t-1}/VA_{t-1} + VA_{i,t}/VA_t)}{2} \qquad (2)$$

An increase (decrease) in productivity of an industry leads directly to a larger (smaller) direct productivity growth effect in absolute terms. The size of the effect is in direct proportion to its share of nominal value added, which in turn is determined by the size of its labour share and the level of its nominal value added per hour worked.

The calculation of the impact of a change in the importance of an industry is more complex. If an industry's labour share increases (decreases), its contribution to aggregate productivity will also increase (decrease) - as shown in the second term in square brackets in Equation (1). As with the direct productivity growth component, an industry's contribution from structural adjustment will be larger when the industry has a relatively larger share of aggregate nominal value-added.

There is, however, an important difference in how the impact of a change in a particular industry's importance needs to be assessed. For the direct productivity growth effect, a change in one industry's labour productivity does not change the productivity of any other industry. Thus, the impact of one industry can be estimated independently of the effect of another industry. In this case, productivity growth among industries is not a zero-sum game, in which one industry's gain is another's loss.

In contrast, measuring structural adjustment is based on the reality that labour shares for all industries sum to one (or 100 per cent); therefore, an increase in the labour share of one industry must be offset by a decrease of the exact same magnitude in one or more other industries. Note that the second term in square brackets of Equation (1) accounts only for the structural adjustment that occurs in a single industry (industry i) when, for instance, its labour share increases. This term does not capture the decline in the labour shares of the other industries that must accompany this increase. The effect on all other industries of one industry growing in relative terms is effectively treated as zero; this causes the individual industry structural adjustment effect, when measured independently, to be incorrectly estimated. For this reason, many studies that use this decomposition refer only to the aggregate structural effect derived as the sum of all industry effects; they do not refer to individual industry structural effects.

The production of accurate single industry estimates that take into account interdependencies across industries requires the stipulation of where the labour share gains (losses) come from; that is, a counterfactual.[6] The counterfactual assumes that the labour share gain (loss) for an industry comes from (is distributed to) all other industries in proportion to their hours worked at the beginning of the period - a result that would be generated by a stochastic process that presumes the labour share of all other industries has the same probability of being shifted to the industry in question. This can be referred to as a "stochastic" counterfactual and this counterfactual implies that, without the share change in industry *i*, there would have been no change in the relative share of any industry.[7] For illustration, an alternative "gainers-versus-losers"

6 Denison (1979, Chapter 5) is one of the few that have calculated the structural effect explicitly and expressed the need for a counterfactual. More recent discussions can be found in Baldwin and Gu (2006). The directionality of these changes can be estimated in some cases (Baldwin and Rafiquzzaman, 1995). This was not attempted here. The CSLS decomposition in de Avillez (2012) does have a counterfactual interpretation of interdependencies across industries but does not directly measure them.

counterfactual, in which industries that gain labour share do so directly from those that lose labour share in a given year, is described in Appendix A.

The effect of inter-industry structural adjustment using the above assumptions is measured by means of a modified version of the Stiroh formula, that is:

$$\Delta ln\left(\frac{Y_t}{H_t}\right) = \Sigma^{N}_{i=1}\left[\bar{S}^{VA}{}_{i,t}\Delta ln\left(\frac{Y_{i,t}}{H_{i,t}}\right) + \bar{S}^{VA}{}_{i,t}\Delta ln\left(\frac{H_{i,t}}{H_t}\right) + \Sigma^{N}_{j=1,j\neq i}\bar{S}^{VA}{}_{j,t}\left(ln\left(\frac{H^{i}{}_{j,t}}{H_t}\right) - ln\left(\frac{H_{j,t-1}}{H_{t-1}}\right)\right)\right] \quad (3)$$

where the first term on the right-hand side in square brackets is the direct productivity growth effect, as in Equation (1). The second term in square brackets is the own-industry structural adjustment term, which is also unchanged from Equation (1). This term does not in any way capture how labour shares in other industries change in response to the change in industry *i*'s labour share. The third term on the right-hand side in square brackets measures the inter-industry structural adjustment. It is the additional term that accounts for the corresponding change in all other industries' labour shares and is calculated as the log difference between the counterfactual labour share for industry *j* in period t and the actual labour share of industry *j* in period t-1. The counterfactual labour share term for each of the other j industries is defined as

$$\frac{H^{i}_{j}}{H_{t-1}} = \frac{H_{j,t-1}}{H_{t-1}} - \left(\frac{H_{i,t}}{H_t} - \frac{H_{i,t-1}}{H_{t-1}}\right)\left(\frac{H_{j,t-1}}{(H_{t-1} - H_{i,t-1})}\right) \quad (4)$$

where H^{i}_{j}/H_{t-1} equals the actual labour share of industry j in period t-1 ($H_{j,t-1}/H_{t-1}$) minus the proportion of the change in the labour share of industry *i* ($H_{i,t}/H_t - H_{i,t-1}/H_{t-1}$) that is reallocated to or drawn from industry *j* based on its relative size among all *j* industries ($H_{j,t-1}/(H_{t-1} - H_{i,t-1})$), which excludes industry *i*.

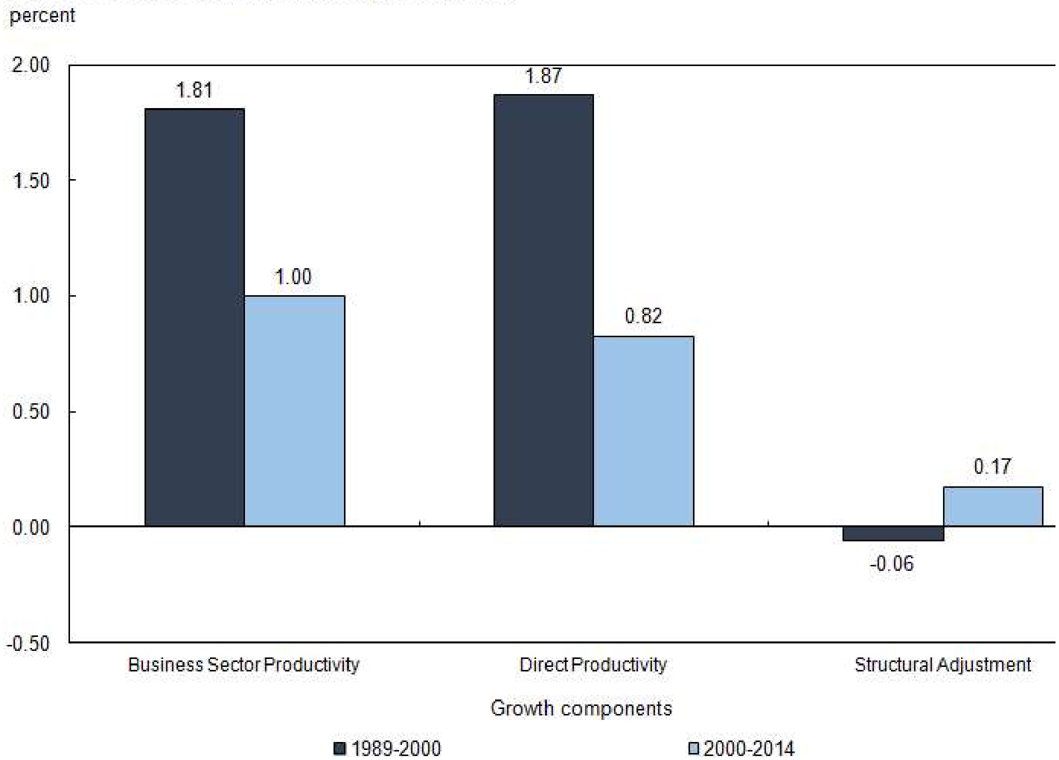
The sum of the inter-industry structural adjustment terms in the other j industries measures the impact of the offsetting labour share decline (increase) when the labour share of industry i increases (decreases). This sum constitutes the required changes in the labour shares of other industries that occur in response to a change in any particular industry's labour share. Inclusion of this term is required to measure the full impact of a change in the relative importance of a particular industry. Simultaneous consideration of the own-industry and inter-industry structural terms has the effect of producing a more complete measure of the total structural adjustment that should be attributed to any one industry.[8] However, it does not change the estimate of the overall impact of structural adjustment across all industries because the inter-industry terms of all industries sum approximately to zero.[9]

7 Shifts in shares of hours worked come from workers moving from one industry to another and from persons joining the workforce. Aggregate productivity may change over time if hours worked in industries grow at different rates; thus, the economy restructures in terms of changing the relative importance of different industries.

8 While the measure produced is more complete, its accuracy depends on the suitability of the counterfactual used to estimate it. In the absence of information on the nature of the replacement process, the chosen assumption was that the replacement follows a general stochastic process.

9 The sum is not exactly zero due to the industry weights in Equation (4), $H_{j,t-1}/(H_{t-1} - H_{i,t-1})$. These weights are used to reallocate the change in industry *i*'s labour share to all other industries. It would be more mathematically accurate to reallocate the change to all industries including industry i in proportion to their hours worked in period t-1. However, there is little economic rationale to an industry reallocating labour share to itself. Distributing the change in industry *i* 's labour share to all industries in equal proportion, regardless of an industry's relative size, is also counterintuitive.

Chart 1
Components of Business Sector Labour Productivity Growth in Canada, 1989-2000 and 2000-2014 (compound annual growth rates)



Note: Business sector productivity growth is the sum of direct productivity growth and structural adjustment, although the sum of the figures may not correspond to the totals shown because of rounding.
Source: Statistics Canada, authors' calculations based on data from CANSIM Table 383-0021.

The Industry Impacts of the Direct Labour Productivity Growth

Estimates of differences in both the aggregate direct productivity growth component and the aggregate structural adjustment component between the 1990s and the 2000s reveal that the origins of the slowdown in Canada's aggregate business sector productivity growth are associated mostly with overall direct productivity growth effects rather than with the overall impact of structural adjustment.[10]

In the 1990s, business sector labour productivity growth came largely from the positive impact of the aggregate direct productivity growth component (1.87 per cent per year), which was slightly offset by the aggregate structural adjustment component (-0.06 per cent) (Chart 1). By comparison, in the 2000s the average aggregate direct productivity growth component (0.82 per cent per year) and the aggregate structural adjustment component (0.17 per cent) were both positive. In the 1990s, the direct effect contributed all of the growth in labour productivity. In the 2000s, the direct

10 The data used here are taken from Statistics Canada's productivity accounts database, which provides an integrated set of industry accounts containing data on real output and labour measured as hours worked. The data on real value added are Fisher-chain-linked indices from CANSIM Table 383-0021. This table includes annual data from 1961 to 2014 though only data from 1989 to 2014 were used in this study. The table also provides information on labour compensation and the cost of capital services. The growth rate of the sum of these two variables was used to extend the nominal GDP series, which currently only includes data to 2012.

Table 1
Business Sector and Industry Labour Productivity Growth in Canada, 1989-2000 and 2000-2014 (compound annual growth rate)

	1989-2000	2000-2014	Difference
	percent		percentage points
Business sector	1.81	1.00	-0.81
Industry[1]			
Agriculture, forestry, fishing and hunting	3.62	3.55	-0.08
Mining and oil and gas extraction	2.32	-2.72	-5.04
Utilities	1.42	0.13	-1.29
Construction	0.00	-0.06	-0.07
Manufacturing	3.57	1.35	-2.22
Wholesale trade	2.14	3.22	1.08
Retail trade	2.28	1.99	-0.29
Transport and warehousing	1.81	0.97	-0.83
Information and cultural industries	1.48	2.00	0.52
Finance, insurance, real estate and renting and leasing	2.35	1.36	-1.00
Professional, scientific and technical services	0.56	1.03	0.47
Administrative and support, waste management and remediation services	-0.12	0.29	0.41
Arts, entertainment and recreation	-1.50	0.07	1.57
Accommodation and food services	-0.40	0.47	0.88
Other private services	-0.44	0.92	1.35

1. Industry is defined by the 2-digit North American Industry Classification System (NAICS) 2007 code.

Note: The sum of the figures may not correspond to the totals shown because of rounding.

Source: Statistics Canada, authors' calculations based on data from CANSIM Table 383-0021.

term accounted for 82 per cent of the growth in productivity.

The aggregate direct productivity growth component fell more than a full percentage point between the 1990s to the 2000s from 1.87 per cent to 0.82 per cent. In contrast, the impact of the aggregate structural adjustment contribution increased 0.23 percentage points. This change in the contribution of structural adjustment, turning from negative in the 1990s to positive in the 2000s, helped mitigate the overall slowdown resulting from weaker direct productivity growth in some industries.

Taking note of the individual industry productivity growth rates and changes in labour shares provides important context for estimating the impact of individual industries on the aggregate direct effect term. Table 1 shows the changes in productivity growth at the industry level over the two periods. The largest declines between the two periods (in descending order) occurred in mining, oil and gas; manufacturing; utilities; and finance, insurance and real estate. Some of the largest improvements in the 2000s occurred in the industries that had the poorest performance in the 1990s (arts and entertainment; other private services; and accommodation and food), although these industries continued to perform poorly in the 2000s compared with the business sector as a whole.

The mining, oil and gas sector recorded a compound annual 2.72 per cent decline in labour productivity in the 2000s. It was the only industry that exhibited a large decline in labour productivity in the 2000s.[11] Labour productivity in the other industries examined grew at an average rate

Table 2
Contributions to Business Sector Labour Productivity Growth from the Direct Labour Productivity Effect in 1989-2000 and 2000-2014 (percentage points per year)

	1989-2000	2000-2014	Difference
	percentage points		
Business sector	1.87	0.82	-1.04
Industry[1]			
Agriculture, forestry, fishing and hunting	0.11	0.08	-0.03
Mining and oil and gas extraction	0.10	-0.30	-0.40
Utilities	0.06	0.00	-0.06
Construction	-0.01	-0.02	-0.01
Manufacturing	0.80	0.22	-0.57
Wholesale trade	0.15	0.22	0.08
Retail trade	0.15	0.13	-0.01
Transport and warehousing	0.10	0.05	-0.05
Information and cultural industries	0.06	0.08	0.02
Finance, insurance, real estate and renting and leasing	0.37	0.21	-0.16
Professional, scientific and technical services	0.04	0.07	0.03
Administrative and support, waste management and remediation services	0.00	0.01	0.01
Arts, entertainment and recreation	-0.01	0.00	0.01
Accommodation and food services	-0.02	0.01	0.03
Other private services	-0.03	0.05	0.07

1. Industry is defined by the 2-digit North American Industry Classification System (NAICS) 2007 code.

Note: The sum of the figures may not correspond to the totals shown because of rounding.

Source: Statistics Canada, authors' calculations based on data from CANSIM Table 383-0021.

of 1.19 per cent per year during this period. As noted, the mining, oil and gas sector had the largest deceleration in labour productivity (-5.04 percentage points) from the compound annual growth rate recorded in the 1990s. Labour productivity growth in mining, oil and gas was faster than in most industries in the 1990s, expanding at an annual pace of 2.32 per cent; by contrast, labour productivity growth was 1.81 per cent in the business sector during the same period.

The strong productivity performance in mining, oil and gas during the 1990s was partly due to a modest increase in hours worked (0.37 per cent annually, while hours worked in the business sector expanded more than four times as fast at an annual pace of 1.26 per cent). Despite limited employment gains, real value added in the mining, oil and gas sector grew at a rate of 2.70 per cent per year in the 1990s, while real value added in the business sector grew at a moderately faster pace (3.06 per cent).

After the mining, oil and gas sector, the next-largest productivity slowdown was observed in manufacturing, where productivity growth decreased 2.22 percentage points, falling from 3.57 per cent annual growth to 1.35 per cent between the two time periods. The utilities and finance, insurance and real estate sectors recorded declines between the periods of 1.29 and 1.00 percentage points, respectively.

An examination of the productivity growth rates by industry alone suggests that the mining,

11 See Bradley and Sharpe (2009) and Sharpe and Waslander (2014) for an extensive discussions of the oil and gas sector's productivity performance over the 1990s and 2000s.

Table 3

Shares of Hours Worked, Shares of Nominal Value Added and Labour Productivity

	Shares of hours worked			Shares of nominal value added			Labour productivity		
	1990-2000	2001-2014	Difference	1990-2000	2001-2014	Difference	1989	2000	2014
	percent		percentage points	percent		percentage points	$/hour worked (chained 2007 dollars)		
Business sector	100.00	100.00	0.00	100.00	100.00	0.00	35.78	41.92	50.04
Industry[1]									
Agriculture, forestry, fishing and hunting	5.47	3.33	-2.14	3.17	2.23	-0.95	14.49	19.82	34.89
Mining and oil and gas extraction	1.46	1.85	0.39	5.43	9.85	4.42	284.69	388.57	249.07
Utilities	0.91	0.81	-0.11	4.17	3.09	-1.08	157.76	182.08	187.60
Construction	8.74	10.18	1.43	8.15	8.86	0.70	41.41	40.14	41.04
Manufacturing	18.73	14.75	-3.99	22.70	17.58	-5.12	33.07	46.30	58.69
Wholesale trade	6.83	6.72	-0.10	6.89	7.01	0.11	30.70	37.83	60.45
Retail trade	12.97	12.68	-0.29	6.72	6.74	0.02	16.56	20.11	27.94
Transport and warehousing	6.00	6.18	0.18	5.67	5.54	-0.13	31.31	37.00	43.68
Information and cultural industries	2.20	2.38	0.17	4.30	4.17	-0.14	55.64	62.75	86.31
Finance, insurance, real estate and renting and leasing	9.09	9.40	0.31	15.32	15.25	-0.07	53.00	69.00	82.67
Professional, scientific and technical services	5.91	7.57	1.66	5.36	6.95	1.59	36.41	37.18	44.69
Administrative and support, waste management and remediation services	4.19	6.01	1.82	2.66	3.51	0.86	26.96	26.41	27.68
Arts, entertainment and recreation	1.39	1.78	0.40	0.84	0.94	0.10	29.05	24.23	24.82
Accommodation and food services	7.31	7.27	-0.04	3.25	2.77	-0.49	18.18	16.72	18.58
Other private services	8.78	9.09	0.30	5.36	5.52	0.16	27.25	25.30	29.51

1. Industry is defined by the 2-digit North American Industry Classification System (NAICS) 2007 code.

Note: The sum of the figures may not correspond to the totals shown because of rounding.

Source: Statistics Canada, authors' calculations based on data from CANSIM Table 383-0021.

oil and gas sector was the key source of Canada's productivity slowdown. However, when the relative size of industries is taken into account, the industry origins and direct contribution to the slowdown across mining, oil and gas, manufacturing, and finance, insurance and real estate converge, while the slowdown for utilities and transportation and warehousing become comparatively minor (Table 2). The increased similarity, especially between mining, oil and gas and manufacturing, reflects the fact that nominal value added (which serves as weights) in the mining, oil and gas sector is just over half the size of that in manufacturing and roughly two-thirds as large as that in finance, insurance and real estate on average over the period from 2000 to 2014. When industry weights are taken into account, the contribution from direct productivity growth in these three industries accounted for 0.57, 0.40, 0.16 percentage points, respectively, of the decline of 1.04 percentage points in business sector productivity growth between the two periods.

The Importance of Labour Share and Total Structural Adjustment by Industry in the 1990s and the 2000s

Table 3 shows the restructuring that affected the relative importance of industries between the 1990s and the 2000s. The manufacturing sector experienced the largest absolute change in labour share, falling from an average of 18.7 per cent to 14.8 per cent (a 21 per cent decline). Large proportionate changes occurred in administration and waste management (43 per cent) and agriculture, forestry and fishing (-39 per cent). Other industries that experienced large absolute changes in labour shares include professional, scientific and technical services and construction. Even though the mining, oil and gas sector had a 27 per cent gain in its labour share, the increase in absolute terms from 1.46 per cent to 1.85 per cent was small compared to that of other industries.

The relationship between the changes in an industry's labour share and whether its productivity level is higher or lower than that of the business sector has important implications for structural adjustment. The intuition that underlies that relationship is presented in Sharpe and Thomson (2010) as follows: an industry that experiences an increase in labour share over a given period will exhibit a corresponding positive total structural adjustment effect if that industry's labour productivity level is above average (that is, above that of the business sector) or a negative total structural adjustment effect if its labour productivity level is below average. Conversely, an industry that experiences a decrease in labour share over a given period will exhibit a corresponding negative total structural adjustment effect if that industry's labour productivity level is above average or a positive total structural adjustment effect if its labour productivity level is below average.[12]

Total structural adjustment is estimated as the sum of two terms. The first term is own-industry structural adjustment as measured by the second term on the right-hand sides of both Equation (1) and Equation (3). However, as noted earlier, the own-industry term for an individual industry is only a partial measure of the impact of a change in labour share of that industry on structural adjustment. Interpreting the own-industry term as an industry's impact on total structural adjustment is misleading since it is a partial derivative. What is required is the equivalent of a total derivative.[13] It is only once the impact of interdependencies associated with labour reallocation across industries - what is referred to here as the inter-industry structural adjustment term - is added to the own-industry term that the total impact of an industry-level structural adjustment can be estimated.[14]

A comparison of the inter-industry and own-industry terms for select industries reveals the size of the potential error from not taking into

12 The CSLS decomposition methodology (Sharpe and Thomson, 2010; Reinsdorf, 2015) uses the difference between the average productivity level and a given industry's productivity level to isolate a "reallocation level effect" and a "reallocation growth effect" to adjust the calculation of industry contributions to aggregate labour productivity growth for labour share changes. The CSLS decomposition methodology implicitly captures the inter-industry effect as a part of its reallocation level effect which is similar to the total structural adjustment effect in this article. For more details, see Appendix B.

13 Stiroh (2002) reported only aggregate values for structural adjustment and did not report any at the industry level, though it has become common to do so since.

14 A variation of the counterfactual used here was also considered – where the sum of the labour share gains across industries was proportionately distributed only to the industries that lost labour share rather than to all industries. Using this counterfactual did not substantially change the findings about which three industries played the largest role or the findings on industries' relative importance in the 2000s productivity growth slowdown. For results, see Appendix A.

Table 4
Own-Industry and Inter-Industry Components of Structural Adjustment in the Canadian Business Sector, 1989-2000 and 2000-2014 (annual percentage point contribution)

	Own-Industry			Inter-Industry		
	1989-2000	2000-2014	Difference	1989-2000	2000-2014	Difference
percentage points						
Business sector	-0.06	0.19	0.24	0.00	-0.01	-0.01
Industry[1]						
Agriculture, forestry, fishing and hunting	-0.09	-0.07	0.02	0.16	0.11	-0.05
Mining and oil and gas extraction	-0.03	0.37	0.39	0.01	-0.06	-0.07
Utilities	-0.06	0.00	0.06	0.01	0.00	-0.01
Construction	-0.16	0.27	0.42	0.17	-0.30	-0.47
Manufacturing	-0.26	-0.53	-0.27	0.23	0.44	0.21
Wholesale trade	0.08	-0.06	-0.13	-0.07	0.05	0.13
Retail trade	-0.02	0.01	0.04	0.06	-0.03	-0.08
Transport and warehousing	0.03	0.01	-0.03	-0.04	-0.01	0.03
Information and cultural industries	0.08	-0.02	-0.10	-0.04	0.01	0.05
Finance, insurance, real estate and renting and leasing	0.03	0.08	0.05	-0.02	-0.04	-0.03
Professional, scientific and technical services	0.18	0.05	-0.14	-0.20	-0.05	0.15
Administrative and support, waste management and remediation services	0.07	0.06	-0.02	-0.12	-0.10	0.02
Arts, entertainment and recreation	0.03	0.00	-0.02	-0.04	0.00	0.04
Accommodation and food services	0.01	0.00	-0.01	-0.02	0.00	0.02
Other private services	0.06	0.02	-0.04	-0.09	-0.03	0.05

1. Industry is defined by the 2-digit North American Industry Classification System (NAICS) 2007 code.

Note: The sum of the figures may not correspond to the totals shown because of rounding.

Source: Statistics Canada, authors' calculations based on data from CANSIM Table 383-0021.

account the interdependencies (Table 4). A large adjustment is required for the manufacturing sector. The own-industry component suggests that, in the 2000s, manufacturing's structural adjustment effect subtracted over half a percentage point from business sector productivity growth. However, using only this component to measure the total impact of increasing manufacturing's share is misleading since the manufacturing sector's inter-industry component has the opposite sign, and at 0.44 percentage points is nearly as large. The total structural adjustment is the sum of these two terms (own-industry and inter-industry), was -0.08 percentage points in the 2000s (Table 5).This suggests that total structural adjustment for the manufacturing sector subtracted very little from productivity growth in the business sector and reflects the fact that the manufacturing sector's level of labour productivity in the 2000s was only moderately higher than the average for the business sector. Therefore, a large amount of structural adjustment, as occurred in manufacturing, does not necessarily translate into a large change in aggregate labour productivity.[15]

15 For a discussion of the relationship between the productivity levels of industries and structural adjustment see Appendix B.

Table 5
Contributions to Business Sector Labour Productivity Growth from the Direct Labour Productivity Growth and Total Structural Adjustment Effects, 1989-2000 and 2000-2014 (percentage points per year)

	Direct productivity effect			Total structural adjustment			Total contribution		
	1989-2000	2000-2014	Difference	1989-2000	2000-2014	Difference	1989-2000	2000-2014	Difference
percentage points									
Business sector	1.87	0.82	-1.04	-0.06	0.17	0.23	1.81	1.00	-0.81
Industry[1]									
Agriculture, forestry, fishing and hunting	0.11	0.08	-0.03	0.07	0.04	-0.03	0.17	0.12	-0.06
Mining and oil and gas extraction	0.10	-0.30	-0.40	-0.01	0.31	0.32	0.09	0.01	-0.08
Utilities	0.06	0.00	-0.06	-0.05	0.00	0.05	0.01	0.00	-0.01
Construction	-0.01	-0.02	-0.01	0.01	-0.04	-0.05	0.00	-0.06	-0.06
Manufacturing	0.80	0.22	-0.57	-0.03	-0.08	-0.06	0.77	0.14	-0.63
Wholesale trade	0.15	0.22	0.08	0.00	0.00	0.00	0.15	0.22	0.07
Retail trade	0.15	0.13	-0.01	0.03	-0.01	-0.04	0.18	0.12	-0.06
Transport and warehousing	0.10	0.05	-0.05	0.00	0.00	0.00	0.10	0.05	-0.05
Information and cultural industries	0.06	0.08	0.02	0.04	-0.01	-0.05	0.10	0.07	-0.03
Finance, insurance, real estate and renting and leasing	0.37	0.21	-0.16	0.01	0.03	0.03	0.37	0.24	-0.13
Professional, scientific and technical services	0.04	0.07	0.03	-0.02	-0.01	0.01	0.02	0.06	0.05
Administrative and support, waste management and remediation services	0.00	0.01	0.01	-0.04	-0.04	0.00	-0.05	-0.03	0.02
Arts, entertainment and recreation	-0.01	0.00	0.01	-0.02	0.00	0.02	-0.03	0.00	0.03
Accommodation and food services	-0.02	0.01	0.03	-0.01	0.00	0.01	-0.03	0.01	0.04
Other private services	-0.03	0.05	0.07	-0.03	-0.01	0.02	-0.06	0.04	0.09

1. Industry is defined by the 2-digit North American Industry Classification System (NAICS) 2007 code.

Note: The sums and differences of the figures may not correspond to the totals shown because of rounding.

Source: Statistics Canada, authors' calculations based on data from CANSIM Table 383-0021.

Like the manufacturing sector, agriculture, forestry and fishing - a low-productivity level industry - lost labour share in the 2000s. The large inter-industry component (0.11 percentage points) more than offset the own-industry component (-0.07 percentage points) for this sector. The relative reallocation of labour away from this low-productivity level industry to other industries that, on average, had higher productivity produced an overall positive contribution from total structural adjustment of 0.04 percentage points to business sector productivity growth.

The industries that gained labour share also had offsetting own-industry and inter-industry terms. For example, mining, oil and gas gained labour share and had a large positive own-industry structural term (0.37 percentage points) in the 2000s. This gain came from comparatively lower-productivity level industries, resulting in a much smaller inter-industry effect of -0.06 percentage points. The two terms summed to a positive total structural effect of 0.31 percentage points.

Finance, insurance and real estate also gained labour share over this period and had a positive own-industry structural impact (0.08 percentage points). As was the case with mining, oil and gas, the productivity level for finance, insurance and real estate was above the average for the business sector. By assumption of stochastic shifts in labour share, one concludes that gains in this sector came largely from industries with relatively lower productivity levels. Thus, the offsetting impact of the inter-industry adjustment was comparatively small (-0.04 percentage points), and resulted in a positive total structural effect of 0.03 percentage points.

Construction, a low productivity level industry, also had gains in labour share in the 2000s. Its own-industry term was 0.27 percentage points, but its inter-industry term was -0.30 percentage points. Construction's labour-share gain came from industries that on average had higher productivity than it did. This resulted in a negative contribution from total structural adjustment of -0.04 percentage points.

These results reveal that the changes due to structural adjustment attributed to individual industries are smaller in absolute terms than those that would be obtained if only the own-industry term were calculated.

The Combined Impact of Direct Labour Productivity Growth and Total Structural Adjustment from the 1990s to the 2000s

A comparison of direct productivity growth and structural adjustment effects allows an evaluation of the sources of overall productivity growth between the 1990s and the 2000s (Table 5). Several conclusions emerge.

First, the mining, oil and gas sector's negative contribution from its direct productivity growth effect between the two periods (-0.40 percentage points) was largely offset by the positive impact on total structural adjustment (0.32 percentage points) from the growth in the relative importance of this sector, as expressed by its share of labour. The overall contribution of mining, oil and gas added 0.09 percentage points in the 1990s and 0.01 percentage points to business sector productivity growth in the 2000s. The mining, oil and gas sector contributed to the productivity slowdown, but did so to a lesser extent than its direct productivity growth alone might suggest. This sector's contribution from both total structural adjustment and the direct productivity growth effect between the two periods declined 0.08 percentage points, which accounts for 10 per cent of the overall inter-period decline of 0.81 percentage points in business sector labour productivity growth.

Second, total structural adjustment associated with the manufacturing sector's decline had only a marginal impact, subtracting 0.06 percentage points from business sector productivity growth. The direct productivity growth effect, however, had a substantial impact, falling from 0.80 percentage points in the 1990s to 0.22 percentage points in the 2000s. The direct productivity growth effect thus subtracted an additional 0.57 percentage points from business sector productivity growth. The manufacturing sector's contribution from both total structural adjustment and the direct productivity growth effect between the two periods declined 0.63 percentage points, which accounted for 78.3 per cent of the overall inter-period decline in business sector labour productivity growth. The manufacturing sector's contribution from the direct productivity growth effect alone was 71.2 per cent of the decline.

Third, another industry that contributed substantially to the productivity slowdown was the finance, insurance and real estate sector. As was the case with manufacturing, this sector's contribution to direct productivity growth slowed sharply between the two periods, falling from 0.37 percentage points in the 1990s to 0.21 percentage points in the 2000s. It differed from manufacturing, however, in that its increasing labour share made a modest positive contribution from total structural adjustment, rising from 0.01 percentage points in the 1990s to 0.03

percentage points in the 2000s. This sector's contribution from both total structural adjustment and the direct productivity growth effect between the two periods declined 0.13 percentage points, which accounts for 16.6 per cent of the overall inter-period decline in business sector labour productivity growth.[16]

The overall declines in these three industries were partially offset by stronger contributions from six service sector industries: other private services; wholesale trade; professional, science and technical services; arts, entertainment and recreation; and administrative and support, waste management and remediation services. The increases in these sectors' contributions were mostly attributable to stronger direct productivity growth, which raised aggregate labour productivity 0.24 percentage points more than if those industries' contributions had been unchanged.

Conclusion

Canada's productivity performance deteriorated from 1.81 per cent annually in the 1990s to just 1.00 per cent in the 2000s. This article examined the extent to which this slowdown was the result of weaker productivity growth within industries and how much of it was due to the restructuring of the economy as labour shifted between industries characterized by different productivity levels. This analysis reveals the degree to which the slowdown was broadly based across several industries or was more narrowly focused on a select few.

The decline in productivity growth between the 1990s and the 2000s was not widespread. The direct effects of labour productivity growth slowdowns within three industries - manufacturing; mining, oil and gas; and finance, insurance and real estate - accounted for more than 100 per cent of the total decline. The contribution from direct productivity growth in these three industries subtracted 0.57, 0.40, and 0.16 percentage points, respectively, from annual business sector productivity growth between the two periods. The overall decline, therefore, was industry-specific, and explanations for the productivity slowdown need to be sought in the events affecting these sectors.

While changes in industry structure occurred over both decades, restructuring did not contribute materially to lower aggregate productivity growth rates in either period. In the 1990s, all of the gains in business sector labour productivity came from the aggregate annual direct productivity growth component (1.87 per cent), while the aggregate total structural adjustment component (-0.06 per cent) detracted slightly from growth. By comparison, annual direct productivity growth was lower (0.82 per cent) in the 2000s, but structural adjustment was higher and positive (0.17 per cent) during this period and thus attenuated the decline in overall productivity growth.

The 2000s were the period when manufacturing lost a substantial amount of labour share and when mining, oil and gas as well as construction experienced increases in their labour shares.

16 Using data for comparable time periods for the 2000s as defined in Almon and Tang (2011; where the 2000s = 2000 to 2008) and also in Sharpe and Thomson (2010; where the 2000s = 2000 to 2007), the methodology used here produces similar findings related to the impact of total structural adjustment in the mining, oil and gas, manufacturing and finance, insurance and real estate sectors. Both studies as well as this one find that total structural adjustment contributed positively to aggregate labour productivity growth for the mining, oil and gas and finance, insurance and real estate sectors while it subtracted from the contribution of manufacturing – though with large differences in magnitude among the three approaches – in the correspondingly defined 2000s. However, an important caveat in making these sorts of comparisons is that revisions to historical data, especially around the 2008-2009 recession, can significantly influence findings even if the same methodology and time period were examined.

During this time, the resource boom favoured the latter two industries, and the concomitant appreciation of the Canadian dollar, weaker U.S. demand, and increased competition from emerging economies reduced the manufacturing sector's relative performance in export markets and led to excess capacity and a decline in productivity growth in this sector.[17] Changes in the importance of one industry - mining, oil and gas - accounted for more than 100 per cent of the increase in the business sector's total structural adjustment in the 2000s. Declines in the importance of the manufacturing sector had only a small impact on this component due to the fact that its average level of labour productivity in the 2000s was only moderately higher than that of the business sector. Consideration of the effect of declines in productivity growth within individual industries and the effect of changes in their relative importance reveals that manufacturing contributed significantly to the overall decline in productivity growth as a result of its internal slowdown, not on account of its decline in relative importance. The analysis also reveals that the slowdown in productivity growth experienced by mining, oil and gas was largely offset by the increase in the labour share of this sector. The productivity level of this sector - though not its growth - was well above the average. The productivity slowdown in finance, insurance and real estate can be similarly explained - although the offsetting impact of structural adjustment here was small by comparison. In this limited sense, industry restructuring matters for productivity performance; however, in the case of these two sectors, the direct effect of the slowdown in productivity growth within each mattered just as much or more.

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Appendix A: Gains-Versus-Losers Counterfactual Versus Stochastic Counterfactual

The counterfactual used in this study - the "stochastic" counterfactual - distributes labour shares in proportion to the original importance of all industries. An alternative counterfactual- the "gainers-versus-losers" counterfactual-postulates that industries gain labour share at the expense of those that lose labour share in a given year. Consideration of the gainers-versus-losers counterfactual, however, does not change the fundamental conclusions based on the stochastic counterfactual.

A comparison of the results from the two counterfactuals is presented in the table below. Despite the modestly different estimates for inter-industry structural adjustment terms, the gainers-versus-losers counterfactual indicates that manufacturing followed by the mining, oil and gas and the finance, insurance and real estate sectors were the three largest contributors to the business sector labour productivity slowdown in the period from 2000 to 2014.

Appendix Table 1

Inter-Industry Contributions to Labour Productivity Growth in Canada, 1989-2000 and 2000-2014 (percentage points per year)

	Inter-Industry Structural Adjustment					
	1989-2000			2000-2014		
	Stochastic	Gainers versus Losers	Difference	Stochastic	Gainers versus Losers	Difference
Industry[1]						
Agriculture, forestry, fishing and hunting	0.16	0.17	-0.01	0.11	0.10	0.01
Mining and oil and gas extraction	0.01	0.01	0.00	-0.06	-0.05	0.00
Utilities	0.01	0.01	0.00	0.00	0.00	0.00
Construction	0.17	0.17	0.00	-0.30	-0.27	-0.03
Manufacturing	0.23	0.24	0.00	0.44	0.41	0.03
Wholesale trade	-0.07	-0.08	0.00	0.05	0.04	0.01
Retail trade	0.06	0.06	0.00	-0.03	-0.01	-0.02
Transport and warehousing	-0.04	-0.04	0.00	-0.01	0.00	-0.01
Information and cultural industries	-0.04	-0.04	0.00	0.01	0.01	0.00
Finance, insurance, real estate and renting and leasing	-0.02	-0.02	0.00	-0.04	-0.05	0.01
Professional, scientific and technical services	-0.20	-0.20	0.00	-0.05	-0.06	0.00
Administrative and support, waste management and remediation services	-0.12	-0.12	0.00	-0.10	-0.08	-0.01
Arts, entertainment and recreation	-0.04	-0.04	0.00	0.00	0.00	0.00
Accommodation and food services	-0.02	-0.02	0.00	0.00	0.02	-0.02
Other private services	-0.09	-0.08	-0.01	-0.03	-0.03	-0.01

1. Industry is defined by the 2-digit North American Industry Classification System (NAICS) 2007 code.

Note: The sums and differences of the figures may not correspond to the totals shown because of rounding.

Source: Statistics Canada, authors' calculations based on data from CANSIM Table 383-0021.

Appendix B: The Relationship between Total Structural Adjustment and Relative Productivity Levels

The total structural adjustment term, including the the own-industry and inter-industry terms, can be approximated by the "reallocation level effect" term in Sharpe and Thomson (2010). Doing so demonstrates that for a given change in the labour share of an industry, whether total structural adjustment contributes positively or negatively to aggregate labour productivity growth depends on the industry's relative labour productivity level.

To see this most clearly, note that the counterfactual labour share term (Equation 4 in the article) can be written as

$$\frac{H^i_{j,t}}{H_t} = \frac{H_{j,t-1}}{H_{t-1}} - \left(\frac{H_{i,t}}{H_t} - \frac{H_{i,t-1}}{H_{t-1}}\right)\left(\frac{H_{j,t-1}}{H_{t-1} - H_{i,t-1}}\right)$$
$$= h_{i,t-1}\left(\frac{1-h_{i,t}}{1-h_{i,t-1}}\right)$$

where $h_{i,t} = H_{i,t}/H_t$ is the labour share of industry *i*. Let $TA_{i,t}$ denote the total structural adjustment effect for industry *i* from equation 3 in the article. Using the expression above, the total structural adjustment effect can be written as

$$TA_{i,t} = \bar{S}^{VA}_{i,t}\ \Delta\ln h_{i,t} + (1 - \bar{S}^{VA}_{i,t})\Delta\ln(1-h_{i,t})$$

where $\Delta\ln(1-h_{i,t})$ denotes $\Delta\ln\left(\frac{1-h_{i,t}}{1-h_{i,t-1}}\right)$ and $\bar{S}^{VA}_{i,t} = \frac{1}{2}(S^{VA}_{i,t-1} + S^{VA}_{i,t})$ as in Equation 2 in the article.

Since $\Delta\ln h_{i,t} \approx \frac{h_{i,t} - h_{i,t-1}}{h_{i,t-1}}$, it follows that

$$\Delta\ln(1-h_{it}) \approx \frac{-(h_{i,t}-h_{i,t-1})}{h_{i,t-1}}\ \frac{h_{i,t-1}}{1-h_{i,t-1}}$$
$$\approx -\Delta\ln h_{it}\ \frac{h_{i,t-1}}{1-h_{i,t-1}}$$

Using these relationships (which are just the log-difference approximations to growth rates), the total structural adjustment effect can be written as

$$TA_{i,t} = \Delta\ln h_{it}\ \frac{h_{i,t-1}}{1-h_{i,t-1}}\left(\frac{\bar{S}^{VA}_{i,t}}{h_{i,t-1}} - 1\right)$$

For simplicity, $\bar{S}^{VA}_{i,t}$ is replaced with $S^{VA}_{i,t-1}$ in the expression for $TA_{i,t}$. Then note that the value added share satisfies the identity

$$S^{VA}_{i,t-1} = \frac{A_{i,t-1}}{A_{t-1}} h_{i,t-1}$$

where $A_{i,t}$ and A_t denote the levels of labour productivity defined as nominal value added per hour worked, for industry *i* and in the aggregate business sector, respectively. Then the total structural adjustment effect can be represented as $T\acute{}A_{i,t}$.

$$T\acute{}A_{i,t} = \Delta\ln h_{it}\ \frac{h_{i,t-1}}{1-h_{i,t-1}}\left(\frac{S^{VA}_{i,t-1}}{h_{i,t-1}} - 1\right)$$
$$= \Delta\ln h_{it}\ \frac{h_{i,t-1}}{1-h_{i,t-1}}\left(\frac{A_{i,t-1}}{A_{t-1}} - 1\right)$$
$$= -\Delta\ln(1-h_{it})\ \left(\frac{A_{i,t-1}}{A_{t-1}} - 1\right)$$

This is a version of the 'reallocation level effect' as in Sharpe and Thomson (2010). The second line expresses total structural adjustment in terms of the change in the labour share of industry *i* ($\Delta\ln h_{i,t}$) while the third line expresses it in terms of the change in the labour share of the rest of the industries in the aggregate sector ($\Delta\ln(1-h_{it})$). Both forms of the expression say the same thing: if the labour share of industry *i* rises (i.e. the labour share of the rest of the economy falls), the total structural adjustment effect is positive if and only if the initial productivity level of industry *i* was above average.

Differences between the two measures, including the use of nominal rather than real value added to define labour productivity; the use of logarithmic rather than factor growth rates; and the use of $S^{VA}_{i,t-1}$ rather than $\bar{S}^{VA}_{i,t}$ are important to note. Nevertheless, conclusions about the role of total structural adjustment presented here are broadly consistent with those found in Sharpe and Thomson (2010).

Explaining the Gap between Productivity and Median Wage Growth in Canada, 1976-2014

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Abstract

Canadian labour is more productive than ever before, but there is a pervasive sense among Canadians that the living standards of the 'middle class' have been stagnating. Indeed, between 1976 and 2014, median real hourly earnings grew by only 0.09 per cent per year, compared to labour productivity growth of 1.12 per cent per year. We decompose this 1.03 percentage-point growth gap into four components: rising earnings inequality; changes in employer contributions to social insurance programs; rising relative prices for consumer goods; and a decline in labour's share of aggregate income. Our main result is that rising earnings inequality accounts for half the 1.03 percentage-point gap, with a decline in labour's income share and a deterioration of labour's purchasing power accounting for the remaining half. Further analysis of the inequality component reveals that real wage growth in recent decades has been fastest at the top and at the bottom of the earnings distribution, with relative stagnation in the middle. Our findings are consistent with a 'hollowing out of the middle' story, rather than a 'super-rich pulling away from everyone else' story.

Motivation and Background

Canada's workers are more productive than ever. Between 1976 and 2014, Canada's labour productivity - the volume of goods and services produced in the average hour of work in Canada - increased by 52.5 percent, or 1.12 percent per year.

At the same time, a common view holds that Canada's 'middle class' is experiencing economic stagnation. In its 2016 budget, the Government of Canada expressed this view as follows:

> [Even] though there has been economic growth over the past three decades, it hasn't much benefitted the middle class. Too often, the benefits have been felt only by already wealthy Canadians, while the middle class and those working hard to join it have struggled to make ends meet. (Government of Canada, 2016)

Survey evidence confirms that this sentiment is pervasive among Canadians. Graves (2014) refers to an "almost universal public consensus that the middle class is in crisis." The share of Canadians who self-identify as 'middle class' fell from 67 per cent in the early 2000s to 47 per cent at the end of 2014 (EKOS Research, 2014). Canadian workers do not feel that their

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improved productivity has raised their standard of living.

Evidence on wage growth in recent decades suggests that these workers may have a point. While cumulative growth in labour productivity over the period was 52.5 per cent, the hourly earnings of the median worker grew by only 3.3 per cent after adjusting for the rising cost of living. This disconnect between growing labour productivity and stagnant earnings for the median worker likely goes a long way toward explaining the prevailing sense of middle class malaise.

Economic history and economic theory suggest that labour productivity growth should generate rising living standards for workers over time, so the apparent disconnect between labour productivity growth and wage growth is puzzling. What factors account for it? In this article, the gap between labour productivity growth and median hourly earnings growth is decomposed into contributions from the following four sources:

- rising earnings inequality;
- changes in the importance of employer contributions to social insurance programs as a form of labour compensation;
- rising relative prices for consumer goods; and
- a decline in labour's share of aggregate income.

Each of these components has its own implications for the welfare of workers. To the extent that the productivity-earnings gap simply reflects a rising share of labour compensation being paid in the form of employer contributions to social insurance plans, for example, it is not obvious that workers are any worse off. On the other hand, rising earnings inequality or a decline in labour's share of income represent more serious obstacles to broad-based prosperity.

If rising inequality is the leading driver of the productivity-earnings gap, is the story simply that super high-earning individuals are leaving everyone else behind? When we examine the wage data more closely, we uncover a subtler story. Wage growth in recent decades has been highest at the top and at the bottom of the wage distribution, with relative stagnation in the middle. These findings are consistent with a 'hollowing out of the middle' narrative, as one finds in the recent literature on the phenomenon of 'labour market polarization.'[2]

In the rest of the present section, we provide evidence on recent trends in labour productivity and in several measures of labour remuneration. Most of our results are evident in these trends, though our technical analysis later in the article will make the results quantitatively precise. We then discuss related literature. This material provides motivation and context for the more detailed analysis that follows.

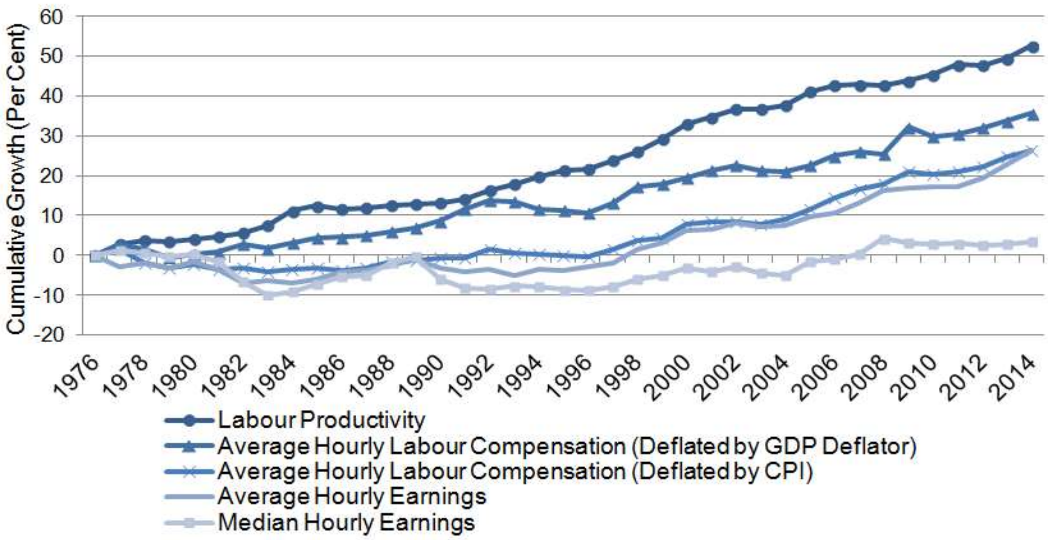
The remainder of the article is structured as follows. The second sections describes our framework for decomposing the gap between labour productivity growth and median annual earnings growth into the components listed above. In the third section the results of the decomposition are presented for the full 1976-2014 period and for five sub-periods chosen based on the timing of business cycle peaks. The fourth and final section contains a concluding discussion.

Preliminary Evidence

Chart 1 depicts the prima facie evidence for the view that middle class living standards have

2 The literature on labour market polarization finds that technological change and globalization have led to a decline in middle-wage jobs in advanced economies, so that employment and wage growth occur only in high-wage and low-wage occupations. This occurs because traditional middle-wage jobs are the ones most susceptible to automation or outsourcing. See Autor and Dorn (2013), Autor *et al.* (2006) and Jaimovich and Siu (2012), among others.

Chart 1
Cumulative Growth in Labour Productivity and in Four Measures of Real Labour Remuneration, Canada, Per Cent, 1976-2014



Source: CSLS calculations, based on Statistics Canada data

been stagnant in recent decades in spite of considerable growth in labour productivity. The chart indicates that growth of labour remuneration has not kept pace with labour productivity over the 1976-2014 period. Most strikingly, while growth in labour productivity over the period was 52.5 per cent (or 1.12 per cent per year), the hourly earnings of the median worker grew by only 3.3 per cent (or 0.09 per cent per year).[3] The 1.03 percentage-point gap between these annual growth rates is what we seek to explain.

How can we understand the disconnect between labour productivity growth and median earnings growth? The three remaining lines in Chart 1 provide a starting point. While median hourly earnings were stagnant, average hourly earnings grew by 26.2 per cent (or 0.61 per cent per year) over the 1976-2014 period. The difference between these two data series is that the median wage reflects the experience of workers in the middle of the wage distribution while the average wage is dragged upward by high-earning individuals. Thus, it appears that rising earnings inequality has played a significant role in the stagnation of median earnings; the gains from labour productivity growth are largely accruing to some workers, but not much is going to the median worker.

The next line in Chart 1 depicts average hourly labour compensation deflated by the consumer price index (CPI).This data series differs from average hourly earnings in that it includes employer contributions to social insurance programs on workers' behalf, in addition to the wage and salary earnings counted in the average hourly earnings data.

Average hourly labour compensation (deflated by the CPI) increased by 26.2 per cent (or 0.61 per cent per year) over the 1976-2014 period, exactly the same cumulative growth as was exhibited by average hourly earnings. This implies that employer contributions to social insurance programs played a negligible role in the productivity-earnings gap over the 1976-2014 period.

3 Following Statistics Canada (1997), earnings are defined as "the sum of wages and salaries, and net self-employment income."

The final line in Chart 1 depicts average hourly labour compensation deflated by the GDP deflator, a measure of the growth of output prices. The gap between the two average hourly labour compensation measures reflects the difference between the growth rates of the output price and the consumption goods price; that is, changes in labour's terms of trade. [4]

Average hourly labour compensation (deflated by the GDP deflator) increased by 35.6 per cent (or 0.81 per cent per year) over the 1976-2014 period, 0.2 percentage-points per year faster than CPI-deflated average hourly labour compensation or average hourly earnings. Consumer prices grew faster than output prices over the period.

Thus, two factors - rising earnings inequality and the rising relative price of consumer goods - appear to explain much of the gap between labour productivity growth and median earnings growth. But they do not explain all of the gap; there remains a substantial discrepancy between labour productivity growth and average hourly labour compensation growth (deflated by the GDP deflator). In our formal analysis in sections two and three in the article, we attribute this remaining gap to a decline in labour's share of aggregate income; a greater share of all the income generated in Canada is being paid either as compensation to other factors of production, with less left for compensation to labour.

Thus, the four factors listed above provide a complete account of the sources of the productivity-earnings gap depicted in Chart 1. Our formal analysis in the following two sections of the article brings quantitative precision to this accounting.

The fact that median earnings have not kept pace with labour productivity may be a matter of concern for workers, but should we be surprised by it? Some economists might answer this question in the negative. They would point out that, under standard assumptions, economic theory implies that labour productivity should grow at roughly the same rate as average hourly labour compensation over the long run. The standard theory is silent about the distribution of earnings. A stagnant median wage in the presence of rising labour productivity presents no inconsistency with basic economic theory; it simply implies that the wage distribution is becoming more unequal, and standard theory has never precluded that possibility.

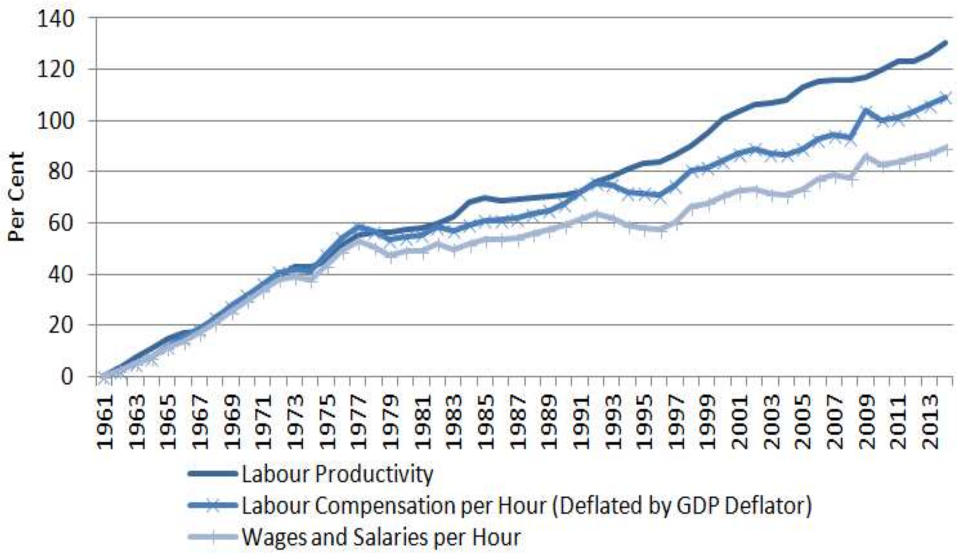
This defense of the basic theory is partly correct, but it ignores the fact that, as noted above, even *average* hourly labour compensation has not kept pace with labour productivity since 1976. This discrepancy is strongly at odds with standard economic theory. Moreover, it represents a change relative to Canada's earlier economic history. Average hourly labour compensation, deflated with the GDP deflator, grew at the same rate as labour productivity between 1961 and the mid-1970s (Chart 2).[5] It was only after 1976 that the two series became decoupled (although average labour compensation did briefly catch up to labour productivity in the early 1990s before falling behind again). Average hourly wages and salaries also grew at the same rate as labour productivity until the mid-1970s.

Thus, recent trends in labour productivity and in labour compensation are puzzling from the perspectives of both economic theory and eco-

4 The output price index (formally called the GDP deflator) is an average price for all goods and services produced, while the Consumer Price Index is an average price for all the goods and services consumed. The evolution of the two price indexes can differ because the bundle of goods produced in Canada is not the same as the bundle of goods consumed. For example, Canada produces products for export to other countries. The prices of those goods have a greater weight in the output price index than in the Consumer Price Index.

5 'Median Hourly Earnings' could not be included in Chart 2 because that data series begins in 1976. See Uguccioni, Sharpe, and Murray (2016) for detailed discussion of data sources.

Chart 2
Cumulative Growth in Labour Productivity and in Two Measures of Real Labour Remuneration, Canada, Per Cent, 1961-2014



Source: CSLS calculations, based on Statistics Canada data

nomic history. The stagnation of real earnings for the median worker while labour productivity has continued to grow appears to have generated a pervasive sense that Canada's middle class is in crisis. These facts provide the context for the analysis in this article.

Literature Review

Sharpe *et al.* (2008) decompose the divergence between real median wages and labour productivity into four overarching factors: rising inequality, deteriorating terms of trade for labour, a decrease in labour's share of income, and measurement inconsistencies.[6] They find that from 1980 to 2005, labour productivity grew 1.26 percentage points per year faster than median real earnings. They decompose the gap into their four factors, attributing 0.35 percentage points per year to inequality, 0.42 percentage points per year to terms of trade for labour, 0.25 percentage points per year to labour's share of income, and 0.25 percentage points per year to measurement issues.[7] Unfortunately, because they employ census data on median real earnings, they are unable to decompose the 1980 to 2005 period into peak-to-peak sub-periods. Our analysis largely follows the method of Sharpe *et al.* but improves upon it in two respects. First, we present a more comprehensive analysis by expanding the time period from 1980-2005 to 1976-2014. Second, we analyze peak-to-peak sub-periods to discuss how the gap evolved over time.

Pessoa and Van Reenen (2012) perform a decomposition of median wage growth and productivity growth similar to the one presented in

6 The term "labour's terms of trade" refers to the ratio of consumption goods prices to producer prices, while the term "measurement inconsistencies" refers to the combined effect of employer social contributions and changes in hours of work per worker.

7 Our estimates for the 1980 to 2005 period are broadly similar to those obtained by Sharpe *et al.* (2008). For 1980 to 2005 we estimate the gap to be 1.41 percentage points per year, of which: inequality made up 0.52 percentage points; terms of trade 0.28 percentage points; labour's share of income 0.41 percentage points; and measurement inconsistencies 0.20 percentage points.

Sharpe *et al.* (2008) for the United Kingdom and the United States. They define two types of measures for the divergence - "gross decoupling" and "net decoupling". The former measures differences in growth between labour productivity and median hourly real earnings, while the latter measures differences in growth between labour productivity and average labour compensation per hour (deflated with the same deflator). Gross decoupling accounts for changes to labour's share of income, labour's terms of trade, differences between growth in median and mean hourly earnings, and the wedge between labour compensation and earnings, while net decoupling is determined by only changes to labour's share of income. Ultimately, Pessoa and Van Reenen (2012) find little evidence of net decoupling in the UK, but significant gross decoupling in the United States and UK. In the UK, gross decoupling was driven by differences between mean and median earnings and the wedge between earnings and labour compensation.

Pessoa and Van Reenen recognize that both gross decoupling and net decoupling are important policy indicators. As gross decoupling relates the "true middle" of the earnings distribution to labour productivity, it avoids issues of a skewed average and uses a more tangible income concept from the point of view of the worker (e.g. EI contributions made by the employer may not be considered income by a given worker). As gross decoupling also deflates earnings with the CPI and labour productivity with the GDP deflator, it also captures any difference in the prices faced by firms and workers. This is an important distinction to make because firms and consumers can at times face very different prices. Net decoupling, on the other hand, is important because it challenges one of the main stylized facts cited by economists - labour's stable share of income. Pessoa and Van Reenen observe that net decoupling could occur for many reasons, including shocks which disturb the long run equilibrium, technological change-biased against labour, changes to the level of competition in the market (in the product market it results in setting higher prices, while in the labour market it results in setting lower wages), and finally changes to labour supply due to structural phenomena like globalization.

Mishel and Gee (2012) also employ Sharpe *et al.* (2008)'s methodology. Much like us, they perform an annual analysis comparing median real wage in the United States with labour productivity and find a significant gap of 1.56 percentage points per year between 1973 and 2011. Rising wage inequality accounted for 0.61 percentage points of the gap, while labour's terms of trade accounted for another 0.44 percentage points. They specifically point to the erosion of labour standards, globalization, high trade deficits, and the rising share of capital depreciation in GDP to explain both growing inequality and the changes in the distribution of income towards capital.

Empirical Framework

In this section, we formally describe the decomposition of the gap between labour productivity growth and median real hourly earnings growth, developed in Sharpe *et al.* (2008). The first subsection presents the technical details of the decomposition without much commentary. In the second subsection, we provide a conceptual discussion of each of the components of the decomposition and explain how they should be interpreted. In the final subsection, we describe the data sources we will use.

Decomposition Method

The starting point for the decomposition is the following accounting identity:

$$\frac{Y_L}{P_C \times L} = \frac{Y}{P_Y \times L} \times \frac{Y_L}{Y} \times \frac{P_Y}{P_C} \tag{1}$$

Here, Y_L is total nominal labour compensation, P_C is the price of consumption goods, and L is total hours worked. Y is total nominal output (or income) in the economy and P_Y is the price of output.

Thus, the ratio $Y_L/P_C \times L$ denotes average real hourly labour compensation in units of consumption goods (i.e. the "consumer wage"). On the right-hand side, the ratio $Y_L/P_Y \times L$ denotes real output per hour in units of output goods; that is, labour productivity. Y_L/Y is labour's share of total income in the economy. The remaining term P_Y/P_C is the relative price of output goods in terms of consumption goods; following the literature, we will refer to this as "labour's terms of trade." More will be said about this below.

For any variable X, let the notation $\Delta\%X$ denote the per cent growth rate of X. Then expressing equation (1) in growth rates, we obtain

Δ% Average Real Hourly Compensation = Δ% Labour Productivity + Δ% Labour Share + Δ% Labour Terms of Trade (2)

Our goal is to explain changes in the gap between labour productivity and median real hourly earnings. Let *Δ% Gap* denote the productivity-earnings growth gap. Formally, it is defined by

Δ% Gap = Δ% Labour Productivity - Δ% Median Real Hourly Earnings (3)

Rearranging (2) and using (3) to eliminate labour productivity growth, we obtain

Δ% Gap = Δ% Average Real Hourly Compensation - Δ% Median Real Hourly Earnings - Δ% Labour Share - Δ% Labour Terms of Trade (4)

Now, the change in average real hourly earnings relative to median real hourly earnings is an indicator of the change in earnings inequality over time. Thus, we define the change in inequality as

Δ% Inequality = Δ% Average Real Hourly Compensation - Δ% Median Real Hourly Earnings (5)

Finally, we need to relate average real hourly compensation to average real hourly earnings. As we discuss in more detail below, the difference between these two measures reflects the impact of changes in employer contributions to social insurance programs:

Δ% Average Real Hourly Compensation - Δ% Average Real Hourly Earnings = Δ% Employer Social Contributions (6)

Substituting (5) and (6) into (4) yields the overall decomposition:

Δ% Gap = Δ% Inequality + Δ% Employer Social Contributions - Δ% Labour Terms of Trade - Δ% Labour Share (7)

Equation (7) is the final decomposition formula. Having presented the technical details of its derivation, we now proceed to discuss its interpretation.

Interpreting the Decomposition

The object of interest to us is *Δ% Gap*, the discrepancy between labour productivity growth and median real hourly earnings growth. Equation (7) expresses this gap in terms of four components, each of which has a precise economic interpretation. In this subsection, we provide a brief explanation of each of the four components. We then conclude with general comments about the decomposition.

Inequality

The inequality component is the gap between the growth rates of average and median real hourly earnings. Empirically, the Canadian distribution of earnings is positively skewed; its mean is greater than its median because the mean is dragged upward by very high earners. When earnings at the top of the distribution grow more quickly than those in the middle of the distribution, the mean rises relative to the median and earnings inequality rises. This would imply that the gains from labour productivity are flowing disproportionately to workers who were already high earners relative to the median worker, so $\Delta\%$ *Inequality* contributes positively to $\Delta\%$ *Gap*.

Employer Social Contributions

Total real compensation includes employer contributions to social insurance programs (e.g. the Canada Pension Plan or Employment Insurance) while real earnings do not. It is possible that part of the gap between labour productivity growth and median hourly earnings growth is accounted for by workers receiving a growing amount of their compensation in the form of employer contributions to social insurance programs rather than cash or in-kind earnings. Whether this makes workers better off depends on how much they value the social programs.

Labour Terms of Trade

The accounting identity in equation (1) includes two prices: the consumption goods price P_C and the output goods price P_Y. These average prices differ because, in general, the bundle of goods consumed by consumers is not the same as the bundle of goods produced in the domestic economy.[8]

Labour productivity is defined as the volume of output goods produced per hour of work, so the relevant price is P_Y. Workers ultimately want to use their compensation to buy consumption goods, so the relevant price for measuring real labour compensation is P_C. The discrepancy between labour productivity and real labour compensation is therefore influenced by the ratio P_Y/P_C. Following the literature, we refer to this ratio as "labour's terms of trade."[9]

When $\Delta\%$ *Labour Terms of Trade* > 0, consumer prices are falling relative to output prices. Everything else being equal, this increases workers' purchasing power relative to labour productivity, and hence reduces the gap between labour productivity growth and real earnings growth. That is why labour's terms of trade enter equation (7) with a negative sign.

Labour Share

The final term in equation (7) accounts for changes in total labour compensation as a share of aggregate income in the economy. Labour productivity measures the economy's average output per hour of labour supplied by workers, but part of that output is paid to other factors of production (primarily capital). The remaining share accrues to labour. These aggregate shares are determined by technological and institutional factors in the long run, though they can be

8 For example, Canada produces goods that are exported to other countries rather than purchased by Canadian consumers. The prices of those exports are included in the output price P_Y but not in the consumption price P_C.

9 Clearly, an analogy is being drawn between P_Y/P_C and the more common notion of "terms of trade," which is the ratio of a country's export prices to its import prices. Intuitively, P_C is the price of the goods workers buy and P_Y is the price of the goods workers produce and sell. It is to workers' advantage when the price of what they sell increases relative to the price of what they buy, just as it is to a country's advantage when the price of what it sells (its exports) increases relative to the price of what it buys (its imports).

Table 1

Decomposition of the Growth Gap between Labour Productivity and Median Real Hourly Earnings into Four Components, Canada, 1976-2014

	Labour Productivity	Median Real Hourly Earnings	Gap	Inequality	Employer Social Contributions	Labour's Terms of Trade	Labour Share
	Growth (per cent per year)			Percentage Point Contributions to the Gap			
1976-2014	1.12	0.09	1.03	0.53	0.00	0.20	0.31
1976-1981	0.90	-0.32	1.21	-0.41	0.03	0.92	0.76
1981-1989	0.94	0.16	0.78	0.15	-0.03	0.48	0.19
1989-2000	1.51	-0.28	1.79	0.92	0.14	0.24	0.48
2000-2008	0.89	0.94	-0.05	0.20	0.01	-0.55	0.29
2008-2014	1.12	-0.14	1.26	1.52	-0.24	0.18	-0.20
				Per Cent Contributions to the Gap			
1976-2014	--	--	--	51.0	0.2	19.1	29.7
1976-1981	--	--	--	-33.9	2.5	75.8	62.3
1981-1989	--	--	--	19.5	-4.0	61.9	24.0
1989-2000	--	--	--	51.7	7.8	13.3	26.6
2000-2008	--	--	--	--	--	--	--
2008-2014	--	--	--	120.5	-19.0	14.4	-15.9

Note: Per cent contributions to the gap are not computed for the 2000-2008 period because the total gap was close to zero over that period.
Source: CSLS calculations, based on Statistics Canada data

influenced by supply and demand conditions in the short run.

When labour's share rises, the gap between labour productivity growth and labour compensation growth falls. This is why labour's share enters equation (7) with a negative sign.

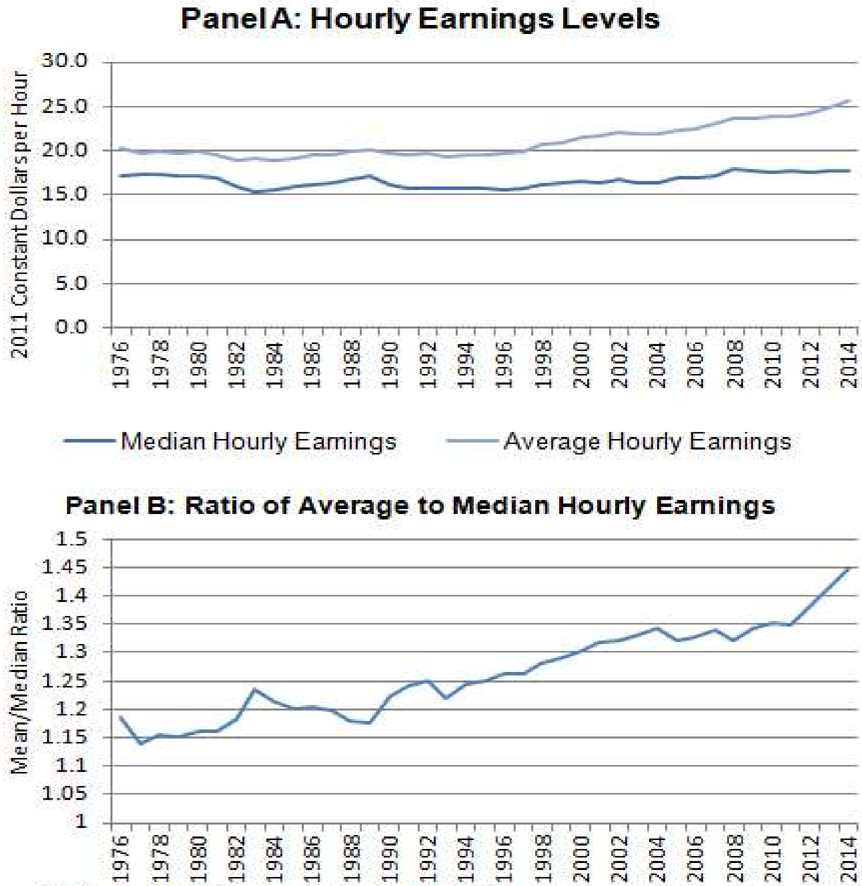
General Comments

The decomposition in equation (7) represents an accounting exercise and does not, on its own, justify any statements about cause and effect. Did the gap between labour productivity and median real annual earnings increase because earnings inequality increased for some reason? Or did measured earnings inequality increase because the productivity-earnings gap increased for some reason? An accounting decomposition cannot answer a question like this.[10] To address such questions would require a structural model that explains why each of the components changed the way it did.

Nevertheless, we think the accounting approach is useful. It draws our attention to the relationships between the productivity earnings gap and several other economic phenomena - rising earnings inequality, the changing impact of laws governing employer contributions to social insurance programs, and so on. It lends a disciplined, quantitative characterization to those relationships. It suggests areas for future research that might clarify the causal mechanisms at play.

10 Similar questions can be asked about the other components as well. Did earnings grow more slowly than productivity because labour's share of income declined? Or did labour's share of income decline because earnings grew more slowly than labour productivity?

Chart 3
Average and Median Real Hourly Earnings, Canada, 2011 Constant Dollars per Hour, 1976-2014



Source: CSLS calculations, based on Statistics Canada data

Data[11]

The analysis employs the Survey of Labour and Income Dynamics (SLID) and System of National Accounts (SNA) data, though we do supplement the SLID data with Labour Force Survey (LFS) microdata. The SNA data allow us to relate average hourly real compensation growth with labour productivity growth for all workers in the economy from 1961 to 2014. The SLID data allow us to investigate the distribution of earnings growth and compare it with our estimates of labour productivity growth. The SLID data cover 1993 to 2011 and were extended back to 1976 using the Survey of Consumer Finance data. The hourly wage variable from the LFS microdata, deflated with the CPI, was used to extend the SLID data to 2014.

Decomposition Results

This section presents and discusses the decomposition results. We begin with an overall summary of the results. We then devote one subsection to detailed analysis of each of the four components: earnings inequality, employer social contributions, labour's terms of trade, and labour's share of income.

Summary of Results

The decomposition results are summarized in Table 1. Over the 1976-2014 period, the growth

11 For a detailed discussion of data sources, see Uguccioni, Sharpe and Murray (2016). All data used in the article are posted at http://csls.ca/reports/csls2016-16-DataAppendix.pdf.

Table 2
Inequality Component and its Determinants, Canada, 1976-2014

	Average Real Hourly Earnings	Median Real Hourly Earnings	Inequality Component
	A	B	C = A - B
1976-2014	0.61	0.09	0.53
1976-1981	-0.73	-0.32	-0.41
1981-1989	0.31	0.16	0.15
1989-2000	0.65	-0.28	0.93
2000-2008	1.14	0.94	0.20
2008-2014	1.38	-0.14	1.53

Growth rates are in per cent per year.
Source: CSLS calculations, based on Statistics Canada data

gap between labour productivity and median real hourly earnings was 1.03 percentage points per year. Of that gap, rising earnings inequality accounted for 0.53 percentage points, or 51 per cent of the total gap. A declining labour share of aggregate income accounted for the next largest component: 0.31 percentage points, or 30 per cent of the gap. A deterioration of labour's terms of trade - that is, an increase in consumer prices relative to output prices - accounted for the remaining 0.20 percentage points, or 19 per cent of the total gap. Employer social contributions were a non-factor.

In addition to the results for the full 1976-2014 period, Table 1 contains results for six sub-periods. The cut-off dates are business cycle peaks (except for the first and last years, which are determined by data availability). The analysis reveals that the proximate sources of the productivity-earnings gap differ from sub-period to sub-period. In 1976-1981, the productivity-earnings gap was large (1.21 percentage points per year) in spite of declining inequality. The gap in that period was driven by a large deterioration in labour's terms of trade and a large decline in the labour share of income. The contribution of inequality has tended to increase over time (except for the 2000-2008 period, which was an unusual period in that the overall productivity-earnings gap was essentially zero). That of labour's terms of trade has tended to decline as consumer price inflation and output price inflation have both stabilized at a similar level (around the Bank of Canada's two per cent annual inflation target). The contribution of labour's share has varied from period to period, while that of employer social contributions has in general been small.

In the most recent period, 2008-2014, the 1.52 percentage-point contribution of rising inequality accounts for more than 100 per cent of the 1.26 percentage-point productivity-earnings growth gap.

Earnings Inequality

Thomas and Uguccioni (2016) show that economic inequality has risen considerably in Canada in recent decades, particularly in the 1990s. Our data also show growing inequality in Canada as mean and median hourly real earnings have diverged. Between 1976 and 2014, median real hourly earnings increased 0.09 per cent per year (from \$17.1 to \$17.7 in 2011 dollars) while mean hourly earnings increased 0.61 per cent

Table 3
Distribution of Real Hourly Wage Growth by Percentile, Canada, Per Cent per Year, 1997-2014

Real hourly earnings	1997-2014	2000-2008	2008-2014
Mean	0.75	0.82	0.81
Percentile			
1st	1.73	1.26	2.37
10th	0.75	0.74	1.44
20th	0.60	0.72	0.64
30th	0.85	0.78	0.68
40th	0.63	0.39	0.83
50th	0.47	0.55	0.34
60th	0.61	0.59	0.75
70th	0.66	0.58	0.84
80th	0.82	0.97	0.86
90th	0.94	1.19	0.73
99th	1.02	1.18	0.75

Percentiles constructed using Labour Force Survey microdata.
Source: CSLS calculations, based on Statistics Canada data

per year (from \$20.3 to \$25.7) (Chart 3, Panel A). Thus, average earnings exceeded median earnings by 19 per cent in 1976 and by 45 per cent in 2014 (Chart 3, Panel B). Average earnings began to pull away from median earnings in the late 1980s, and earnings inequality grew quickly throughout the 1990s. Inequality stabilized in the early 2000s, but appears to have begun another steep increase after 2010. Table 2 summarizes the inequality component and its determinants - the growth rates of median and average real hourly earnings - for the 1976-2014 period and for the six sub-periods.

Growing inequality is not simply a matter of comparing mean and median workers, but rather a matter of widening the distribution of earnings on the whole. Using Labour Force Survey microdata obtained from Statistics Canada, we construct hourly real earnings for all workers by deflating nominal hourly earnings with the CPI. Our data only cover 1997 to 2014, but still allow us to glean important insights into the evolution of inequality in the 2000 to 2008 and 2008 to 2014 periods. The results are presented in Table 3.[12]

First and foremost, in Table 3 we see the divergence between median (50th percentile) and average hourly real earnings which our inequality component of the gap measures in all three periods. Just like the inequality component, average hourly real earnings grew much quicker than median hourly real earnings from 2000 to 2008 and from 2008 to 2014.

12 Although the annual growth rates of median hourly earnings in the SLID and the LFS are similar for the 1997-2011 period (at 0.44 per cent and 0.53 per cent, respectively), Table 2 and Table 3 reveal substantial differences between the growth rates implied by the two data series for sub-periods. This reflects a combination of sampling error and definitional differences (e.g. the LFS "earnings" data exclude bonuses and stock options). It may also reflect error arising from our assumption that the change in annual hours worked has been the same for all workers. Nevertheless, we think the analysis of differences in wage growth across the wage distribution - which the LFS makes possible - remains informative in spite of the existence of some discrepancies between the two data sources.

Earners in the 99th percentile (the "top one per cent") experienced stronger hourly real earnings growth than any of the deciles from 1997 to 2014 and in the 2000 to 2008 peak to peak period, though the 1st percentile's hourly real earnings grew quicker than the 99th percentile's from 1997 to 2014. From 2008 to 2014, real earnings growth for the 99th percentile was in line with growth throughout the middle of the distribution. The highest growth rates were actually experienced by earners in the bottom decile of the distribution during the 2008-2014 period.

The U-shaped distribution of real earnings growth means that our use of the term 'inequality' to refer to the slow growth of median earnings relative to average earnings may be slightly misleading. If real earnings for those who earn the least grow at broadly the same rate as those who earn the most, then inequality in Canada (as measured, say, by a 90-10 ratio) is more or less stable. However, as those in the middle lag behind in growth, they are being caught by those who earn the least. The story is less about overall earnings inequality than it is about a 'hollowing out' of the middle of the wage distribution.

Overall, the inequality component contributed 0.53 percentage points per year to the gap between productivity growth and median hourly earnings growth over the 1976-2014 period, making it the largest contributor of any of the components. What explains the stagnation of earnings in the middle of the wage distribution in recent decades? The two forces that have received the most attention in the literature are globalization and technological change.

The world's increased openness to international flows of goods and capital has created opportunities for advanced economies' capital to seek high returns around the world and, at the same time, has brought advanced economies' workers into competition with the workers of relatively low-wage countries. Recent research suggests that the effect on advanced economies' employment levels and wages resulting from trade with low-wage countries may be larger and more persistent than economists once thought.[13] We would expect these effects to be largest in industries with the greatest direct trade exposure, such as manufacturing - industries that traditionally accounted for many jobs in the middle part of the wage distribution.

Technological change also affects the distribution of earnings. Traditionally, economists have focused on the notion of skill-biased technological change; that is, the idea that advanced technologies tend to raise the wages of highly skilled workers relative to the wages of comparatively unskilled workers. More recently, some economists have pointed out that computer technology is increasingly able to automate the kinds of routine tasks once performed by middle-wage workers in clerical or middle-management occupations. This is on top of the continuing automation of factory jobs, which also used to comprise part of the middle of the wage distribution. The result of these technological forces is 'labour market polarization,' a phenomenon whereby the middle of the wage distribution is 'hollowed out' and workers' labour market outcomes are increasingly bifurcated between highly skilled, high-wage 'winners' and low-wage 'losers.'[14] Our findings on the U-shaped distribution of real earnings growth are consistent with a story like this.

As noted in the introduction to this report, economic theory implies that labour productivity and average real hourly labour compensation should grow at roughly the same rate over the

13 See Acemoglu *et al.* (2016), Autor *et al.* (2013a), Autor *et al.* (2016) and Autor *et al.* (2014), among others.

14 See Autor *et al.* (2006), Autor and Dorn (2013), Autor *et al.* (2013b), Autor *et al.* (2015), and Jaimovich and Siu (2012), among others.

Table 4
Labour's Terms of Trade and Its Determinants, Canada, 1976-2014

	Output Price (GDP Deflator)	Consumption Price (CPI)	Change in Labour's Terms of Trade
	A	B	C = A - B
1976-2014	3.54	3.73	-0.20
1976-1981	8.82	9.74	-0.92
1981-1989	4.81	5.30	-0.48
1989-2000	2.00	2.24	-0.24
2000-2008	2.81	2.26	0.55
2008-2014	1.38	1.56	-0.18

Growth rates are in per cent per year.
Source: CSLS calculations, based on Statistics Canada data

long term. In terms of how middle class people feel about their economic situation, however, median hourly earnings is arguably a more important measure than average hourly compensation. The fact that earnings inequality accounts for 51 per cent of the gap between labour productivity growth and median real hourly earnings growth implies that the theoretical link between labour productivity and labour compensation may not have broken down as much as it might seem at first glance. Labour productivity is still leading to earnings growth for workers, but that earnings growth is benefitting workers at the top and at the bottom of the earnings distribution while the median worker - the representative of the 'middle class' - has benefitted hardly at all.

That being said, economic theory has not been vindicated yet. After accounting for earnings inequality, 49 per cent of the productivity-earnings gap remains to be explained. We now proceed to the next step in our decomposition.

Employers' Social Contributions

In addition to wages and salaries and taxable in-kind benefits captured on T4 tax forms, workers take part of their compensation in the form of government-mandated employer contributions to social insurance programs (e.g. the Canada Pension Plan and Employment Insurance). These contributions are included in real hourly labour compensation, but not in real hourly earnings. Thus, part of the gap between labour productivity growth and median hourly earnings growth should in principle be accounted for by growth of employers' social contributions.

In practice, Table 1 reveals that employers' social contributions made a negligible contribution to the productivity-earnings growth gap over the 1976-2014 period.

This result is somewhat surprising because employer social contributions as a share of employees' compensation increased from 8 per cent in 1976 to 13.9 per cent in 2014. A possible explanation for these findings is that they reflect the influence of the self-employed. Another possibility is that the effect of employer social contributions is masked by measurement error in the average real hourly earnings data.[15]

Labour Terms of Trade

As we explained in section two, the term "labour's terms of trade" refers to the ratio of the output price P_Y to the consumer price P_C. These average prices differ because, in general,

15 See Uguccioni, Sharpe, and Murray (2016) for discussion of these explanations.

Table 5
Growth of the Implicit Price Indexes for Components of GDP, Canada, Per Cent per Year, 1981-2014

	Final Consumption Expenditure	General Governments Final Consumption Expenditure	Gross Fixed Capital Formation	Exports of Goods and Services	Imports of Goods and Services
1981-2014	2.83	3.41	2.10	1.48	1.09
1981-1989	5.33	5.56	3.43	1.50	1.35
1989-2000	2.27	2.74	1.02	1.91	2.14
2000-2008	2.02	2.98	2.53	1.75	-0.52
2008-2014	1.66	2.41	1.75	0.31	0.98

Growth rates in terms of per cent per year.
Source: CSLS calculations, based on Statistics Canada data

the bundle of goods consumed by consumers is not the same as the bundle of goods produced in the domestic economy. Workers produce and sell output, then use the proceeds (i.e. their labour compensation) to buy consumer goods. If consumer prices rise relative to output prices, workers' purchasing power decreases. We would refer to this as a deterioration in labour's terms of trade. Since labour productivity is measured in output units while real earnings are measured in units of consumer goods, a deterioration in labour's terms of trade decreases workers' real earnings relative to labour productivity, and hence increases the productivity-earnings gap.

Over the 1976-2014 period, worsening terms of trade for labour accounted for 0.20 percentage points (or 19 per cent) of the gap between labour productivity growth and median real hourly earnings growth (Table 1). For the 1976-2014 period and for the six sub-periods,Table 4 shows how changes in output prices (measured by the GDP deflator) and consumption prices (measured by the consumer price index, or CPI) led to the changes in labour's terms of trade shown in Table 1.[16]

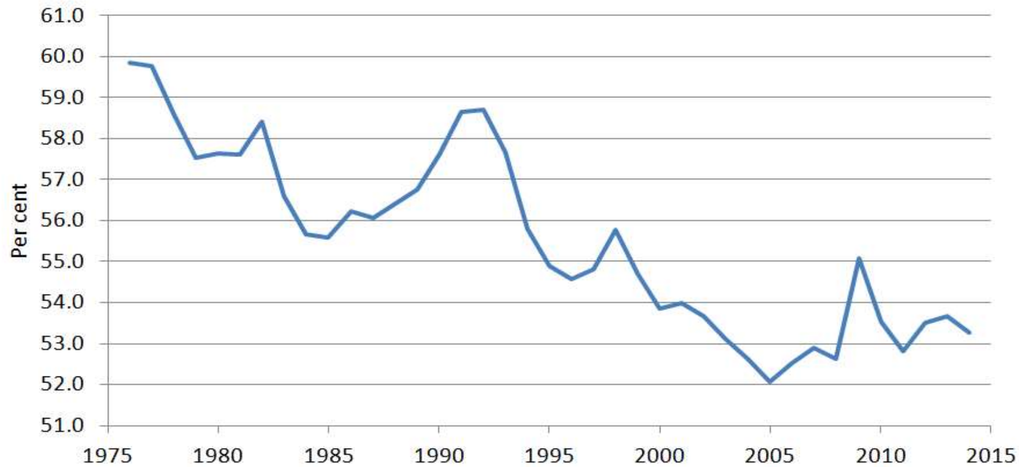
In every sub-period except 2000-2008, consumer price inflation exceeded output price inflation and, hence, labour's terms of trade deteriorated. Labour's terms of trade made its largest contributions the gap in the 1976 to 1981 and 1981 to 1989 periods, adding 0.92 percentage points per year and 0.48 percentage points per year in each period respectively. The CPI's growth slowed relative to the GDP deflator's growth as time went on, so much so that from 2000 to 2008 it actually decreased the gap by 0.55 per cent per year. This in part reflected the impact of cheap imports from countries such as China. From 2008 to 2014, GDP deflator growth fell more than CPI growth, resulting in terms of trade contributing 0.18 percentage points per year to the gap.

Table 5 shows the implicit price indexes of the various components of GDP from 1981 to 2014. The CPI should roughly track the implicit price index of household final consumption expenditure, and comparison of Table 4 and Table 5 confirms that the two price indexes grew at similar rates in each sub-period. The GDP deflator, however, is affected by the implicit price indexes

16 The labour terms of trade numbers in Table 4 and in Table 1 have opposite signs because labour's terms of trade enters the decomposition (equation (7)) with a negative sign. Thus, the negative terms of trade values in Table 4 show up in Table 1 as positive contributions to the productivity-earnings gap.

Chart 4

Labour Compensation as a Share of GDP, Canada, Per Cent, 1976-2014



Source: CSLS calculations, based on Statistics Canada data

of the other constituent parts of GDP. Implicit price indexes of imports and exports are driven by changes in the exchange rate of the Canadian dollar against foreign currencies, as well as commodity prices and the differences in inflation rates between Canada and its trade partners. While the growth rates of export and import prices were well below the growth rate of final consumption expenditure prices, overall their net weight in GDP is small, so their effect on the GDP deflator's growth is likely minimal.

A second explanation for the deterioration of labour's terms of trade lies in capital equipment prices. The price index for gross fixed capital formation grew at a much lower rate than that of household final consumption expenditure throughout the 1980s and 1990s. This likely explains most of the difference in growth between the CPI and GDP deflator in that time period. The major difference between the consumption and investment prices over these two periods was the falling price of investment in information and communication technology (ICT) equipment. As ICT investment prices fell, they pulled down the implicit price index of gross fixed capital formation and, with it, the overall GDP deflator.

Labour Share of Income

We began with the growth gap between labour productivity and median real hourly earnings. After adjusting for earnings inequality, employer social contributions and labour's terms of trade, we are left with the growth gap between labour productivity and average real hourly labour compensation, both inflation-adjusted using the output price index. Standard economic theory suggests that this gap should be zero over the long term because labour market competition should force firms to raise wages in line with productivity growth.

Our empirical decomposition shows that earnings inequality, employer social contributions and labour's terms of trade together account for 70.3 per cent of the productivity-earnings gap. That part of the gap may have substantial implications for middle class Canadians' subjective sense of their own economic welfare, but it poses no challenge to economic theory. The remaining 29.7 per cent of the gap, however, does represent a breakdown of the traditional view that labour productivity and average labour compensation should grow together.

That traditional view is based on the assumption that labour's share of aggregate income remains approximately constant over time.[17] If instead the structure of the economy changes in a way that reduces labour's aggregate income share, then such a change would show up in the data as a wedge between labour productivity growth and average real hourly labour compensation growth. That is precisely what we observe in the Canadian data. Thus, we attribute the remaining 29.7 per cent of the productivity-earnings gap to a decline in labour's share.

Labour income's share of total income has decreased from 59.9 per cent in 1976 to 53.3 per cent in 2014 (Chart 5). Broadly speaking the decline of labour's share of income was steady, with minor blips of improvement from 1986 to 1993 and 2005 to 2009. Those temporary improvements reflect the fact that returns to capital are more volatile than wages over the business cycle, so that labour's share of income tends to rise during recessions and fall during the early parts of booms. The effects of recessions are transitory, however; the long-term trend in labour's share is downward.

Overall, labour's share of income fell 0.31 per cent per year from 1976 to 2014. As shown in equation (7), changes in labour's share of income contribute inversely to the gap, meaning a fall in the former contributes growth to the latter and vice versa. Consequently, labour's share of income added 0.31 percentage points per year to the gap from 1976 to 2014 - the second-largest contribution of any component. Labour's share of income fell the most during the 1976 to 1981 period, adding 0.76 percentage points per year to the gap.

Labour's lost share of income is largely accounted for by an increase in the income share of gross operating surplus.[18] From 1981 to 2014, the net operating surplus of corporations as a share of aggregate income in Canada increased from around 23.7 per cent to 27.5 per cent. Over the same period, labour's share of income fell by almost 4 percentage points (Chart 4). As net operating surplus reflects payments to capital net of depreciation, an increase in net operating surplus reflects increased profits.

In a recent report, the OECD (2012) tried to explain the falling income share of labour from 1990 to 2007. In theory, it could simply be a matter of labour movement from labour-intensive sectors to relatively capital-intensive sectors. However, the OECD argues that developments within sectors have been more important than changes between sectors. They find that total factor productivity growth and capital deepening explain up to 80 per cent of the falling share of labour. Traditionally, total factor productivity growth has worked as a complement to employment, but the OECD posits that the technological developments of recent decades are entirely different than the technological developments which relied on workers in the past. Specifically, investment in information and communication technologies in the last two decades have boosted productivity across the board, but have also led to the automation of repetitive jobs. This is closely related to the literature on labour market polarization, which we mentioned in our discussion of earnings inequality above.

17 This assumption was initially based on historical observation, and it led to the development of theories in which the income shares of factors of production remain constant over time because of the nature of production technology in the economy.

18 Gross operating surplus is the income of corporations, governments, households, and non-profit institutions serving households accruing to the capital factor of production from the production of goods and services. Its increased share was driven by increased net operating surplus of corporations (i.e. capital remuneration) and a slight uptick in capital consumption by corporations (likely due to the increased importance of ICT capital investments, which depreciate quicker than conventional capital equipment due to obsolescence).

The OECD (2012) also finds that globalization accounted for at least 10 per cent of the fall of labour's share of income in advanced economies. Consistent with Dufour and Russell (2015), they argue that the effects of globalization operate on labour's share through bargaining power both because of increased domestic competition (reduced transportation costs allow for delocalized supply chains) and increased international competition (the threat of offshoring and import competition).

Finally, the OECD (2012) proposes other more minor determinants of labour's share of income worth considering. They argue that the privatization of state major owned firms in many advanced economies in the early 1990s led to significant productivity gains, in part from shedding unproductive labour. Indeed, in the Canadian case Uguccioni (2016) found that the privatization of Canadian National Railway in 1995 was followed by significant cuts to labour at the firm. The OECD also argue that the coverage and structure of bargaining institutions also affect the extent of the fall of labour's share of income by affecting bargaining power. Minimum wages could also affect labour's share, although the direction of the effect is ambiguous; a minimum wage increase raises some workers' wages directly but may also incite employers to exploit opportunities for automation (especially because minimum wage workers are predominantly low skilled).

Conclusion

Over the 1976-2014 period, labour productivity in Canada grew by 1.12 per cent per year. Over the same period, median real hourly earnings were stagnant; they grew only 0.09 per cent per year. This means that while Canadian labour was growing more productive over time, middle-class workers did not feel that their living standards were rising.

In this article, we have decomposed the 1.03 percentage-point gap between labour productivity growth and median real hourly earnings growth into four components: earnings inequality, employer social contributions, labour's terms of trade, and labour's share of aggregate income. Our main accounting result is that rising earnings inequality accounts for half the 1.03 percentage-point gap, with a decline in labour's income share and a deterioration of labour's terms of trade accounting for the remaining half. Employer social contributions played no role.

If the increased income generated by labour productivity growth has not flowed to the median worker in the form of higher earnings, where has it gone? Our analysis suggests a two-part answer to this question:

1. **Higher earnings at the top and bottom of the earnings distribution**: Much of the increase in labour productivity over the 1976-2014 period did flow to Canadian workers - just not to the median worker. In recent decades, the fastest real wage growth has occurred at the top and at the bottom of the earnings distribution. Earnings in the middle of the distribution have been relatively stagnant.

2. **Higher incomes for capital owners**: Between 1976 and 2014, labour's share of aggregate income declined and capital's share increased.

Our accounting decomposition does not reveal the reasons for these developments, but in our discussion we related our findings to existing research that, we suspect, provides part of the explanation. Globalization has allowed capital to seek the highest returns globally and, at the same time, has brought workers in Canada's traded goods sector into competition with the workers of low-wage countries such as China and India. At the same time, technological developments in robotics and computer software have increased the scope for capital-labour substitution in the performance of routine production tasks. Such tasks - production-line work, repetitive white-collar work, and so on - formerly provided jobs with wages in the middle of the earnings distribution. Institutional factors, such as the decline of unionization, may have been an additional contributing factor.

As these forces play out, labour market outcomes for Canadian workers are increasingly bifurcated. Highly skilled workers (e.g. people who can design new computer software) enjoy high earnings growth. Their increased demand for services may deliver spillover benefits in the form of higher wage growth in low-wage occupations. But in the middle, earnings do not grow.

Our findings do not imply that labour productivity growth has not been beneficial for Canadian workers, nor does it imply that policy efforts to raise productivity growth would be misplaced. Labour productivity growth has increased the compensation of Canadian workers, just not in the 'middle class.' To the extent that Canadians are unhappy with the way in which income growth has been distributed in recent decades, policy can be used to adjust that distribution. Productivity growth makes this easier, not harder; it is easier to ensure that everyone gets a larger slice of the pie when the pie itself is growing over time.

That being said, the forces that are likely causing the stagnation of middle-class earnings are unlikely to disappear in the near future. If anything, the possibilities for further substitution of capital for labour are likely to expand with the advent of self-driving vehicles, self-service technology in retail, automated fast food preparation, and so on. At some point, policymakers will have to grapple with the implications of these changes for the living standards of the middle class.

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Two Books for the Price of One: Review Article of *The Rise and Fall of American Growth* by Robert J. Gordon

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ABSTRACT

Robert Gordon has written a remarkable book; actually two "books," one about the past and one about the future. The first "book" is an account of the dramatic changes in American living standards since 1870. Looking forward, the second "book" makes the case that the miracles that powered the economy upward in the century to 1970 cannot be repeated and that the rate of economic growth has stepped down. Moreover, given headwinds facing the economy, Gordon argues that the typical American family will see only sluggish improvements in living standards. The first "book" is truly extraordinary in its coverage and creativity - it is insightful, compelling, and highly entertaining (and would be for non-economists as well as economists). The second "book" - not so much. It is more speculative and controversial. While Gordon's more pessimistic narrative has gained significant traction, I argue that there is plenty of room for optimism.

Robert J. Gordon's *The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War* (Princeton University Press, 2016) is a remarkable book; well, actually two "books," one about the past and one about the future. The first "book" is an account of the dramatic changes in American living standards since 1870. Looking forward, the second "book" makes the case that the miracles that powered the economy upward in the century to 1970 cannot be repeated and that the rate of economic growth has permanently stepped down from that heady pace. According to Gordon's rather grim view, the typical American family faces a new normal of sluggish growth in living standards.

I found the first "book" to be truly extraordinary in its coverage and creativity - it is insightful, compelling, and entertaining. The second "book" - not so much. It is more speculative and controversial, and I offer a counter view below.

Book I: The Past

Gordon first focuses on the dramatic rise in living standards in the United States from 1870 to 1940. To document these changes, he organizes the narrative in terms of key features of daily life. On its surface, the organization appears to track that of household consumption in the national accounts, covering the major categories of goods and services consumed by households, including chapters on food and

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clothing, the character of home life, as well as transportation and communication.

This framework would naturally lead to measuring living standards with real GDP per person. However, Gordon is careful to highlight two shortcomings of real GDP per person as a measure of living standards. First, he argues that properly measured real GDP per person rises faster than in official statistics because price indexes fail to capture some of the welfare benefits of new and improved products, such as antibiotics. Second, Gordon appropriately has a more expansive view of living standards than just what appears in the national accounts. He includes the role of home production, increases in the quality of leisure time, significant declines in the unpleasantness of work, as well as dramatic improvements in health and mortality. Accordingly, he also includes chapters on health; working conditions (both for men mostly working outside the home and for women working mostly inside the home in the earlier decades); as well as the role of risk in everyday life.

This material is magnificent and a terrifically fun read. The major theme for the period from 1870 to 1940 is the revolutionary change in living standards. Each page is chock full of carefully gathered data along with anecdotes and fascinating insights into life in an earlier era. This in-depth analysis reaches far enough back before our time that many of the facts will be startling to all but those who have studied this period. Indeed, one could randomly pick pretty much any page and find an interesting tidbit that reveals just how dramatically life has changed since 1870.

Here is a snapshot of life in 1870: 172 babies out of every 1,000 died in infancy. For Americans who survived childhood, few were in school past age 12. Diets were repetitive and bland, with heavy reliance on salted and smoked pork and corn. Home life was dark, dirty, smelly, and going to the bathroom meant using a chamber pot or the outhouse. Most jobs required hard physical labour, with 87 per cent characterized as unpleasant. While the quality of life certainly had moved beyond "nasty, brutish, and short," Gordon reminds us that living standards were shockingly primitive by the norms of modern life in America.

Gordon next focuses on the period from 1940 to 2015. This section also is exceptional in its breadth and coverage. It covers the same broad topics, describing the further advances in key areas, including food, clothing, housing, transportation, and entertainment. Gordon highlights the role of air conditioning (making more intensive development of the South and Southwest feasible), the interstate highway system, and commercial air transportation. The main theme in this part of the book is that advances were evolutionary rather than revolutionary, especially after 1970. And, Gordon begins weaving into his narrative the precursors of the period of slower growth from 1970 to 2015.

Book II: The Future

The second "book" makes Gordon's well-known argument that the first and second industrial revolutions that lifted growth through 1970 cannot be repeated. Moreover, the revolution in information and communications technologies (ICT) just does not stack up to earlier innovations in terms of their impact on economic growth. Combined with the economic headwinds that Gordon predicts will slow growth in living standards, he argues that this state of play condemns the United States to a disappointing economic future. Gordon marshals the evidence as well as anyone could to make the downbeat case. That being said, much of his evidence also could be used or reinterpreted to support a more optimistic view.

The first part of his argument is that the current pace of innovation can support a rather paltry rate of increase in labour productivity growth relative to the long-run historical average. In particular, he forecasts an average rate of growth in total economy real GDP per hour of 1.2 per cent from 2015 to 2040, compared with 1.6 per cent over 1970 to 2014 and 2.8 per cent over 1920 to 1970.[2] The second part of his argument is that the economy faces a set of headwinds that will restrain increases in real median disposable income per person to just 0.3 per cent a year over this period. While his argument is extensive, counter arguments can challenge his conclusions.

The Slow Pace of Innovation?

Gordon argues that the pace of innovation in the future will look nothing like that prior to 1970 and that the ICT-related boost that occurred during the 1995-2004 period was a one-off event that will not be repeated. In particular, he makes the case that innovation in ICT will be slower than in the past and that productivity gains outside of the ICT sector will be limited. Regarding modest increases outside of ICT, Gordon indicates that this outcome should be expected both because innovations in these areas will continue to be more incremental and because gains in ICT will have a smaller impact outside of ICT than in the past.

To support this argument that progress in ICT will be more modest, he makes the case that especially rapid advances in semiconductor technology - a key driver of the ICT revolution - are behind us. He colourfully labels this argument the "Death of Moore's Law." (Moore's Law is the idea, put forward by Intel founder Gordon Moore in 1965, that the density of transistors on semiconductors will double every two years.[3])

A key exhibit in this argument is a figure (Gordon, 2016: Figure: 13-1) that plots the number of transistors on microprocessors over time; this line fluctuates around a steadily rising trend line that embodies Moore's Law. The series for the actual semiconductor count flattens out in recent years and dips slightly below the trend line. This flattening of the actual count could, of course, represent the end of Moore's Law; however, it occurs following an extended period in which the actual count was well above the trend line. As a matter of simple data analysis, it seems somewhat of an over-reach to suggest that the uptrend in a time series largely has come to an end because that series has slowed to slightly below its rapid upward trend. That would be like announcing the "Death of real GDP growth" when real GDP flattens out and dips in a recession.

More importantly, a recent paper on semiconductor prices by Byrne, Oliner, and Sichel (2015) provides evidence of continuing rapid advances in semiconductor technology. First, Intel's pace of advance in chip density (the number of transistors on a given area of silicon) remained just as rapid on average over the 2004-2014 period as over the 1994-2004 period. Looking ahead, Intel - the largest producer of microprocessors - recently stated that it remains on a path to double chip density every two and a half years, slower than in recent years but still quite rapid (Clark, 2015).

Second, and not surprising given the advances in chip density, measures of actual microprocessor performance - gauged in terms of how quickly microprocessors complete a suite of applications that users actually undertake - have increased around 30 per cent a year since the mid-2000s. Taken together, this evidence suggests ongoing rapid gains; accordingly, I dis-

2 Gordon's projection of a 1.2 per cent average increase in total economy real GDP per hour corresponds to roughly a 1.4 per cent rate of advance in output per hour in the business sector.

3 Moore's original formulation (Moore, 1965) pegged the doubling time at only one year, but in 1975 he revised the period to two years based on actual experience to that point.

agree with Gordon's assessment that the pace of innovation in ICT has recently slowed.

Regarding productivity gains outside of the ICT sector, the economic historian Joel Mokyr (2014) describes remarkable progress that is occurring in genetic engineering, materials science, 3-D printing and associated mass customization, and the gradual lessening of the importance of location and distance in the organization of work. He suggests that these and other new technologies have the potential to be highly transformative. I agree. As a blue sky example, if 3-D printing develops sufficiently, the structure of manufacturing could change dramatically with goods produced on demand and on location.

As for whether advances in ICT will boost the broader economy, Gordon states that technological progress in PCs largely has stopped (or at least slowed) because no one needs a more powerful PC, implying that users of PCs will not create additional productivity advances. The comment about PCs may be correct, but it completely misses the point. The locus of innovation has shifted far beyond the personal computer and the pace at which PC performance is improving tells us very little about the future impact of ICT. The locus of ICT innovation has shifted to software, mobile devices, robotics, artificial intelligence, virtualization and cloud computing, and a host of other areas.[4] And, access to computing power is becoming ubiquitous and available on demand with the rise of cloud computing and simpler interfaces. These changes seem likely to engender many hard-to-anticipate changes with the potential to boost productivity.

More generally, how should Gordon's productivity forecast for 2015 to 2040 be evaluated? I offer a few observations. First, as Branstetter and Sichel (2016) highlight, economists have a terrible record when it comes to forecasting productivity growth. During the 1930s and then again in the late 1980s and early 1990s, stretches of poor economic performance led to pessimistic narratives about the economic future. In the 1930s, Alvin Hansen (1939) projected an extended period of "secular stagnation" for the economy.[5] In the late 1980s and early 1990s, many economists expected continued weak productivity growth, and Paul Krugman (1990) penned the book *Age of Diminished Expectations*, arguing that slow growth would be with us for a long time. In both cases, the economy improved dramatically not so long after these gloomy prognostications. The lesson Branstetter and Sichel take from this record is that recent trends in productivity provide very little information about its future path.

Second, I would quibble with Gordon's reliance on past forecasts of technology as supportive evidence for his projection. While Gordon cites a fascinating array of past forecasts of technology that turned out to be more or less right, there are many examples of past forecasts of technology that turned out to be spectacularly wrong (Information Week, 2011; Telegraph, 2016). In 1876, Western Union concluded in an internal memo "This 'telephone' has too many shortcomings to be seriously considered as a means of communication." In 1943, the president of IBM suggested that, "I think there is a world market for maybe five computers." Lastly, in 1977 the founder of Digital Equipment Corporation (a leading maker of mini

4 Byrne, Oliner, and Sichel (2016) shows that the rate of quality-adjusted price decline for PCs slowed significantly after 2010. But,for tablets, quality-adjusted prices have fallen rapidly since Apple introduced the iPad in 2010.

5 Hansen (1939) described secular stagnation as "sick recoveries, which die in their infancy and depressions which feed on themselves and leave a hard and seemingly immovable core of unemployment." Larry Summers (2014) resurrected the term "secular stagnation," providing another gloomy take on U.S. economic prospects.

computers) argued that, "There is no reason for any individual to have a computer in his home."

These examples illustrate that predicting the future is hard. A more subtle point is that each of these incorrect predictions was made through the lens of then-current technologies. In 1876, telegrams were a far more effective communication tool than early telephones and their limited network. Our unfortunate forecaster at Western Union could not see how quickly telephones would advance, how rapidly their price would fall, nor how extensive the network would become. Not surprisingly, the same type of shortcoming afflicted the other prognosticators. I suspect that observers today suffer from the same inability to anticipate technologies that have not yet been thought of.

Finally, I have one other serious concern about Gordon's argument that the ICT revolution provided a one-time, one-decade boost to productivity growth. The economic effects of innovation rarely occur in a linear pattern, but rather come with a lag and in waves. Paul David (1990) makes a powerful case that the economic benefits of electricity occurred about a quarter of a century after the key inventions occurred, once electricity became more widespread and businesses had made the necessary adjustments to exploit electricity. Chad Syverson (2013) suggests that the gains from electricity occurred in waves. One wave started about 1915 and lasted about a decade. Then, an extended productivity lull occurred, followed by another upward surge. Productivity gains from ICT may or may not follow the pattern of those related to electricity, but the electricity experience certainly raises the possibility that the economy is undergoing a transition period prior to a second wave of productivity advance from ICT.

The Role of Headwinds?

While an increase in real GDP per hour of 1.2 per cent a year over the next quarter century would be disappointing, Gordon argues that the typical (median) American will see an even smaller rate of increase in real disposable income - just 0.3 per cent a year - as gains are restrained by a series of headwinds. These restraints on growth include rising inequality, slowing increases in educational attainment, demographic shifts that will restrain hours worked per person, and the fiscal challenges facing the United States.

I agree with Gordon on the restraining role of demographic shifts. On the other headwinds he cites, I think it is a tougher call. The year 2040 is a long way off; much could and will happen that is unexpected. Moreover, as Mokyr (2014) points out, the U.S. economy has faced enormous headwinds in the past and still has prospered. In the 20th century, the United States faced two World Wars, a drawn out Cold War, a major Depression, huge demographic shifts, and dramatic social changes. Still, the economy powered ahead. Each of the restraints that Gordon identifies outside of demographic changes - inequality, education, and fiscal challenges - could be overcome by good policy choices. Indeed, in the book's postscript Gordon provides a comprehensive summary of policies that have the potential to support and boost growth. Of course, in the current political climate in the United States, the easy call is to say that such policies will never happen. Yet, the United States has overcome major challenges in the past. Indeed, the year 1870 was just a few years after the Civil War, a period when political divisions and polarization likely were even greater than they seem now. Yet, 1870 was the beginning of an amazing century of growth.

Is a Brighter Future Possible?

What might a brighter productivity future look like? Branstetter and Sichel (2016) sketch out some possibilities outside of the ICT sector, quantifying possible effects related to advances in robotics, education, and health care. Branstetter and Sichel also highlight the importance of a widening pool of researchers around the world whose work can benefit people in all countries. They suggest that these and other changes could boost productivity growth well above its average pace during the past decade. That position is also supported by a simulation relying on a multi-sector Solow growth model, which suggests that the current disappointing pace of productivity growth is well below the steady-state growth rate implied by the model.[6] Indeed, a plausible alternative simulation points to steady-state labour productivity growth of 2¼ per cent a year in the business sector. While such a growth rate is far above productivity's recent pace, it is just about equal to the average growth rate of business sector labour productivity since 1889.

Should one believe this brighter scenario given Gordon's case that growth has permanently slowed? The pessimistic narrative has gained considerable traction recently, aided by the very weak performance of actual productivity. However, the reasons for that poor performance are not well understood by economists, and, at key times in the past the emergence of a consensus around a downbeat view of the future occurred shortly before a productivity revival. Will the United States experience such a revival in coming decades? We will not know the answer until the future unfolds, but I believe that a brighter scenario is highly plausible and that that possibility has been too readily dismissed. In short, there is plenty of room for optimism.

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6 The simulation is based on an update of the steady-state analysis in Byrne, Oliner, and Sichel (2013).

Comments on Daniel Sichel's Review Article on *The Rise and Fall of American Growth*

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ABSTRACT

Daniel Sichel's review focusses mainly on the future of innovation and technology. In contrast, my book is mainly about the past, and the reasons why the growth rate of total factor productivity in the years since 1970 has averaged only about one-third the rate registered between 1920 and 1970. My explanation is that a series of "Great Inventions" in the late 19th century, led by electricity and the internal combustion engine, utterly changed methods of production in the business economy and conditions of work on the job and at home. The digital revolution since 1960 has transformed business methods further and led to a temporary recovery of productivity growth between 1995 and 2004, but slow growth since 2004 suggests that the major impacts of the digital revolution are largely over, while technological transformations in the future will be evolutionary rather than revolutionary.

Daniel Sichel's thoughtful review article in this issue of the *International Productivity Monitor* divides my book *The Rise and Fall of American Growth: The U.S. Standard of Living since the Civil War* (Princeton University Press, 2016) into two parts, devoted respectively to the "past" and the "future". His review consists of three paragraphs about the past and 11 about the future. Readers of Sichel's review who have not seen the actual book might be surprised to learn that Sichel has stood the book's organization on its head. In contrast to his review, the book devotes 16 chapters to the past, one to recent and future innovation, and one to the "headwinds." Sichel's main topic, whether to be pessimistic or optimistic about future technological change, is a minor side-show in the book.

The Growth Slowdown Has Already Happened - When and Why

Instead, the book's case for the decline in American growth rests on what has already happened prior to 2015, not what is about to happen. Slower growth is nothing new, but extends back to 1970. In the data that I constructed for the book that refer to the total economy, the annual growth rate of total factor productivity (TFP) reached 1.89 per cent for the 50 years between 1920 and 1970, and has been just one-third as much, 0.63 per cent, in the 45 years between 1970 and 2015. For the standard BLS data covering the private business sector, as interpreted by John Fernald, the annual TFP growth rate slowed from 2.05 per cent between

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1947:Q1 and 1972:Q4 to just 0.79 per cent between 1972:Q4 and 2016:Q3, and the latter rate drops further to 0.53 per cent when the dot-com decade of 1995: Q4 to 2004: Q4 is excluded.[2]

The primary contribution of the book is to argue that economic growth does not proceed steadily through time, and that there are good reasons why growth is faster in some eras than others. Growth ignited slowly with the first industrial revolution of the late 18th century and then gathered full speed with the second industrial revolution of the late 19th century. The book singles out what it calls the "special century" of 1870-1970 as exhibiting utter and complete change in methods of farming, manufacture, office work, and household production.

Its honour role of "great inventions" begins with electricity and all its spinoffs including electric light, elevators, machines for every industry, and home appliances. Joining electricity in importance is the internal combustion engine, which made possible motor and air transport. Other inventions of that era include entertainment and communications including the telephone, phonograph, radio, motion pictures, and television, and progress in chemicals and plastics. Central heating that was initially introduced in the late 19th century was joined by air conditioning in movie theaters and offices in the 1920s and 1930s and in homes starting in the 1950s. The standard of living was greatly enhanced by the diffusion of two old inventions - clean running water and piped waste disposal. In the first half of the 20th century, infectious diseases were largely eliminated, as was infant mortality, and life expectancy grew twice as fast as in the second half of the 20th century. While all this was going on, the American economy was benefitting from the permanent one-time boost in productivity as the urban-rural division shifted from 25-75 to 70-30.

The book asks why the third industrial revolution (post-1970) associated with computers and communications did not have the same impact on TFP as had the inventions of the earlier second revolution. Its answer is that the digital revolution, while profound, did not alter economic life along as many dimensions as had the earlier inventions. Computers did little to transform the "big three" of household consumption - food, clothing, and shelter. Transportation by auto, truck, and airplane was little changed by the computer. The big changes were in business practices as the typewriter and the Marchant calculating machine were replaced in the 1980s by personal computers driving spreadsheet and word processing software, and when in the 1990s the personal computer became connected to the rest of the world with access to search engines and e-commerce.

Interpreting the Recent Past

For reasons that are not entirely understood, the transition from typewriters to PCs to the internet, which could have been predicted to provide a steady impetus to the growth of business sector productivity between 1970 and 2015, had its main impact on growth in labour productivity and TFP during the shorter interval 1995-2004. That decade stands out in the data not only for a robust albeit temporary revival in TFP growth, but also for an acceleration in the rate of price decline and quality improvement in computer hardware, a boom in the GDP share of ICT investment, a temporary rise of economy-wide net investment, and a temporary surge in the growth of manufacturing capacity.

2 The TFP data are constructed by John Fernald from the Federal Reserve Bank of San Francisco based on the underlying BLS and BEA data. See http://www.frbsf.org/economic-research/indicators-data/total-factor-productivity-tfp.

When the book proposes controversially that the major impact of the third industrial revolution was largely over by 2005, it is again commenting on the past rather than speculating about the future. In the twelve years since the end of 2004, growth in TFP has been even slower than during 1973-95. Perhaps more important, the outstanding statistical features of the 1995-2004 decade have gone away - the GDP share of ICT investment peaked at 4 per cent of nominal GDP around 2000 and by 2014 had fallen to 3 per cent, economy-wide net investment has declined to the lowest level of the postwar years, and manufacturing capacity is barely growing. Worse yet, according to research at the Federal Reserve Board by David Byrne, the share of computer and communications hardware that is imported from abroad has increased to nearly 90 per cent, depriving the economy of this source of rapid TFP growth within the manufacturing sector.

More broadly, production methods in the business sector appear to have stabilized since 2005 after the rapid changes made possible by internet-enabled personal computers in the 1980s and 1990s, including the transition from card and paper catalogues to electronic catalogues with their unlimited capacity and their ability to keep track of inventory. While e-commerce continues to grow, it has reached only about 8 per cent of retail sales, leaving the other 92 per cent of the retail sector stuck in its traditional production methods with hardly a robot in sight, including humans at checkout counters, stocking shelves, and slicing meat and cheese at the deli counter. Goods travel from warehouses to retail stores in trucks driven by humans, and there is still little use of robots in warehouses. Even at Amazon warehouses, the robots merely move shelves to the humans, who still select the goods and pack them.

Throughout the service sector, checking in at the office of the doctor, dentist, or veterinarian is handled by a human sitting behind a 2005-era flat-screen desktop computer. Doctors and nurses now enjoy the efficiency of electronic medical records, but nurses still draw blood, hook patients up to IVs, and doctors still make diagnoses with equipment including CT scans and MRIs that was introduced long ago. Just as the ATM machine did not eliminate bank tellers, so the use of artificial intelligence (AI) has proven to be complementary to radiologists rather than replacing them all.

All this appears to neglect the smart phone revolution, which is truly a remarkable new invention that has become ubiquitous among young and old, rich and poor alike. There is a debate among economists as to how much extra consumer welfare has been created that has been excluded from GDP. The amount is surely very large, but social networks, photo-taking, and game-playing are part of consumer leisure activities that do not enhance business sector productivity or allow business firms to pay higher wages. While smart phones have made limited inroads in the business world, for instance as dashboard GPS assistants for taxi drivers and tablet ordering devices in fast-food restaurants, they have so far had little impact in replacing laptops and desktops, and may indeed subtract from productivity by being a distraction at work.

There are those who argue that the benefits of the smart phone demonstrate that productivity growth is fundamentally mismeasured. Yes, the consumer surplus has been omitted from GDP, but history provides a steady stream of examples of consumer welfare that has been created by inventions whose value was never included in GDP. The book argues that the value of omitted consumer surplus was greatest in the first half of the 20th century, when we consider the consumer surplus added by electric light, motor transport creating freedom to travel and ridding the streets of horse manure, the value of kitchen appliances, bathrooms, running water, central heating, and above all the cure of infectious diseases and infant mortality along with the extension of life expectancy.

The Future of Productivity Growth

The book's forecast of future labour productivity growth for 2015-2040 is 1.2 per cent for the total economy, about the same as the 1.26 annual rate registered in Fernald's quarterly business sector data for 2004:Q4 to 2016:Q3. Thus I am not forecasting some new age in which innovation disappears. There has been lots of innovation in the past 12 years and I expect it to continue in the areas of medical advances, 3-D printing, robotics, artificial intelligence, and self-driving vehicles.

A bedrock assumption is that the temporary productivity growth revival of 1995-2004, that brought us the transition from the typewriter to the web-enabled personal computer with its plethora of free information, will not recur because none of the other characteristics of the 1995-2004 era are present now, because IT investment is now low as is economy-wide net investment, because computer equipment is increasingly imported rather than produced domestically, and because the growth of manufacturing capacity has slowed radically since its late 1990s bubble.

Sichel's view of the future rests in part on the convincing work with his co-authors showing that official statistics understate the rate of advance of semiconductor technology. But none of this research forecasts an acceleration of advance beyond that already experienced since 2005. However fast semiconductor technology has advanced since 2005, it has not mattered for business sector productivity. As Hal Varian, Chief Economist of Google, stated in a quote for the book, technological change in desktop and laptop computers has come to a halt "because no one needs a superfast chip on their desktop."

Sichel offers numerous examples of ongoing innovation that make him optimistic that future labour productivity growth will be faster than my assumed 1.2 per cent rate. But he does not consider the countervailing possibility that it could be slower, as it has been in the real world which has generated business sector labour productivity growth of only 0.6 per cent in the six years since 2010.

The Headwinds

Sichel devotes only a single paragraph to the headwinds. He accepts the demographic headwind, the fact that the retirement of the baby boomers will reduce hours worked per member of the population for most of the next 25 years, reducing growth in output per capita by 0.4 per cent per year. He dismisses the education, inequality, and fiscal headwinds, suggesting that they can all be overcome by "good policy choices."

I take the headwinds more seriously. The steady advance of educational attainment was a basic source of productivity growth in the 20th century, but now high school attainment has reached a plateau while college attainment inches up, increasingly inhibited by tuition cost inflation. Most of those who enter community colleges drop out, while 40 percent of those who graduate from four-year colleges are unable to find a job that requires a college education. The sources of rising inequality are not going away, nor are the barriers to social mobility faced by children growing up in poverty as contrasted with children lucky enough to have two college-educated parents.

The book concludes the headwinds section with a section on "sociological decay," a set of changes which government policy can do little to offset. Marriage has declined as a share of the population, particularly for those with a high school education or less. The percentage of children growing up in single-parent families has greatly increased, as has the share of the high-school educated male population which has experienced time in prison. These inescapable facts suggest that the quality of the labour force may decline in the next two decades rather than improve. Nothing in Sichel's review denies the likelihood that future growth of median income per person will be substantially slower than productivity growth, close to if not equal to the 0.8 percentage point subtraction suggested in the book.

Final Assessment

The main point of the book is not about the future but about the past. Economic growth is not a steady process but for good reasons peaked in terms of labour productivity and TFP growth in the middle five decades of the 20th century, 1920-70. Sichel's hopes for the future cannot erase the decline in TFP growth by roughly two-thirds when the 1920-70 half century is compared to the 45 years since 1970. Since 1970 we have had 35 years of disappointing productivity growth only partially offset by 10 years of revival between 1995 and 2004. For me, the odds are 35-10 that the future will look much like the past 45 years excluding the miraculous but temporary 1995-2004 revival.

The Mystery of TFP

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Abstract

The objective of this article is to critically examine explanations of Total Factor Productivity (TFP) growth. TFP growth is analysed at the sectoral and aggregate level, using data for 10 industry groups covering the market sectors of 18 countries over the period 1970-2007 drawn from the EU KLEMS dataset. In all countries resources have been shifting away from industries with high TFP growth towards industries with low TFP growth. Nevertheless structural change has favoured TFP growth in most countries. Errors in measuring capital or in measuring the elasticity of output with respect to capital are unlikely to substantially reduce the role of TFP in explaining growth. The article concludes that the mystery of TFP is likely to remain as long as measurement error persists.

It is generally agreed that increases in labour productivity are the only long run source of growth in living standards. And since Solow (1956) a wide though not universal consensus has existed that behind the growth of labour productivity stands the growth of Total Factor Productivity (TFP). Without continuing TFP growth there can be no growth in labour productivity since capital accumulation by itself would be subject to diminishing returns. But what are the sources of TFP growth? The literature (surveyed by Hulten (2001)) suggests that *measured* TFP growth can arise in one or more of the following ways:

- From technical and scientific progress (including improvements in management techniques). This does not include progress embodied in new or improved types of capital or which is purchased directly via for example consultancy. Only progress which comes for free is to be included here.
- From learning effects, either learning by doing or learning from others, or more broadly from externalities and economies of scale.
- By reallocation of inputs towards more (or less) productive uses, either at the firm or the industry level.
- As an artefact of measurement error (as when increases in the quality of human or physical capital are wrongly ignored or output is mismeasured) or when some types of asset (such as intangibles) are wrongly omitted.

A particular concern in the literature has been the role of capital. In the past, at least some of measured TFP growth would have been rightly attributed to the fact that indices of capital input were crude, e.g. horsepower. And some, includ-

1 Nicholas Oulton is Member of the Centre for Macroeconomics, London School of Economics, and Fellow at the National Institute of Economic and Social Research. He thanks participants at the 34th IARIW General Conference held in Dresden, Germany in August 2016, in particular the discussant, Marcel Timmer, for comments. He also benefited from comments received when the paper was presented at the Philadelphia Fed, particularly from Leonard Nakamura. The current version has been greatly improved by the comments of Andrew Sharpe and two anonymous referees. This article is an abridged version of Oulton (2016). Email: n.oulton@lse.ac.uk.

ing the originator of TFP as a theoretical concept and pioneer of its empirical measurement (Solow 1957), thought that price indices of capital goods did not allow for quality change. But nowadays it is accepted that they should and this principle is enshrined in the OECD Productivity and Capital Manuals (OECD 2001 and 2009). But the extent to which capital is well-measured in practice is still open to debate and will be discussed in what follows. The earlier growth accounting literature also paid considerable attention to capital measurement (Griliches and Jorgenson 1967; Jorgenson *et al.* 1987); in particular, it introduced the important distinction between capital stocks and capital services. The result of these pioneering efforts was to reduce but not eliminate the role of TFP.

This article discusses some of the (non-exclusive) explanations of TFP growth listed above. A particular focus is the extent to which they are consistent with the pattern of TFP growth at the industry level. For example, it is not obvious how technical and scientific progress leads, year by year, to TFP growth in retailing. The factors which are important here are likely quite different from those which are important in (say) semiconductors. The fact that industry TFP growth rates differ suggests adding a fifth source of TFP growth at the aggregate level:

- Shifts in the structure of output and demand leading to changes in the aggregate growth rate of TFP and hence of aggregate labour productivity. These shifts could be favourable or unfavourable to growth.

The article therefore employs data from the EU KLEMS dataset to study the properties of TFP growth at the industry level. It seeks to quantify and assess the sources listed above as causes of TFP growth (except I shall have very little to say about the third source). I refer to the "mystery" of TFP since, though almost everyone agrees it is fundamental to growth, there is no consensus as to how much of measured TFP growth should be allocated to each of the five sources just listed. And as we shall see, the likelihood of significant measurement error bedevils further progress in understanding.

The first section of the article describes the EU KLEMS dataset to be used in the empirical work. This dataset provides the broad facts about TFP growth and the allocation of resources to different industries in 18 countries over the 1970-2007 period (though not every country has data for all years).

Section 2 then turns to the issue of structural change (the fifth source of TFP growth) and whether it has tended to increase or reduce TFP growth at the aggregate level. This section is motivated by the observation that resources have been shifting into business services yet this industry has experienced negative TFP growth in 17 out of the 18 countries. The possibility of measurement error (the fourth source) plays an important part here.

Section 3 examines measurement error in more detail, considering whether mismeasurement of capital, usually leading to understatement of capital growth, can account for an appreciable part of measured TFP growth. Such mismeasurement could take the form of understated quality change, missing assets (such as certain intangibles), or failure to account for increases in the variety of capital goods available on the market.

Section 4 analyses whether, even if capital is measured correctly, its impact on growth may not be. There might be externalities which make the elasticity of output with respect to capital greater than the value suggested by capital's share in the value of output (the standard measure in the growth accounting literature); this is the second source of TFP growth. Whether the evidence is more consistent with a two-sector than a one-sector model is also considered. Section 5 concludes.

The EU KLEMS Dataset

The empirical analysis to follow uses data from the EU KLEMS dataset described in O'Mahony and Timmer (2009), which is freely available at www.euklems.net.[2] More specifically, the March 2011 update of the November 2009 release is used. This file contains data on national accounts and growth accounting variables for 29 countries over 1970-2007. In particular, it contains data on TFP (the value added concept), real and nominal value added, real and nominal gross output, labour services and capital services. Estimates of labour input incorporate changes in labour quality. Estimates of capital services distinguish between ICT and non-ICT assets and are estimated on a comparable basis across countries. However, these data are not available for all countries and all years. Data on TFP are only available for 15 European countries (Austria, Belgium, Czech Republic, Denmark, Spain, Finland, France, Germany, Hungary, Ireland, Italy, Netherlands, Slovenia, Sweden, and the UK) and three non-European countries (Australia, Japan and the United States). The maximum number of annual time series observations for a country is 37 (Italy and the UK) and the minimum number is 11 (Slovenia).[3]

The EU KLEMS dataset has two great strengths. First, it is consistent with the national accounts of the countries included. Second, it goes beyond the national accounts by using a common methodology for estimating labour quality and capital services. Furthermore, labour quality and capital services are estimated in a disaggregated manner: 18 types of labour (distinguished by educational attainment (three types), sex (two types) and age (three groups)) and seven types of capital asset (three in ICT and four in non-ICT assets).[4] Labour input is measured by hours worked, not number of workers.

The EU KLEMS dataset therefore contrasts with micro (firm-level or establishment-level) data which are not usually consistent with the national accounts. Also in micro data, estimates of capital and labour are often crude. For example, for capital frequently only nominal book value (a stock not a flow measure) is available which then has to be deflated by an overall deflator. This is generally the case for all studies based on company accounts (e.g. Bartelsman *et al*., 2013; Hsieh and Klenow, 2009). Studies based on census data usually have to make do with investment, often aggregated over asset types, to which it is difficult to apply the Perpetual Inventory Model. Firm-level prices are usually not available so firm output has to be deflated by an industry deflator; on the rare occasions when firm-level prices can be observed there are often substantial differences between them and the corresponding industry-level deflators (Foster *et al.* 2008). Labour input must frequently be measured by the number of employees.

These criticisms are not meant to disparage micro-level studies, just to point out that the data on which they are based do not dominate empirically the data behind industry-level studies. So micro-level studies should be seen as complements to, not substitutes for, industry-level ones.[5]

2 The EU KLEMS database has been analysed by Timmer *et al.* (2010).

3 Table 1 in the on-line Appendix (csls.ca/ipm/31/oulton-appendix.pdf) provides the time period covered in the 18 countries.

4 ICT assets: computers, communication equipment, and software. Non-ICT assets: transport equipment, other machinery and equipment, non-residential structures, other. Residential structures are also in the EU KLEMS dataset but are not used in productivity analysis.

5 See Syverson (2011) for a survey of work on productivity based on micro data. The focus of much of this work is on explaining why productivity levels differ across firms rather than on explaining differences in growth rates. He does not address the issue of data reliability.

The growth accounting variables in EU KLEMS are broken down by industry in accordance with Revision 1 of the NACE.[6] The analysis to follow is confined to the market sector and its constituent 10 industries for two reasons. First, the measurement of real output in the non-market industry groups is problematic and likely inconsistent across countries. Second, since most of the non-market industries are publicly-owned, the motivations of decision makers are probably not focused on cost minimization or profit maximization, thus calling into question the growth accounting methodology. On average, across all available years and countries for which TFP data are available in EU KLEMS, the market sector as defined here accounted for 71 per cent of total value added and 75 per cent of total hours worked (Table 2 in the on-line Appendix).

In summary, the results to be reported are for 18 countries and the 10 industry groups comprising the market sector over a maximum time span of 1970-2007. The EU KLEMS dataset is in the process of being extended to cover the period of the Great Recession and its aftermath. But at the time this research began, it stopped in 2007. This means that the article can have nothing to say directly about the effects of the financial crisis on TFP, which has led to at the very least a temporary slowdown in growth.[7]

TFP Growth and the Allocation of Resources across Sectors: an Overview

TFP Growth

Chart 1 shows TFP growth in the market sector in the 18 countries, both the actual growth rate and the growth of TFP after smoothing by the Hodrick-Prescott (HP) filter. Most countries show little sign of either accelerating or decelerating growth.[8] Four countries were clearly above their own long run average at the end of our period: Austria, Finland, Netherlands and the UK. And five were by then below their own long run average: Australia, Spain, Ireland, Italy, and Japan, though in the case of Japan and Italy the HP trend is more encouraging. For five others, the data period was too short to allow a conclusion (Czech Republic, Germany, Hungary, Slovenia and Sweden). Much more striking is the difference between countries in their mean growth rate (Chart 2). Bottom of the class is Spain at 0.23 per cent per year and top is Hungary at 2.55 per cent per year (though over a short period). Other strong performers were Austria, Finland, Ireland and Japan.

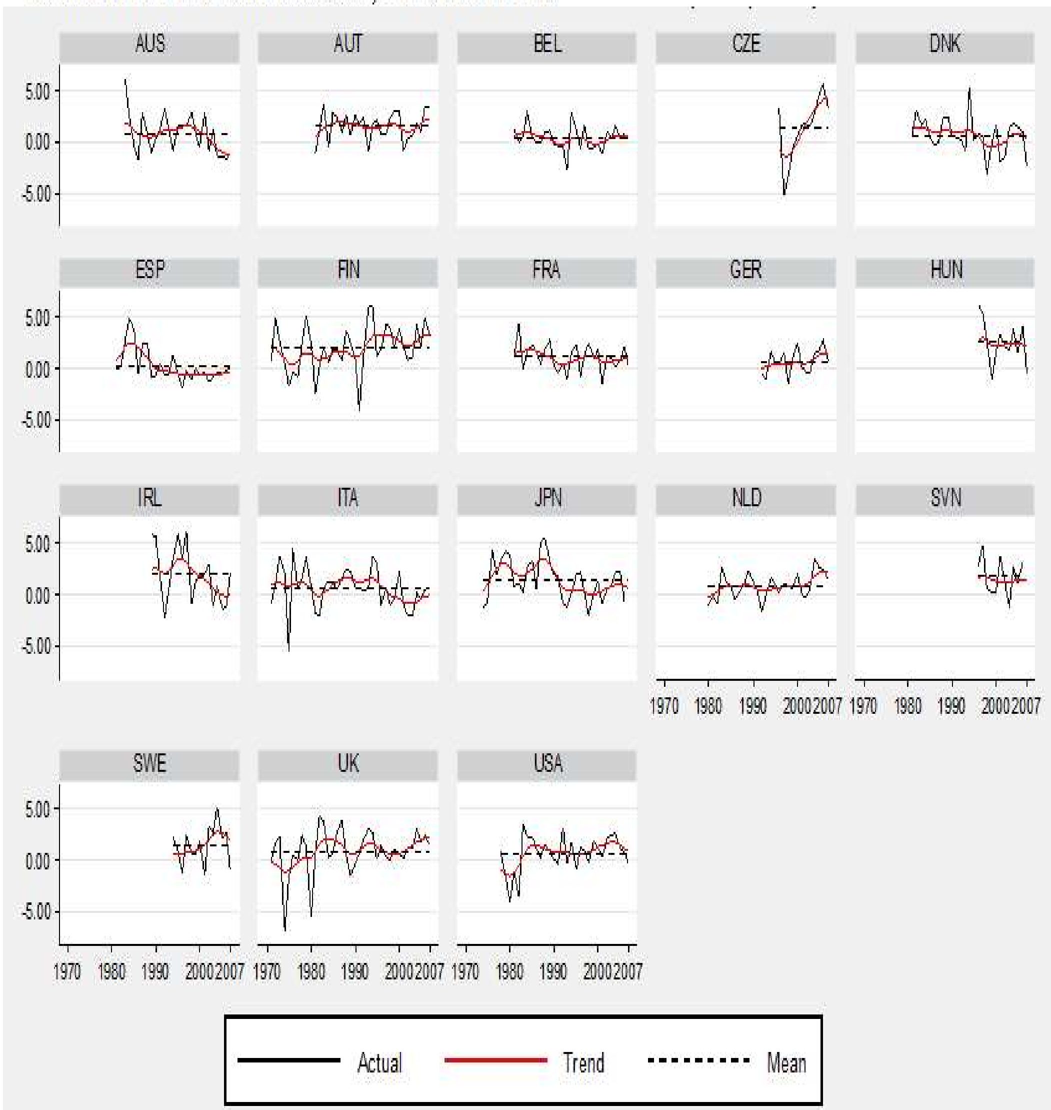
Chart 1 in the on-line Appendix to this articleshows mean TFP growth rates in 10 sectors within the market sector for the 18 countries in the EU KLEMS dataset. The highest growth rates are found in agriculture where the unweighted cross-country mean is 2.86 per cent per year and in manufacturing where it is 2.15 per cent. The lowest are in construction, hotels and restaurants, and business services where the cross-country means are -0.18 per cent, -1.16 per cent and -1.17 per cent respectively. It is

6 For a list of the sectors in the statistical classifications economic activities in the European community (NACE) see Table 2 in the on-line Appendix.

7 See Oulton and Sebastiá-Barriel (2016) who discuss whether the crisis will affect not just the level but also the future growth path of labour productivity and TFP.

8 This contrasts with labour productivity at the whole economy level where there are signs of a pervasive slowdown commencing prior to the global financial crisis, at least in large economies (Cette *et al.*, 2016; OECD 2016, chapter 5). For the United States Byrne *et al.* (2016) document slowing TFP and labour productivity growth since 2004.

Chart 1
Growth of TFP in the Market Sector, Per Cent Per Year

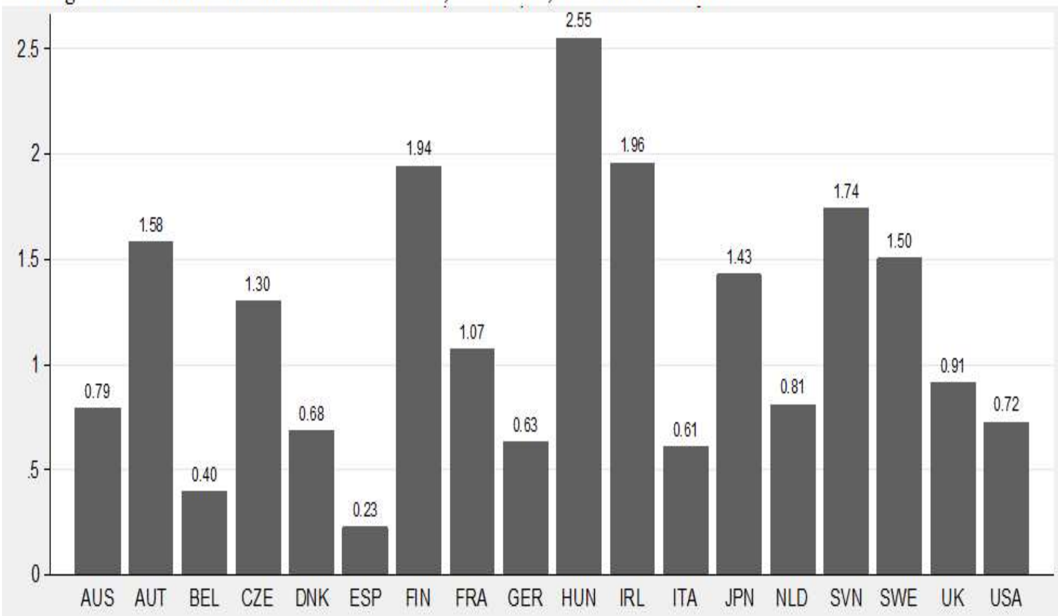


Source: EU KLEMS.
Note: Trend growth rate is that of HP-smoothed TFP level. Dashed lines denote country means of actual TFP growth rate.

worrying that there are a considerable number of negative rates. For example, eight out of 18 countries show negative TFP growth in mining and quarrying, five in electricity, gas and water, nine in construction, twelve in hotels and restaurants, five in finance and no less than seventeen in business services.

Negative TFP growth suggests firms in these industries are becoming less efficient over time or that technical knowledge is being forgotten, which seems highly implausible in peaceful conditions. Negative growth may be explicable in some cases. For instance in mining and quarrying deposits may be becoming harder to extract as they are progressively worked out. In electricity, gas and water an increasing burden of environmental regulation might be the cause: the costs of meeting the regulations are measured but the benefits in terms of lower emissions are not included in output. These explanations do

Chart 2
Average TFP Growth Rates in the Market Sector, 1970-2014, Per Cent Per Year



Source: EU KLEMS.

not seem to apply to construction or hotels and restaurants and still less to business services which as we shall see is one of the sectors to which resources are shifting in all countries.

Hence one must suspect measurement error, as already noted by Timmer *et al.* (2010) in the case of business services. If measurement error is present the first place to look is errors in output measurement. It is well known that price indices for private services are poorly developed by contrast to those for industrial products (though even those are not beyond reproach as discussed below).[9] It is quite plausible that the relative prices of sophisticated services like legal and advertising services or software are falling but that this is not picked up by the deflators actually used (often the GDP deflator or the CPI).

Value Added Shares

The pattern of resource allocation, as measured by the nominal value added share of each sector in market sector GDP, has been changing in all countries (as shown by Chart 2 in the online Appendix). In most countries, the share of agriculture and manufacturing has been declining while that of finance and business services has been rising. The agriculture share is falling in all countries except perhaps the United States. The share of manufacturing has been falling in 11 countries (including even Germany). In construction in most countries the share is flat. The share of wholesale and retail trade shows little change. The share of hotels and restaurants is flat in most countries. Finance displays a rising trend in nine countries though in some the rise is in the first half of our period, e.g. France. The clearest pattern is seen in business services whose share has been rising in every country. This means that in most countries resources have been shifting away from agriculture and manufacturing, where TFP growth is apparently at its most rapid, towards in particular business services where TFP growth is measured as negative. The implications of this (on the face of it) puzzling fact will be pursued in the next section.

9 See Bean (2016, chapter 2) for UK evidence on this.

Structural Change and Increasing Specialization

The first aim of this section is to show theoretically that aggregate TFP growth rises when resources (value added) are shifting towards industries supplying intermediate goods and services. This is the case even when these supplying industries themselves have low TFP growth (provided it is positive). The second aim is to quantify the size of these effects in our 18 countries.

Aggregate and Industry-Level TFP Growth: Theory

Let us begin with a brief review of TFP growth at the aggregate and industry levels; see Oulton (2016) for a more detailed exposition. The growth rate of aggregate TFP (a.k.a. the Solow residual) is defined as

$$\mu := \hat{V} - \alpha\hat{K} - (1-\alpha)\hat{L} \qquad (1)$$

where V is real GDP, K is aggregate capital services, L is aggregate labour input, α is the capital share, and hats denote growth rates. The symbol ":=" denotes a definition. Assuming marginal cost pricing and that a given input receives the same price in all industries, the Solow residual in a multi-industry setting is interpretable as a measure of the outward shift of the production possibility frontier made possible by technological change, with all inputs (including intermediate ones) held constant (Hulten, 1978; Gabaix, 2011, Appendix B).

The economy is made up of different industries and it seems plausible that the rate of technical progress varies across industries. How is the aggregate rate of technical progress related to the rates in different industries? Consider an industry production function

$$Y_i = f_i(K_{i,1}, \ldots, K_{i,C}; L_{i,1}, \ldots, L_{i,D}; M_{i,1}, \ldots, M_{i,N}; t) \qquad (2)$$

Here Y_i is real (gross) output in the i-th industry (i = 1,...,N) and there are assumed to be C types of capital K_{ik}, D types of labour L_{il}, and N types of intermediate input M_{ij} (produced by the N industries but possibly also imported). Now let μ_i^{GO} denote TFP growth in industry i.[10] Taking the logarithmic derivative of the production function with respect to time yields an expression for μ_i^{GO}:

$$\mu_i^{GO} = \hat{Y}_i - \sum_{k=1}^{C} \alpha_{ik}\hat{K}_{ik} - \sum_{l=1}^{D} \beta_{il}\hat{L}_{il} - \sum_{j=1}^{N} m_{ij}\hat{M}_{ij} \qquad (3)$$

where $\alpha_{ik}, \beta_{il}, m_{ij}$ are the elasticities of output with respect to capital, labour and intermediate inputs. Assuming competitive conditions these elasticities can be equated empirically to the share of each input in the value of gross output (the input cost shares).

Given this measure of μ_i^{GO} for each industry, it can be shown that aggregate TFP growth is[11]

$$\mu = \sum_{i=1}^{N} d_i \mu_i^{GO} \qquad (4)$$

10 The superscript "GO" indicates that this is the gross output concept of TFP growth. There is an alternative approach to industry-level TFP measurement based on industry-level value added. The gross output concept of industry TFP growth is more fundamental than the value added one. The value added concept is derived from the gross output one under an additional, restrictive assumption: real gross output per unit of real intermediate input is determined entirely by input prices and can never be reduced by technical progress. It can be shown that the TFP measures based on gross output and value added satisfy the following relationship: $\mu_i^{VA} = \left[\frac{GO_i}{VA_i}\right]\mu_i^{GO}$, where GO_i and VA_i are the nominal gross output and nominal value added of industry i. We will use this equation to convert the industry-level value-added-based TFP measures from EU KLEMS into gross output measures, but otherwise we will not use the value added concept of TFP in this article.

11 For this aggregation result to hold we just need to assume that a given input earns the same return wherever it is employed. If this is not the case then the aggregate formulas become more complex with additional terms reflecting the shift of resources to or from industries where they are more highly valued (Jorgenson *et al.* (1987: 66). In this article, these complications are ignored. They are not likely to be of great empirical importance in advanced economies (at least, Jorgenson *et al.* (1987) did not find them important for the United States over 1948-79).

Here d_i is the Domar (1961) weight for the i-th industry, defined as

$$d_i := \left[\frac{GO_i}{GDP}\right] \quad (5)$$

where GO_i is the nominal gross output of industry *i* and GDP is nominal aggregate GDP.[12]

Increasing Specialization as an Additional Source of Growth

The aggregation result reveals that aggregate TFP growth depends not only on the industry-level TFP growth rates but also on the pattern of demand embodied in the set of Domar weights. This means that structural change - that is, change in the pattern of demand across industries - can lead to changes in aggregate TFP growth even with no change in any industry-level rate of TFP growth. A well known example of this phenomenon is the cost disease model of Baumol (1967). Suppose that over time consumer demand is shifting towards final demand services, such as entertainment, health and education, which have low productivity growth. Everything else being equal, this shift of resources toward industries with relatively low TFP growth reduces aggregate TFP growth.

But this is not the whole story. To see why, consider the Domar weight in more detail. It can be decomposed as

$$d_i = \frac{GO_i}{GDP}$$

$$= \frac{\text{Final Sales by } i}{GDP} + \frac{\text{Intermediate Purchases by } i}{GDP}$$

Consider for simplicity a closed economy. Then there are three points to note. First, the first ratio on the right hand side must be a fraction between 0 and 1 and these fractions must sum to 1 across industries since the sum of final sales equals GDP. Second, the second ratio on the right hand side can take any non-negative value. So the sum over industries of the Domar weights must be at least 1 (and is typically much greater, over 2, as we shall see). Third, it is possible for the sum of the Domar weights to rise over time if the degree of outsourcing (i.e. intermediate sales relative to gross output) is rising generally.

This adds a new source of aggregate TFP growth that is different from those usually considered. Even if industry-level TFP growth were the same across industries and constant over time, an increase in the degree of outsourcing in the economy (reflected in an increase in the sum of the Domar weights) would result in an increase in aggregate TFP growth.

This point is clarified by the following simple example. Consider a closed economy with only two industries. The first industry ("cars") makes only final sales. It buys intermediate inputs from the second industry ("business services") which uses only primary inputs and makes only intermediate sales. Then the Domar weights in the two industries are:

$$d_1 = \frac{GO_1}{GDP} = \frac{VA_1 + M_{1,2}}{GDP} = \frac{VA_1 + VA_2}{GDP} = 1$$

$$d_2 = \frac{GO_2}{GDP} = \frac{M_{1,2}}{GDP} = \frac{VA_2}{GDP}$$

Here $M_{1,2}$ denotes intermediate input sales from industry 2 to industry 1. Since industry 2 uses no intermediates itself and sells all its output to industry 1, $M_{1,2}$ is equal to both the gross output and the value added of industry 2. Since industry 1 produces all the final goods in this economy, its gross output is equal to aggregate GDP.

12 Note that under this approach there is no role for differences in the level of TFP across industries to affect the aggregate TFP growth rate, e.g. by shifts in labour and capital towards industries with a higher TFP level. This contrasts with the situation for labour productivity, on which see for example Reinsdorf (2015). The reason is that a given input is assumed to receive the same return in every industry, so there is no possibility for example of capital earning a higher return in some industries than in others. There is in any case competitive pressure to equalise TFP levels across different industries in a given country (Baumol and Wolff, 1984).

Now, suppose the degree of outsourcing increases, so that industry 1 uses more intermediates to produce a given amount of gross output. Industry 2 produces more intermediates to supply to industry 1. The result is a decrease in the value added share of industry 1 and an increase in that of industry 2 (i.e. $\frac{VA_2}{GDP}$ rises). The Domar weight of industry 1 remains unchanged, but that for industry 2 increases. As long as the industry-level TFP growth rate in industry 2 is positive, this change will result in an increase in aggregate TFP growth via equation (4).[13] This is true even if TFP growth in industry 2 is lower than TFP growth in industry 1.

So we have reached the paradoxical conclusion that the aggregate TFP growth rate can rise even if resources are shifting towards industries with lower productivity growth, provided these industries are selling intermediate and not final products (and provided that TFP growth in these industries is positive; if it is negative, then outsourcing will reduce aggregate TFP growth).[14] Intuitively, productivity growth in industries that produce intermediate inputs contributes indirectly to the output of the final goods industries that buy those intermediates, and it is the output of final goods that is relevant for aggregate productivity growth. Outsourcing (i.e. an increase in the value added share of intermediate input producers) increases the size of this contribution, even with the industry-level productivity growth rates held constant. Oulton (2001) provides a more fulsome discussion of the intuition behind this result.

How Much have the Domar Weights Changed in Practice?

Chart 3 in the on-line Appendix shows the Domar weights over time in the 18 countries in the EU KLEMS dataset for three important sectors: manufacturing, finance and business services. The weight for manufacturing is clearly declining in eight countries, flat in five, and clearly rising in only two. In finance, the Domar weight is rising in 14 of 18 countries. In business services, the weight is rising in all 18 countries.

A clearer picture emerges by collapsing the 10 sectors into three broad groups: the goods-producing or "production" part of the economy; consumer services; and services to other industries, or producer services.[15] The broad picture is that the Domar weight for the goods producing part of the economy has declined in 13 of the 18 countries (the largest declines were in Japan and the UK). For consumer services the weight rose by a modest amount. The weight for producer services services broadly defined (sections I, J and K) rose in all 18 countries and on average by more than the fall in the weight for production. In consequence there was a rise in the sum of the Domar weights in 13 out of the 18 countries. A rise in this sum reflects an increase in outsourcing and would push aggregate TFP

13 In this simplified case the sum of the Domar weights increases; the upper limit of the sum is 2. In general, if there were N-k industries selling final goods and k selling intermediate goods the limit of the Domar sum is again 2. In practice the Domar sum exceeds 2 (even in a closed economy) since all industries have some intermediate sales.

14 This is a qualification to the cost-disease argument in Baumol (1967). The latter is still correct as long as it is understood to refer to industries producing final, not intermediate, products. All this is explained more fully in Oulton (2001). The basic point was generously acknowledged by Baumol in Krueger (2001: 223), in Baumol (2002), pages 277-278, and further analysed in Baumol (2012), particularly chapters 9 and 10 (Wu 2012a and 2012b). Ngai and Pissarides (2007) subsequently showed that Baumol's original conclusion that the aggregate growth rate would decline need not follow in the long run: in a model with capital the equilibrium growth rate is constant even though employment shifts progressively to the stagnant sectors. However their model predicts that value added shares are constant in the long run and this is hard to square with the evidence presented above that these shares have been steadily changing over periods measured in decades.

15 Table 1 in the on-line Appendix provides a full list of the 10 sectors.

Table 1
Change in Domar Weights between First Year and Last Year

Countries	Net Goods Production	Consumer Services	Producer Services	Total
	A-F	G, H	I, J, K	
Australia	-0.255	0.151	0.227	0.123
Austria	-0.086	0.035	0.275	0.224
Belgium	-0.104	0.117	0.371	0.384
Czech Republic	0.179	0.005	0.124	0.308
Denmark	-0.308	-0.024	0.369	0.037
Finland	-0.022	0.050	0.272	0.300
France	-0.290	0.062	0.297	0.069
Germany	0.130	-0.008	0.177	0.299
Hungary	0.152	0.011	0.086	0.249
Ireland	-0.246	-0.027	0.306	0.033
Italy	0.003	0.182	0.369	0.554
Japan	-0.507	0.042	0.222	-0.243
Netherlands	-0.356	0.065	0.268	-0.023
Slovenia	-0.043	-0.017	0.090	0.030
Spain	-0.525	0.050	0.192	-0.283
Sweden	0.054	0.011	0.079	0.144
United Kingdom	-0.697	0.118	0.452	-0.127
United States	-0.458	0.003	0.300	-0.155
Mean	-0.188	0.046	0.249	0.107
Number negative	13	4	0	5

Note: The goods sector includes agriculture, hunting and forestry, and fishing; mining and quarrying; manufacturing; and electricity, gas, and water. Consumer services includes wholesale and retail trade and repair services. Business services includes transport, storage and communications, financial intermediation and business services excluding real estate (see Table 1 in the on-line Appendix).

growth upward if the industry-level TFP growth rates remained constant and positive.

Measuring the Impact of Structural Change

We are now in a position to estimate the impact of structural change on aggregate TFP growth, making use of equation (4):

$$\mu = \Sigma_{i=1}^{N} d_i \mu_i^{GO}$$

Gross output estimates of TFP growth by industry are not available, but they can be calculated from the value added estimates in EU KLEMS (see footnote 10). Then treating these as parameters we can estimate the effect of different patterns of demand, both final and intermediate (the Domar weights), on the aggregate TFP growth rate. Two natural questions are first, what would the aggregate TFP growth rate have been if the pattern of demand in each country had remained that of the beginning of the period? And second, what would it have been if the pattern at the end of the period had prevailed throughout the period?

Table 2 shows the answers to these two questions. For reference, column 1 shows the mean TFP growth rate in the market sector that was actually observed (as already shown in Chart 2). A first shot at the answers appears in columns (2), (3) and (6). Column (2), headed "Initial structure", shows for each country the mean TFP growth rate with the pattern of demand (the d_i) set equal to the average of the first two years of the sample in each country. Column 3, headed "Latest structure", shows a similar calcu-

Table 2
Effect of Structural Change on TFP Growth in the Market Sector, Per Cent Per Year

		No TFP adjustments		Only business services adjusted		Change in TFP growth due to structural change		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Country	Actual demand structure	Initial demand structure	Latest demand structure	Initial demand structure	Latest demand structure	No TFP adjust-ments	Only business services (B.S.) adjusted	B.S. adjusted to half Market Sector rate
Australia	0.79	0.75	0.60	0.68	0.67	-0.15	-0.01	-0.03
Austria	1.58	1.80	1.69	1.66	1.79	-0.11	0.13	0.06
Belgium	0.40	0.55	0.39	0.50	0.45	-0.16	-0.05	-0.08
Czech Republic	1.30	1.06	1.42	1.04	1.44	0.36	0.40	0.39
Denmark	0.68	0.76	0.95	0.68	0.99	0.19	0.31	0.28
Finland	1.94	2.02	1.90	1.88	2.06	-0.12	0.18	0.10
France	1.07	1.17	1.02	1.08	1.16	-0.15	0.08	0.03
Germany	0.63	0.71	0.69	0.60	0.75	-0.02	0.15	0.14
Hungary	2.55	2.50	2.58	2.50	2.66	0.08	0.16	0.13
Ireland	1.96	1.70	1.72	1.79	1.92	0.02	0.13	0.10
Italy	0.61	0.76	0.44	0.71	0.54	-0.32	-0.17	-0.21
Japan	1.43	1.50	1.36	1.44	1.46	-0.14	0.02	-0.04
Netherlands	0.81	0.83	0.72	0.75	0.83	-0.11	0.08	0.05
Slovenia	1.74	1.85	1.65	1.82	1.65	-0.20	-0.17	-0.19
Spain	0.23	0.33	-0.14	0.28	0.04	-0.47	-0.24	-0.25
Sweden	1.50	1.45	1.54	1.38	1.63	0.09	0.25	0.19
United Kingdom	0.91	1.17	0.66	1.11	0.78	-0.51	-0.33	-0.42
United States	0.72	1.07	0.49	0.94	0.57	-0.58	-0.37	-0.42
Unweighted mean	1.16	1.22	1.09	1.16	1.19	-0.13	0.03	-0.05

Source: EU KLEMS, March 2011 update of the November 2009 release (www.euklems.net).
Note: Column headed "Actual structure": annual TFP growth calculated using the actual, annually-changing weights. Columns headed "Initial structure": annual TFP growth calculated using the average of the Domar weights of the first two available years. Columns headed "Latest structure": annual TFP growth calculated using the average of the Domar weights of the last two available years. "Only business services adjusted" (columns 4, 5 and 7): for each year and country, TFP growth rate of business services set equal to TFP growth rate in the market sector in that year and country; other sector growth rates adjusted to maintain the original market sector growth rate. Column 6: for each year and country, TFP growth rate of business services set to half TFP growth rate in the market sector in that year and country; other sector growth rates adjusted to maintain the original market sector growth rate. "Change in TFP growth due to structural change": TFP growth with latest structure minus growth with initial structure. For each country, TFP growth averaged over the period for which TFP growth is available.

lation but with the pattern of demand set equal to an average of the last two years of the sample. In both columns (2) and (3) the actual TFP growth rates estimated for each industry are used. Column (6) shows the difference between columns (2) and (3): the growth rate under the latest structure minus the growth rate under the initial one.

The effect of structural change is seen to be predominantly negative. Only 5 out of the 18 countries show a positive effect: the Czech Republic, Denmark, Hungary, Ireland and Sweden. The unweighted cross-country mean of the change is -0.13 per cent per year. Arithmetically, the reason for this is clear: in all countries resources have been shifting to business services but in this sector TFP growth is almost invariably estimated to be negative. So any shift of resources towards this sector will seemingly have reduced the aggregate growth rate (it will make an increasingly negative contribution to the Domar-weighted sum).

As noted above the negative TFP growth rate in business services is very implausible. So in the next variant of the calculations, the TFP growth rate in this sector is set equal to the actual market sector TFP growth rate observed in each country and each year. That is, it is assumed that the overall TFP growth rate is correct, but the measured rate in business services is wrong. So there must be offsetting errors in the other sectors which need to be correspondingly adjusted to leave the aggregate rate unchanged.[16] See Oulton (2016) for details of this adjustment.

Columns (4), (5) and (7) show the results after the TFP growth rate in business services is set equal to the market sector rate, with corresponding adjustments to the other sectors. Now a different picture emerges, with 11 countries showing a positive effect of structural change; the unweighted mean of this change is 0.03 per cent per year. Though the overall average effect is small, the effect is quite large for individual countries such as Austria, Denmark, Finland, Germany and Sweden which all received a boost to productivity growth from structural change on the order of 0.1 to 0.3 per cent per year. For the 11 gainers there was an average boost to growth of 0.17 per cent per year. This can be compared to the average TFP growth rate in these countries of 1.4 per cent per year. So the effect is of an economically significant size.[17]

How sensitive is the finding that most countries have gained from structural change to the assumption that TFP growth in business services, correctly measured, equals that of the market sector as a whole? We can test this by setting TFP growth in business services equal to half that of the market sector in each year and each country (column 8 of Table 2). Naturally this reduces the effect of structural change; the cross-country mean increase in TFP growth due to structural change is now -0.05 rather than 0.03. But the pattern of gainers and losers is very similar: ten countries are net gainers and eight are net losers with the winners gaining on average 0.15 per cent per year and the losers losing 0.21 per cent per year.

It is also possible to show the contribution of each sector to the change in overall TFP growth stemming from structural change, based on the assumption that the TFP growth rate in business services is equal to that of the market sector (Table 3 in the on-line Appendix). The contribution of business services to the overall change is positive in all countries, ranging from 0.01 per

16 An alternative, more radical assumption is to adjust the business services rate upwards but to leave the rates in other sectors unchanged, thus raising the overall average. But this would be a dubious move for two reasons. First, insofar as business services are sold to other domestic sectors (rather than exported) an understatement of TFP growth in this sector (say because output is understated) means that TFP growth in the purchasing sectors is overstated. Second, that the aggregate rate is correct or at any rate more accurate than the sectoral rates can be justified by the way in which national statistical ofices (NSIs) estimate real GDP. Typically this is from the expenditure side since expenditure-side price indices like the CPI are considered more accurate than PPIs or service industry price indices; sectoral growth rates are then adjusted so that when aggregated they conform to the estimated growth rate of GDP based on expenditure. Hence the more radical alternative should be rejected.

17 There is a case for adjusting the TFP growth rate in finance as well, because of the well-known difficulties of measuring output here. In finance the TFP growth rate is usually positive but less than the aggregate rate (Chart A2). But adjusting the TFP growth rate of finance as well as that of business services does not make much difference compared with just adjusting business services. Ten countries now show a positive effect and the unweighted mean of the change is plus 0.04 per cent per year (Oulton, 2016).

cent per year to 0.16 per cent per year; it averaged 0.08 per cent per year. But in some countries, notably Japan, the United Kingdom and the United States, this was more than offset by a negative contribution from manufacturing, so that the overall effect of structural change is negative. In other words in these countries deindustrialisation has apparently gone so far as to impact negatively on overall TFP growth.[18]

Mismeasurement of Capital

In this section and the next I ask whether capital is mismeasured and if so, whether the mismeasurement is large enough to substantially reduce or even eliminate the role of TFP in the growth process.

Mismeasurement of Quality Change

It is entirely plausible that capital growth is understated due to understated quality change, i.e. overstated investment goods price indices (Gordon, 1990). But how much does this affect TFP measurement? The traditional argument (Jorgenson, 1966) is that any errors in measuring capital show up on the output side as well as the input side. If the growth rate of capital services is underestimated due to measurement error, this will tend to overestimate TFP growth. But there is an offsetting factor: the growth of GDP will be understated as well. This is because the growth of GDP is a weighted average of the growth rates of the expenditure components, one of which is investment. So the overall error depends on the size of the weights given to investment on the output side (the investment share in GDP) and to capital on the input side (the profit share).[19]

However, these results are for a closed economy. Consider by contrast an economy, typically a small one, which imports all its capital goods. Then there is no error in real GDP since investment is balanced by capital goods imports of equal size. So any error in real investment is canceled out by an equal error in real imports. But capital input is still understated. So in this case there is no offset and the error in capital measurement translates directly into TFP. In this case the TFP error is the profit share times the capital input error. For example, if there is a 1 per cent per year understatement of the growth of capital and the capital share is 0.35 then TFP growth will be overstated by 0.35 per cent per year. The significance of this can be judged by noting that the cross-country mean TFP growth rate was 1.16 per cent per year (Table 2). In general, the TFP error is likely to be larger in small countries than in bigger ones. But errors in measuring capital growth do not seem likely to eliminate TFP as a source of growth. According to Table 3, capital per hour is growing at 3-4 per cent per year. So a 1 per cent understatement of capital growth would be a large error but would reduce TFP growth by only about 0.35 per cent and that is before allowing for any countervailing error on the output side.

All this is for the aggregate economy. But the errors in TFP measurement are likely to be larger at the industry level. The reason is that most industries are users but not producers of capital goods. So there are no offsetting errors on the output side to at least partially cancel out the input side error and so reduce the TFP error. This means that TFP growth in capital-

18 The UK saw the second largest positive effect from business services but the largest negative effect from manufacturing. However, a substantial fraction of the UK's business services output is exported. So for the UK there is a case for revising up the growth rate of market sector TFP if indeed the growth of business services output is understated by conventional price indices. If so, the UK might finish up as a net gainer from structural change.

19 See Oulton (2016) for a methological exposition.

Table 3
TFP, Labour Productivity (LP), Labour Quality (LQ) and Capital Per Hour (KH) in the Market Sector, Per Cent Per Year (average annual rate of change)

Country	TFP	LQ	LP	KH	LP_ Solow	Capital share	Hypothetical Capital Elasticity (γ)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Australia	0.79	0.25	2.12	2.98	1.43	0.354	0.626
Austria	1.58	0.30	2.70	2.55	2.69	0.332	0.938
Belgium	0.40	0.43	2.27	4.77	1.03	0.328	0.386
Czech Republic	1.30	0.45	3.92	5.57	2.61	0.408	0.623
Denmark	0.68	0.33	2.30	4.58	1.30	0.295	0.432
Finland	1.94	0.63	3.86	4.50	3.49	0.289	0.719
France	1.07	0.57	2.59	3.41	2.01	0.264	0.591
Germany	0.63	0.06	1.89	4.73	0.94	0.271	0.386
Hungary	2.55	0.71	3.93	1.82	4.85	0.391	1.770
Ireland	1.96	0.03	3.88	3.61	3.48	0.447	1.066
Italy	0.61	0.12	2.07	3.98	0.92	0.260	0.489
Japan	1.43	0.56	3.48	4.25	2.70	0.343	0.688
Netherlands	0.81	0.37	1.78	2.24	1.58	0.315	0.631
Slovenia	1.74	0.74	5.24	3.46	2.90	0.204	1.304
Spain	0.23	0.55	1.98	3.39	0.91	0.360	0.423
Sweden	1.50	0.40	3.48	4.94	2.62	0.323	0.624
United Kingdom	0.91	0.43	2.47	4.78	1.74	0.285	0.427
United States	0.72	0.33	2.07	3.67	1.40	0.315	0.475
Cross-country mean	1.16	0.40	2.89	3.85	2.14	0.321	0.700

Source: EU KLEMS, March 2011 update of the November 2009 release (www.euklems.net).
Note: LP: real value added per hour worked. LQ: labour quality (labour services per hour worked, LAB_QPH in EU KLEMS). LP_Solow: TFP growth divided by labour share (estimated as LAB/VA in terms of EU KLEMS variables) plus the growth of labour quality. For each country, growth rates are Törnqvist indices built up from sectoral growth rates and are averaged over the period for which TFP growth is available. Capital share (col. 6): 1 minus labour share. The parameter γ (col. 7) is the hypothetical elasticity of output with respect to capital which would reduce TFP growth to zero: see equation (16).

goods-producing industries is likely to be understated and in other industries overstated.

Missing Capital Input

It is possible that whole classes of capital assets have been omitted from the growth accounting calculations because they have been misclassified as intermediate inputs. This argument was first raised in regard to software and R&D. In this case the argument was accepted and expenditures on software and R&D are now recognized as forms of investment in the System of National Accounts (SNA); software but not R&D appears as an investment in EU KLEMS. It has also been argued that there is a whole range of other expenditures, dubbed intangible investment, which should also be reclassified as investment. These include expenditures on building organizational capital, in-house training, and design and marketing.[20] These expen-

20 See Corrado *et al.* (2005) and (2009) for the United States, Dal Borgo *et al.* (2013) for the UK, and Corrado *et al.* (2013) for a comparison covering the United States, Japan and Europe.

ditures have not yet been accepted as investment in the SNA. But changing the SNA is a lengthy process and it is quite possible that some or all of these expenditures will be in a future SNA revision.

The effect of the shift from intermediate goods to investment goods for intangibles on TFP is quite complicated. The level of GDP rises since there are new forms of investment to include. But whether the growth rate of GDP changes depends on whether the new forms of investment are growing faster or slower than GDP. A similar point applies to the growth rate of capital on the input side. In fact the analysis is very similar to the case just considered of mis-measured quality change, except that in addition the various weights involved in the calculation also change. The net effect is that TFP is still an important factor in the growth process. TFP estimates that include intangible capital (Corrado *et al.*, 2013: Table 2) find that TFP accounted for 26 per cent of labour productivity growth in the EU (unweighted average), for 22 per cent in Japan and for 39 per cent in the United States over 1995-2007 (their Table 2). These figures are similar to estimates from the EU KLEMS database. While a fuller accounting for the inputs behind the growth process is clearly desirable, on the evidence so far it does not seem likely to eliminate TFP as a factor or even to change its importance in a growth accounting sense.

Increasing Capital Variety and the Romer Model

In Romer's (1986) and (1990) model of economic growth there is a goods sector with a production function of the following form:

$$Y = L_Y^{1-\alpha}\int_0^A \chi_j^{\alpha} d_j$$

Here a composite good (Y) is produced with the aid of labour (L_Y) and (a continuum of) A types of capital good ($\chi_1, \chi_2, ..., \chi_A$). The composite good can be either consumed or invested. In equilibrium the production function can be re-written as:

$$Y = K^{\alpha}(AL_Y)^{1-\alpha}$$

where K is aggregate capital services. This is identical to a standard Cobb-Douglas aggregate production function. Clearly, capital is subject to diminishing returns so the only long run source of growth is the factor A, the number of types of capital good, which acts here like labour-augmenting technical progress. If we apply conventional growth accounting to the goods sector under the usual assumptions we find that TFP growth is given by

$$\mu := \hat{Y} - \alpha\hat{K} - (1-\alpha)L_Y = (1-\alpha)\hat{A}$$

where $(1-\alpha)$ can be measured by the labour share (Barro, 1999). So TFP growth should now be interpreted as the growth in capital variety weighted by the labour share.

Suppose we apply the Romer production function to the EU KLEMS sectors studied here. How then should we interpret conventionally-measured TFP growth? After all, the latter may reflect conventional notions of TFP such as increasing efficiency or manna from heaven technical progress as well as increasing variety. We could in fact trivially expand the Romer production function to incorporate "conventional" TFP as well as increasing variety:

$$Y = BK^{\alpha}(AL_Y)^{1-\alpha}, B > 0$$

where B is conventional TFP, assumed to grow exogenously. Now the ordinary measure of TFP becomes

$$\mu = \hat{B} + (1-\alpha)\hat{A}$$

But how then do we decide how much of measured TFP growth should be attributed to increasing variety and how much to the other sources?

One response is that we should revise the measure of capital to take explicit account of the increasing (or for that matter decreasing) variety of capital types, whether human or physical. After all, the proximate source of productivity growth in the Romer model is more capital though not more of the same capital. And it is now generally accepted by NSIs that investment and capital should allow for increasing quality. So why not also for increasing variety? This is the approach suggested by Feenstra and Markusen (1992). But to apply their method it is necessary to know the range of inputs in every period and the expenditures on each. It is also necessary to know (or estimate) the elasticity of substitution between varieties. At the moment this makes the approach impractical on a large scale. But in principle it could be used to allocate measured TFP growth between increased variety and other sources.

Capital Externalities and the Relationship between TFP and Capital Accumulation

Externalities, Economies of Scale, and Learning-by-Doing: an Upper Limit

The previous section considered whether capital services are generally mismeasured and if so what is the likely size of the resulting error in TFP growth. Another possibility is that even if capital is correctly measured its impact may not be. In other words, the elasticity of output with respect to capital may exceed capital's share. This could be because of economies of scale. But at the industry level such economies seem likely to be important in only a few industries where a square-cube law prevails, such as pipelines or electricity generation. A more plausible reason is network externality effects as a new technology such as the Internet is deployed. Another is learning by doing arising from capital investment, either within the firm or by follower firms learning from early adopters.

If the elasticity of output with respect to capital (the capital elasticity) has been understated by the capital share, then how large would it have to be to eliminate TFP entirely as a source of growth? Suppose our model is

$$y_t = A k^{\gamma} h_0 e^{\lambda t} \tag{6}$$

where y is output per hour, k is capital per hour, h is human capital per hour worked (labour quality), λ is the growth rate of labour quality, and γ is the capital elasticity, which is now not necessarily equal to the capital share. Assume that TFP (A) is constant over time (though not necessarily across countries). Then the growth of output between time 0 and time t is given by

$$ln(y_t/y_0) = \gamma\, ln(k_t/k_0) + \lambda t$$

from which we can solve for γ:

$$\gamma = \frac{ln(y_t/y_0) - \lambda t}{ln(k_t/k_0)} \tag{7}$$

The parameter γ is therefore the hypothetical capital elasticity which would reduce TFP growth to zero. Columns (2)-(4) of Table 3 show the data necessary for calculating this parameter. Column (7) shows the resulting estimates while Column (6) shows the actual capital share for comparison. On average the hypothetical elasticity is more than twice as large as the actual share. This seems far too large a difference to attribute to network effects or learning-by-doing. Apparent exceptions are Belgium and Spain where the hypothetical elasticity is only about 12 per cent larger than their actual capital shares. But this is because both countries had exceptionally low TFP growth (Column (2)).[21]

We can also test the hypothesis that the capital elasticity exceeds capital's share econometri-

21 Hall and Jones (1999) and Caselli (2005) attribute most of the cross-country variation in levels of GDP per capita to TFP differences. Their measures of capital are cruder than the ones in EU KLEMS so the present finding can be taken as a useful confirmation of theirs. In fact, if the hypothetical capital elasticity which would reduce the cross-country differences in TFP levels to zero is estimated from the data in Hall and Jones (1999, Table 1), using the same model as above, its average value over all their 127 countries is 0.793. This compares with the value they assumed for the capital share, 1/3. The mean value of 0.793 is remarkably close to the mean value of 0.700 in Table 3.

cally. We can regress the growth of output per hour on the growth of capital per hour and check whether the coefficient on capital differs significantly from capital's share. This approach runs into well-known econometric difficulties since capital growth is likely correlated with the error term which includes TFP. Nevertheless, a model was estimated in which the current growth of labour productivity in the market sector depends on its own lagged growth rate and on the growth rate of capital per hour plus country and year controls. Both lagged productivity growth and capital per hour growth were highly significant. When estimated by OLS the long run capital elasticity was 0.42 and it was 0.40 when using the Arellano-Bond method. This is higher than the actual capital shares shown in Table 3 but not high enough to eliminate TFP as a source of growth.

TFP and the Solow model

In Solow's (1956) model, extended to include human capital, the long run growth rate of both output per hour and capital per hour is the TFP growth rate divided by the labour share, $\mu/(1-\alpha)$, plus the growth rate of labour quality.[22] In fact the actual labour productivity growth rate exceeds the rate predicted by the Solow model in 17 out of the 18 countries here; on average the actual rate is higher by 0.75 per cent per year (compare columns (3) and (5) of Table 3). The sole exception is Hungary. Also the growth of capital per hour exceeds that of labour productivity by on average 0.96 per cent per year; the only exceptions are Austria, Hungary, Ireland and Slovenia.

Two explanations come to mind. First, during a catch-up phase capital and labour productivity will grow faster in emerging economies than their long run rate. Against this we find actual growth exceeding the Solow prediction in mature economies as well as emerging ones and even in the United States which is not catching up to anyone. Second, the relative price of capital goods, particularly of ICT assets, has been falling in recent decades. So a two-sector model where the first sector produces consumer goods and some types of investment goods (e.g. buildings) while the second sector produces high-tech investment goods may be more appropriate (Whelan, 2001). In such a model the long run growth rate of capital exceeds that of output even though in value terms the capital-output ratio is constant. This is the case even for countries which import all their advanced capital equipment. Aggregate growth is still driven by TFP growth at home, but also by TFP growth abroad; the latter benefits capital-goods-importing countries via favourable changes in the terms of trade (Oulton, 2012).

Concluding Remarks

Based on an analysis of TFP growth in 10 industries within the market sector for 18 countries over the 1970-2007 period, drawn from the EU KLEMS dataset, we draw four main conclusions.

First, in all the countries considered here resources have been shifting out of agriculture and manufacturing, where TFP growth is high, and into finance and particularly business services where it is low. In fact, in business services TFP growth is measured to be on average negative in 17 out of the 18 countries studied. Despite this we conclude that structural change has probably been favourable to growth in most countries. The negative TFP growth in business services is very implausible. When this rate is set at the average rate in the market sector as a whole, with a corresponding downward adjustment in all other sectors to maintain the same

22 This can be seen from equation (6) after setting $\gamma = \alpha$, the capital share, and requiring that in the long run the growth of capital should equal the growth of output.

aggregate rate, structural change is found to favour growth in 11 out of the 18 countries.

Second, underestimation of quality change in capital goods could cause the role of TFP growth to be overstated and the role of capital to be correspondingly understated. And such underestimation, due to the failure of price indices for capital goods to fully reflect quality change, is plausible. But the upper limit for the effects of this mismeasurement seems to be fairly low, of the order of 0.35 per cent per year. At the aggregate level such an error is partially offset by a corresponding error in measuring the growth of output. However, at the industry level there is usually no such offset so here the effect on TFP is larger. Also the overstatement of TFP growth is larger in countries which import most of their high-tech capital goods.

Third, capital's role could also be understated if expenditure on some inputs is wrongly classified as intermediate consumption rather than as investment. The SNA now counts expenditures both on software and on R&D as investment where previously they were classified as intermediate. The net could be cast wider to include other types of expenditure on intangibles. But the evidence to date is that this will not reduce the importance of TFP in the growth process. This is because treating more inputs as investment changes the measurement of output as well as of capital.

Fourth, capital's role in the growth process would be larger if the elasticity of output with respect to capital were higher than capital's share, the latter being the standard growth accounting measure. This could be due to economies of scale, network externalities or to learning-by-doing. But we found that the increase in the elasticity necessary to reduce the role of TFP to zero was far too large to be plausible.

In summary, we have seen that any attempt to eliminate TFP from the growth story and replace it with some wider or better measure of capital seems unlikely to succeed. But we still have much to learn about TFP. Given the importance to TFP in growth theory and current fears of a pervasive growth slowdown (e.g. Cowen 2011; Gordon 2016), it is depressing that so much of the discussion still needs to be about measurement error. This is not the fault of the data compilers who are doing their best with limited resources. But though policy-makers everywhere are concerned about these issues, they are generally unwilling to devote the (quite limited) additional resources needed for improved measurement to advance understanding. Until this changes the mystery of TFP is likely to remain unresolved.

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Appendix Tables and Charts for "The Mystery of TFP"[1]

Tables

Charts

[1] Oulton, Nicholas (2016) "The Mystery of TFP," *International Productivity Monitor*, Number 31, Fall, pp. 68-87, http://www.csls.ca/ipm/31/oulton.pdf.

Table 1
The 18 Countries in the EU KLEMS Dataset for which TFP data are Available

Code	*Country name*	*First year*	*Last year*	*Number of years*
AUS	Australia	1983	2007	25
AUT	Austria	1981	2007	27
BEL	Belgium	1981	2006	26
CZE	Czech Republic	1996	2007	12
DNK	Denmark	1981	2007	27
ESP	Spain	1981	2007	27
FIN	Finland	1971	2007	37
FRA	France	1981	2007	27
GER	Germany	1992	2007	16
HUN	Hungary	1996	2007	12
IRL	Ireland	1989	2007	19
ITA	Italy	1971	2007	37
JPN	Japan	1974	2006	33
NLD	Netherlands	1980	2007	28
SVN	Slovenia	1996	2006	11
SWE	Sweden	1994	2007	14
UK	United Kingdom	1971	2007	37
USA	United States	1978	2007	30

Source: EU KLEMS, March 2011 update of the November 2009 release (www.euklems.net).
Note: The first and last years mark the period for which data on TFP growth are available for each country. TFP appears in EU KLEMS in level form so one year is lost in taking growth rates.

Table 2
Sectors of NACE, Revision 1

Sector code	*Sector description*	*Value added share of GDP, %*	*Share of total (whole economy) hours, %*
A & B	Agriculture, hunting and forestry. Fishing	4.3	8.3
C	Mining & quarrying	1.4	0.5
D	Manufacturing	22.1	21.1
E	Electricity, gas & water	2.4	0.9
F	Construction	6.6	8.0
G	Wholesale & retail trade; repair of motor vehicles, motorcycles, and personal and household goods	11.9	15.3
H	Hotels & restaurants	2.4	4.1
I	Transport, storage and communications	7.3	6.6
J	Financial intermediation	5.1	2.9
K (exc. 70)	Business services	7.1	7.0
L	Public administration & defence; compulsory social security	6.5	6.5
M	Education	5.0	5.3
N	Health & social work	6.1	7.8
O	Other community, social and personal services activities	3.3	4.0
P	Activities of private households as employers and undifferentiated production activities of private households	0.3	1.0
Q	Extraterritorial organisations and bodies	0.0	0.0
70	Real estate	8.2	0.9
A-K (exc. 70)	Market sector	70.6	74.6
A-Q	Whole economy (GDP)	100.0	100.0

Source EU KLEMS, March 2011 update of the November 2009 release (www.euklems.net).
Note 10 sectors, A-K (exc. industry 70, real estate), make up my definition of the market sector. Shares of GDP and total hours worked are means across 18 countries and time (maximum span is 1970-2007). Official name of sector K (including real estate) is “Renting and business activities”.

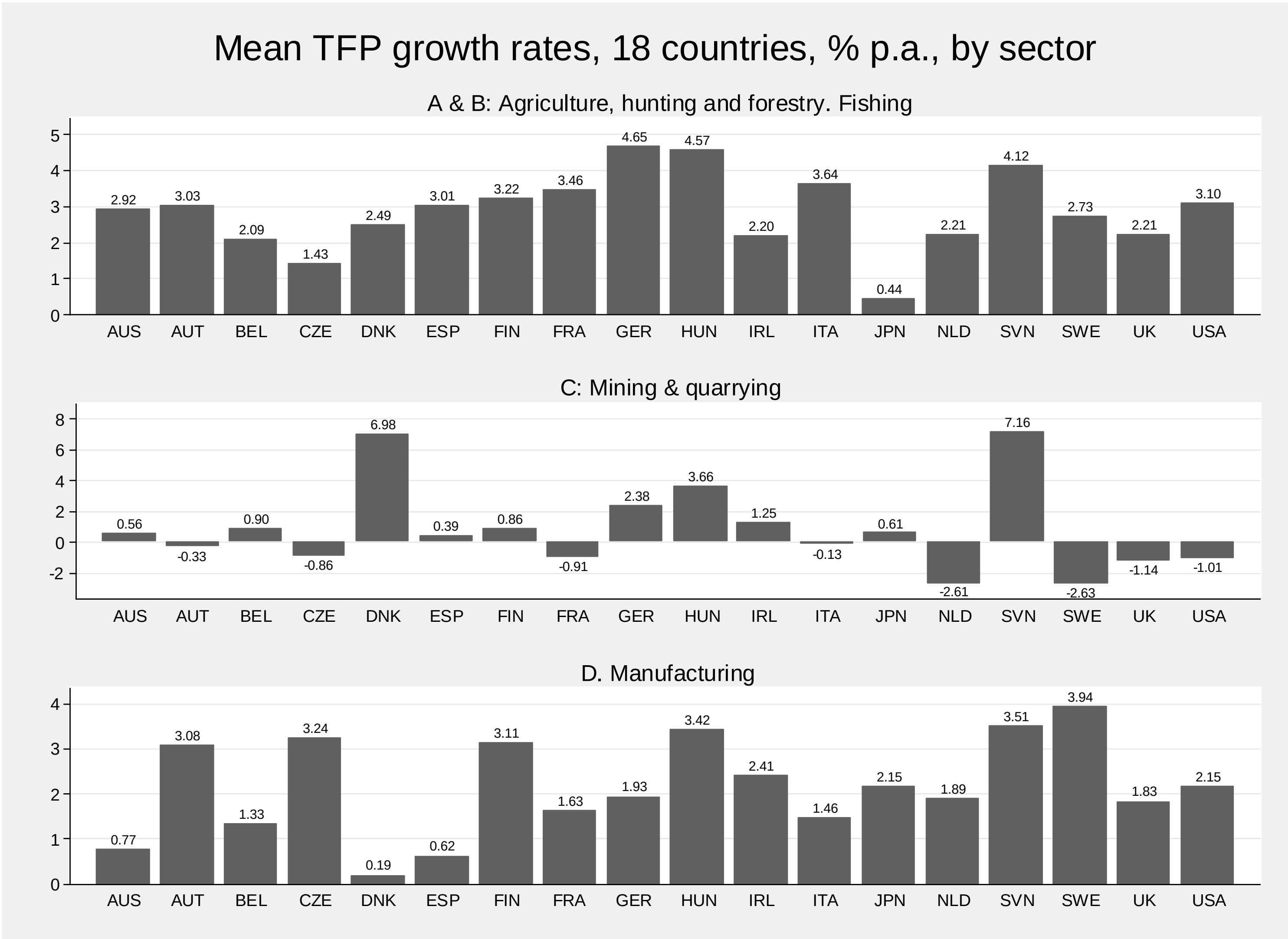
Table 3

Contribution of Each Sector to the Effect of Structural Change on TFP Growth, by Country (TFP growth in business services set equal to market sector rate)

Country	*Sectors*										
	A&B	C	D	E	F	G	H	I	J	K	*Total*
Australia	-0.09	0.00	-0.04	-0.01	0.00	0.04	-0.01	0.01	0.04	0.04	*-0.01*
Austria	-0.13	0.01	-0.03	0.04	0.01	0.01	0.00	0.06	0.00	0.15	*0.13*
Belgium	-0.04	0.01	0.00	-0.01	-0.01	-0.09	-0.01	0.02	0.04	0.05	*-0.05*
Czech Republic	-0.04	0.01	0.24	0.04	0.01	0.05	0.07	-0.02	0.02	0.03	*0.40*
Denmark	-0.15	0.25	0.00	0.00	0.00	-0.02	0.00	0.07	0.08	0.06	*0.31*
Spain	-0.15	0.00	-0.05	-0.01	-0.01	-0.02	-0.04	0.00	0.02	0.01	*-0.24*
Finland	-0.31	0.00	0.15	0.00	0.00	0.04	-0.01	0.06	0.06	0.18	*0.18*
France	-0.08	0.02	-0.06	0.02	0.00	0.04	-0.03	0.07	0.00	0.11	*0.08*
Germany	-0.02	-0.01	0.05	0.01	0.04	0.00	0.01	0.06	-0.01	0.04	*0.15*
Hungary	-0.21	-0.01	0.22	-0.01	0.00	0.01	0.00	0.04	0.04	0.07	*0.16*
Ireland	-0.18	0.01	-0.09	0.01	-0.05	-0.05	0.00	0.00	0.43	0.08	*0.13*
Italy	-0.27	0.00	0.04	-0.01	0.01	0.02	-0.05	0.09	-0.06	0.06	*-0.17*
Japan	-0.01	0.00	-0.23	0.02	0.04	0.05	-0.03	0.03	0.08	0.09	*0.02*
Netherlands	-0.06	0.06	-0.09	0.00	0.01	0.06	0.00	0.04	0.00	0.07	*0.08*
Slovenia	-0.10	-0.03	-0.03	-0.01	0.00	-0.01	0.00	-0.02	0.00	0.03	*-0.17*
Sweden	-0.04	-0.01	0.13	0.01	0.00	0.02	0.00	0.00	0.03	0.09	*0.25*
United Kingdom	-0.06	-0.03	-0.44	0.00	0.01	0.00	-0.01	0.07	-0.04	0.16	*-0.33*
United States	-0.06	0.00	-0.26	0.00	0.01	-0.01	0.00	0.00	-0.12	0.09	*-0.37*
Mean	*-0.11*	*0.02*	*-0.03*	*0.01*	*0.00*	*0.01*	*-0.01*	*0.03*	*0.03*	*0.08*	0.03

Source EU KLEMS, March 2011 update of the November 2009 release (www.euklems.net) and own calculations.
Note See text and note to Table 4. The rightmost column here is the same as column (9) of Table 4.

Chart 1



Mean TFP growth rates, 18 countries, % p.a., by sector
A & B: Agriculture, hunting and forestry. Fishing
2.92
3.03
2.09
1.43
2.49
3.01
3.22
3.46
4.65
4.57
2.20
3.64
0.44
2.21
4.12
2.73
2.21
3.10
AUS AUT BEL CZE DNK ESP FIN FRA GER HUN IRL ITA JPN NLD SVN SWE UK USA
C: Mining & quarrying
0.56
-0.33
0.90
-0.86
6.98
0.39
0.86
-0.91
2.38
3.66
1.25
-0.13
0.61
-2.61
7.16
-2.63
-1.14
-1.01
AUS AUT BEL CZE DNK ESP FIN FRA GER HUN IRL ITA JPN NLD SVN SWE UK USA
D. Manufacturing
0.77
3.08
1.33
3.24
0.19
0.62
3.11
1.63
1.93
3.42
2.41
1.46
2.15
1.89
3.51
3.94
1.83
2.15
AUS AUT BEL CZE DNK ESP FIN FRA GER HUN IRL ITA JPN NLD SVN SWE UK USA

Chart 1 (continued)

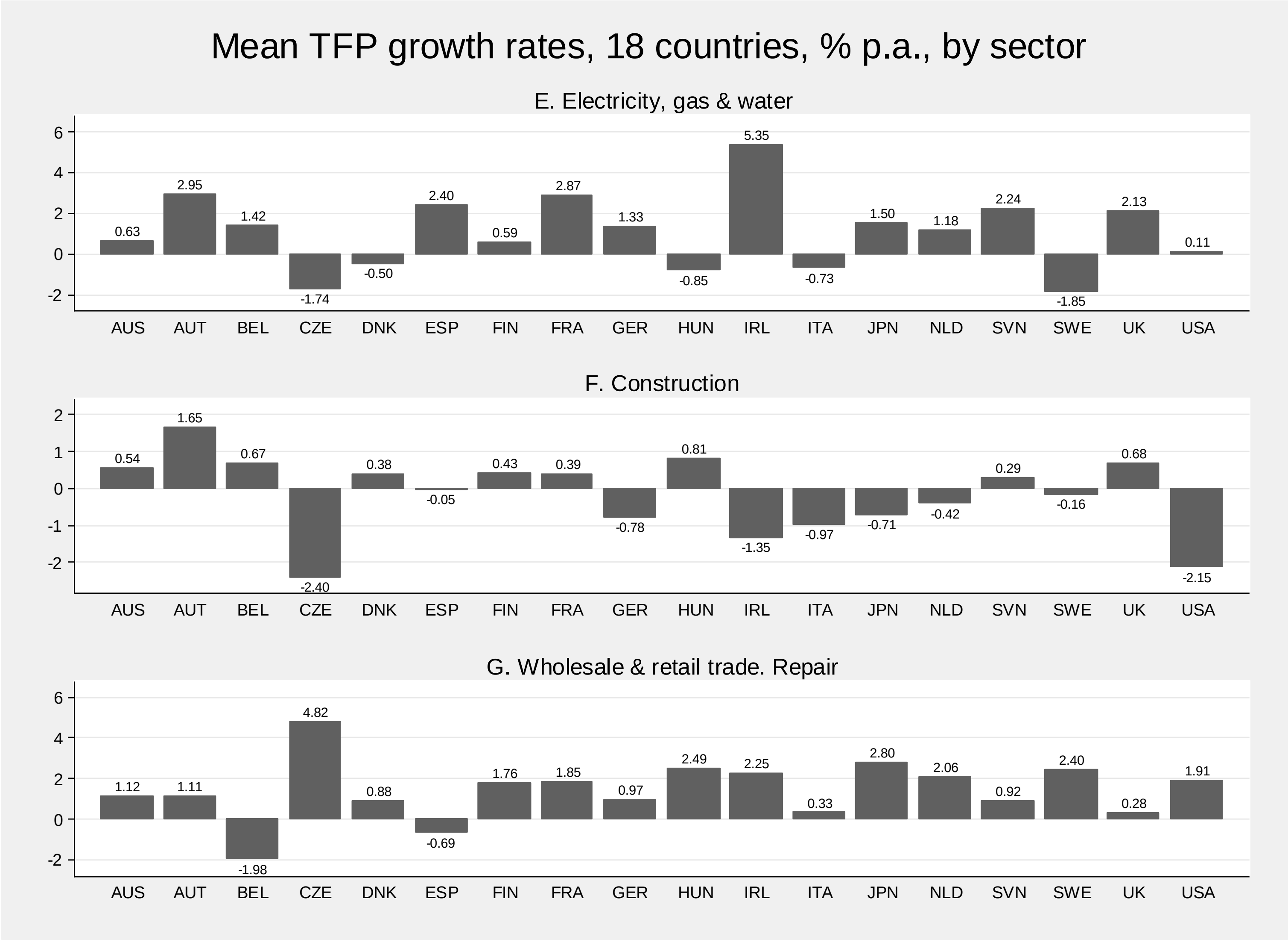


Chart 1 (continued)

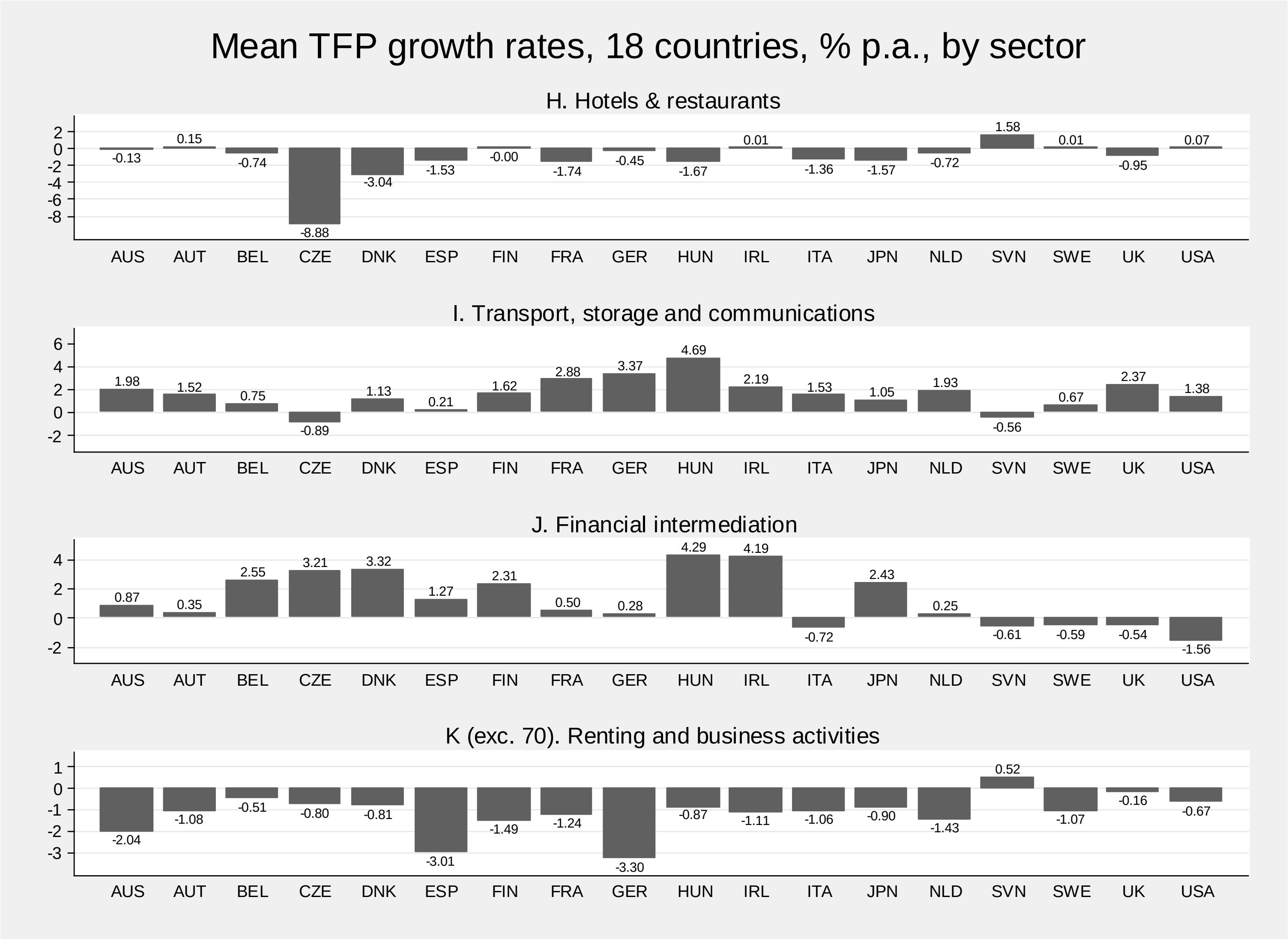


Chart 2

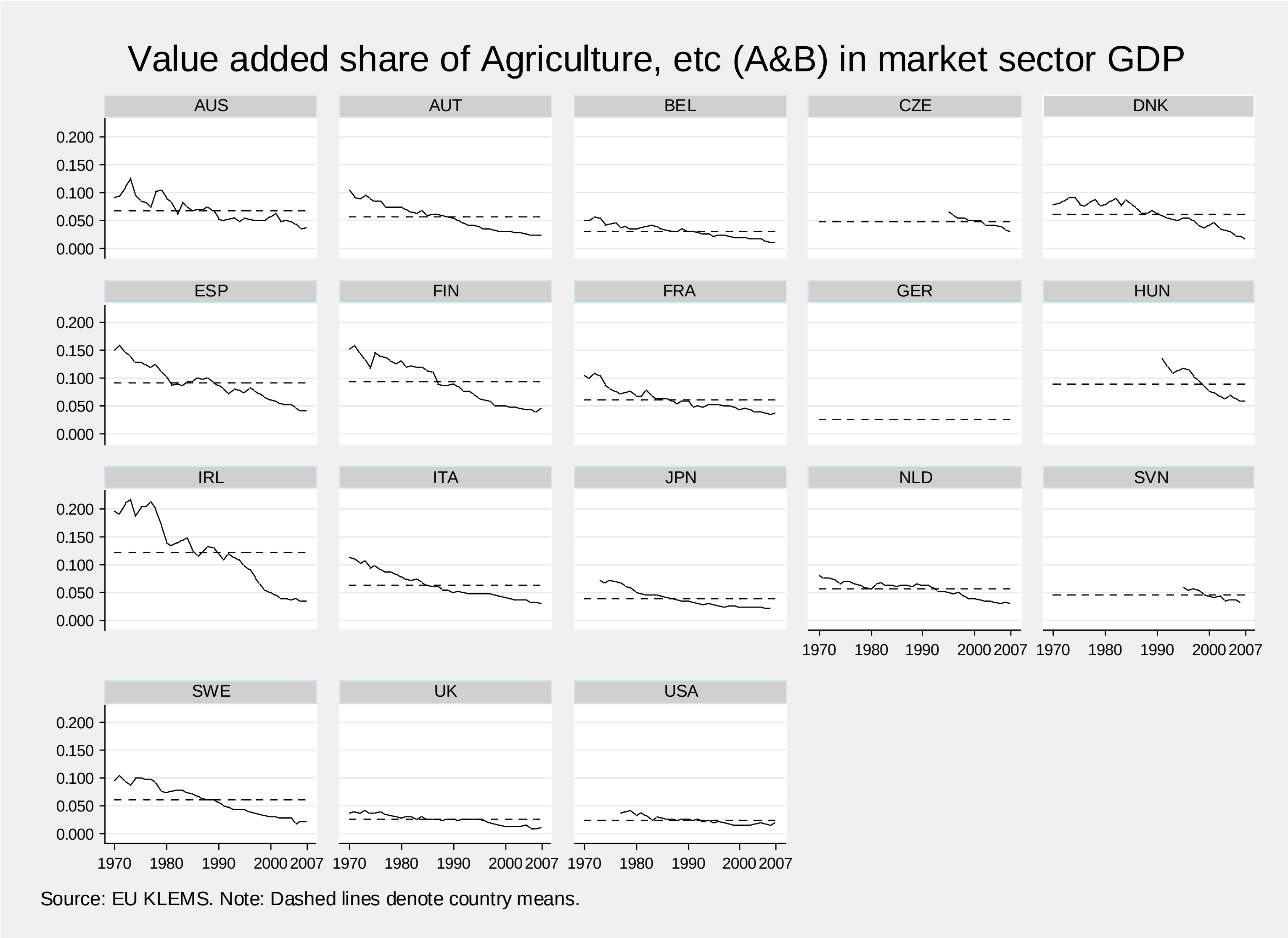

Value added share of Agriculture, etc (A&B) in market sector GDP
AUS
AUT
BEL
CZE
DNK
ESP
FIN
FRA
GER
HUN
IRL
ITA
JPN
NLD
SVN
SWE
UK
USA
0.200
0.150
0.100
0.050
0.000
1970
1980
1990
2000
2007
Source: EU KLEMS. Note: Dashed lines denote country means.

Chart 2 (continued)

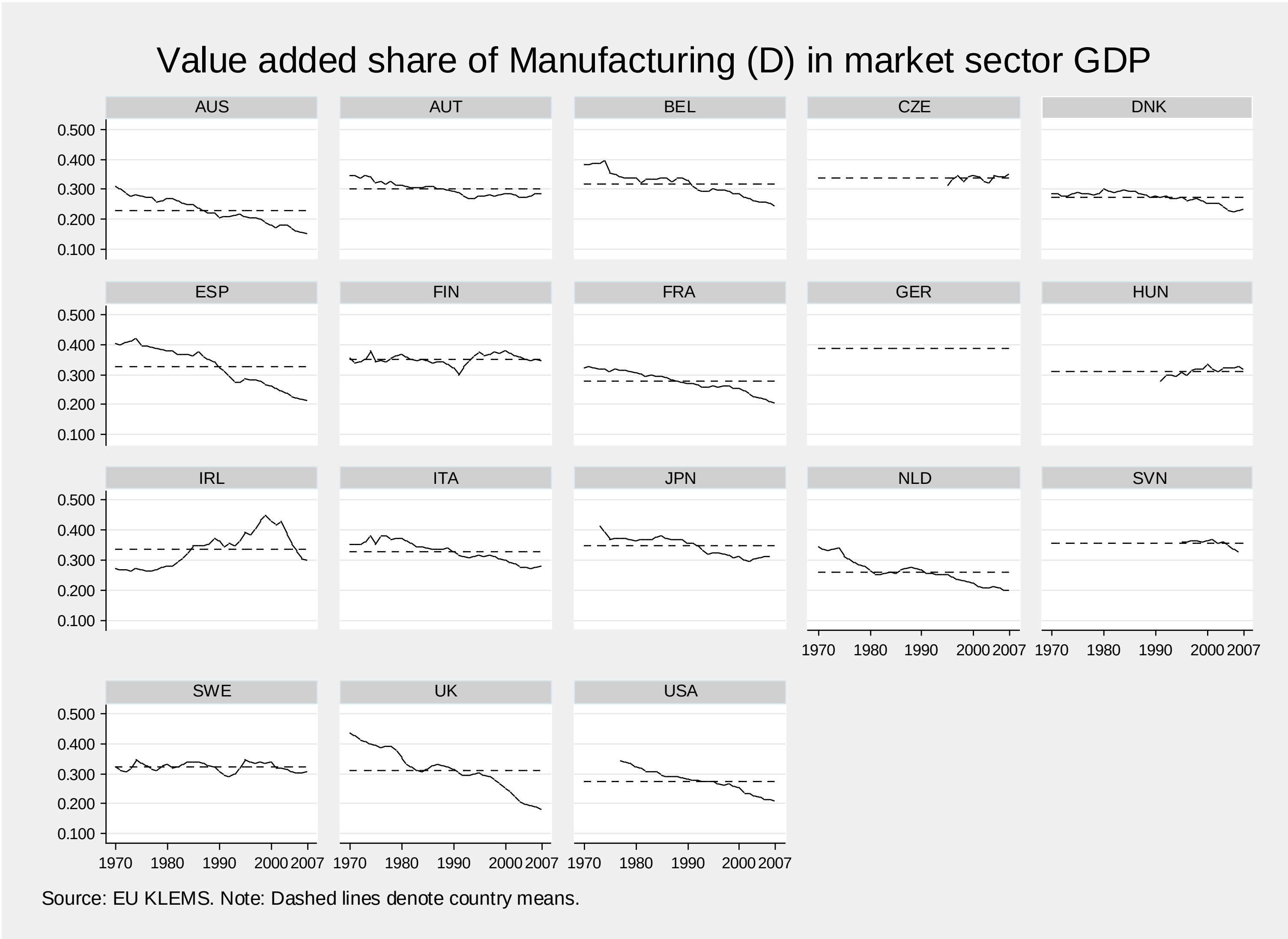
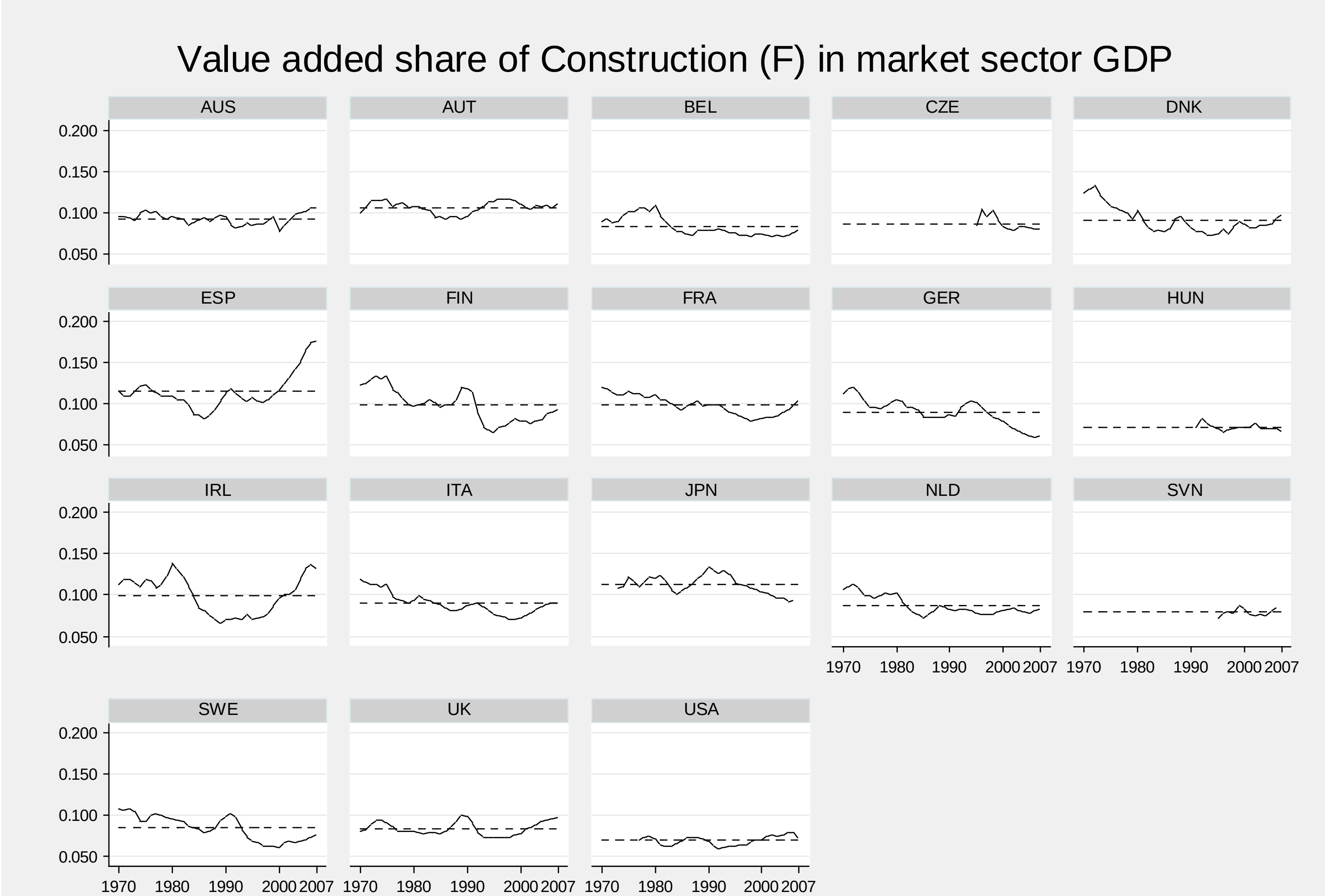


Chart 2 (continued)



Source: EU KLEMS. Note: Dashed lines denote country means.

Chart 2 (continued)

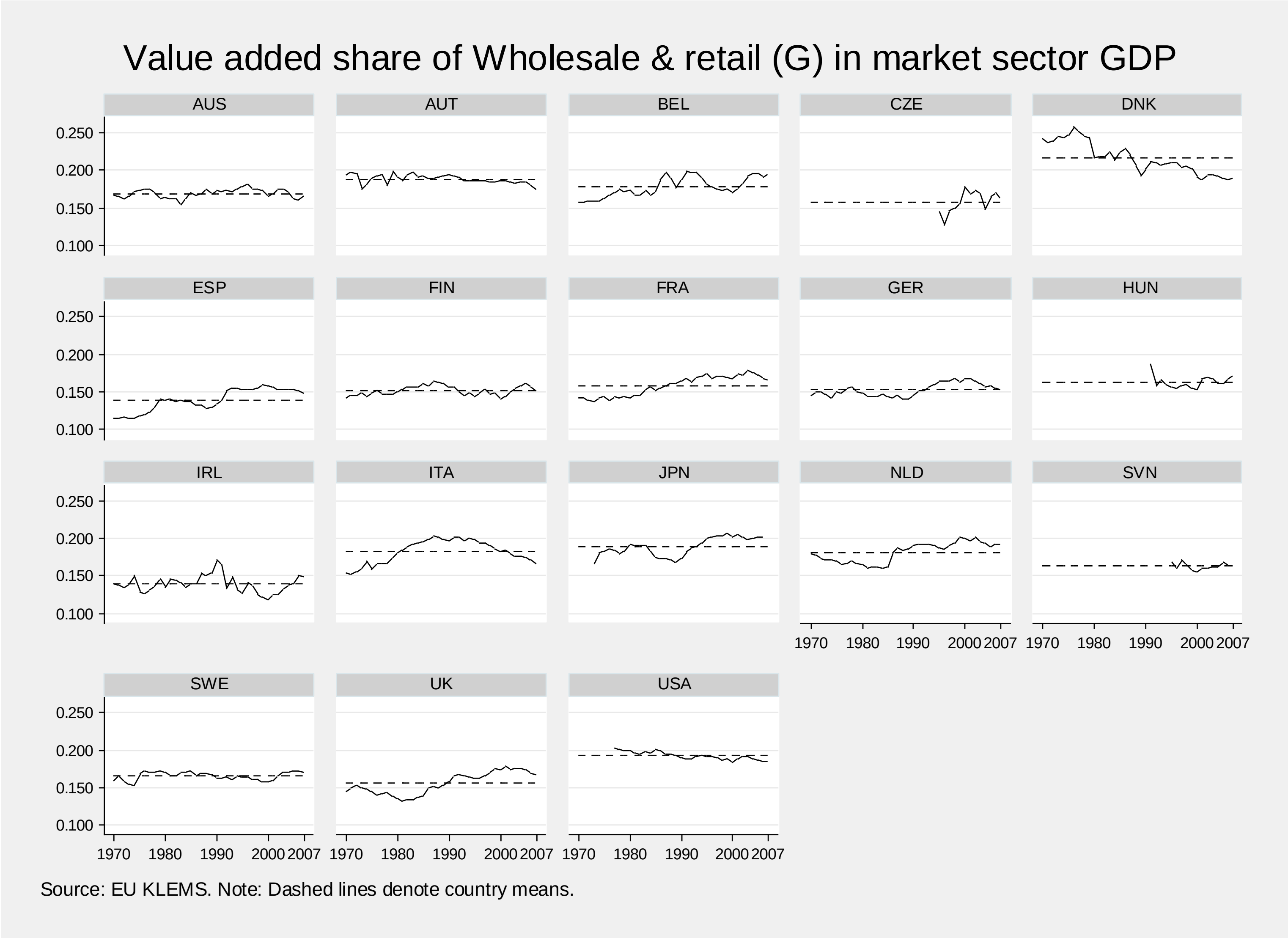


Chart 2 (continued)

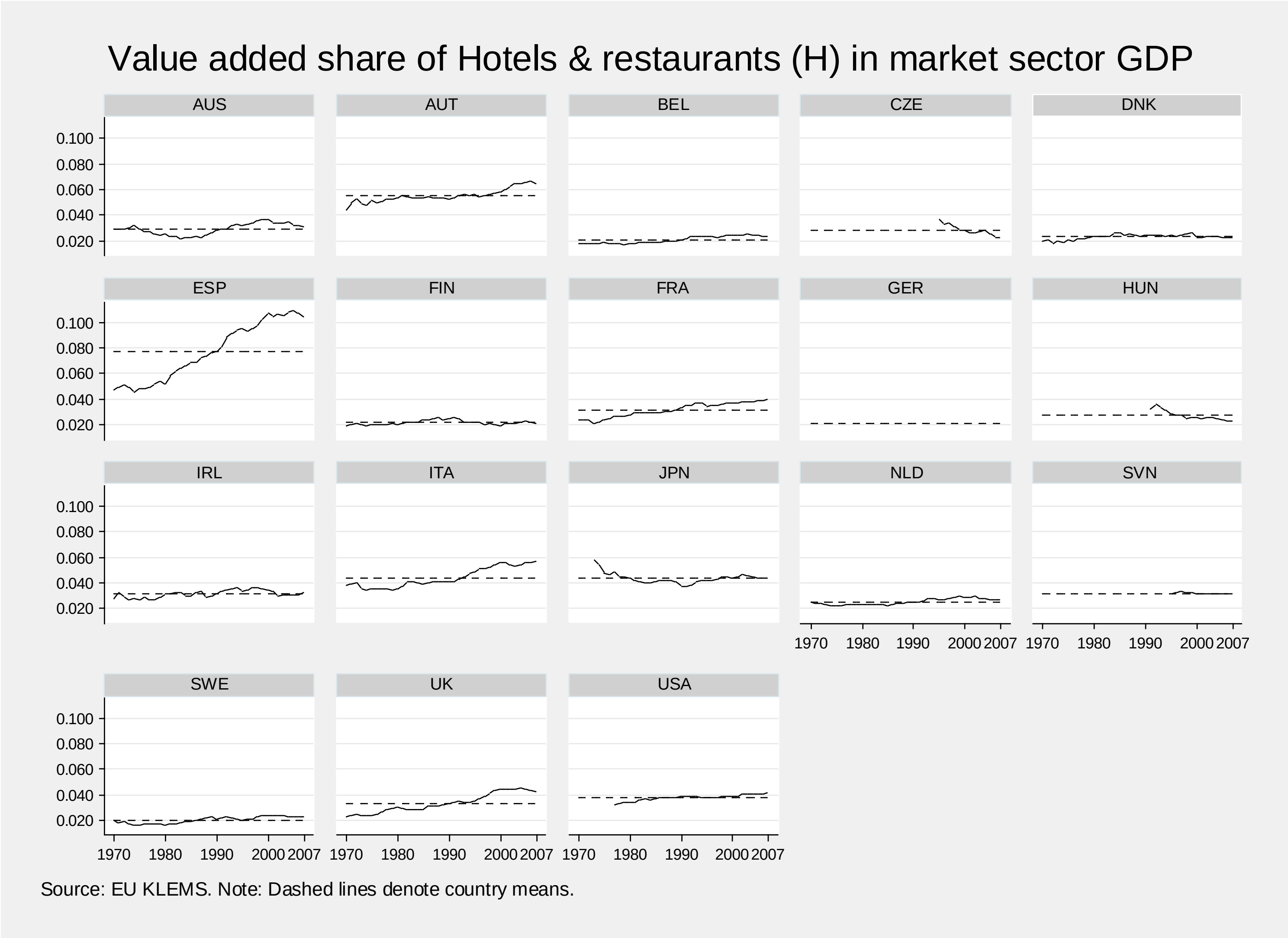
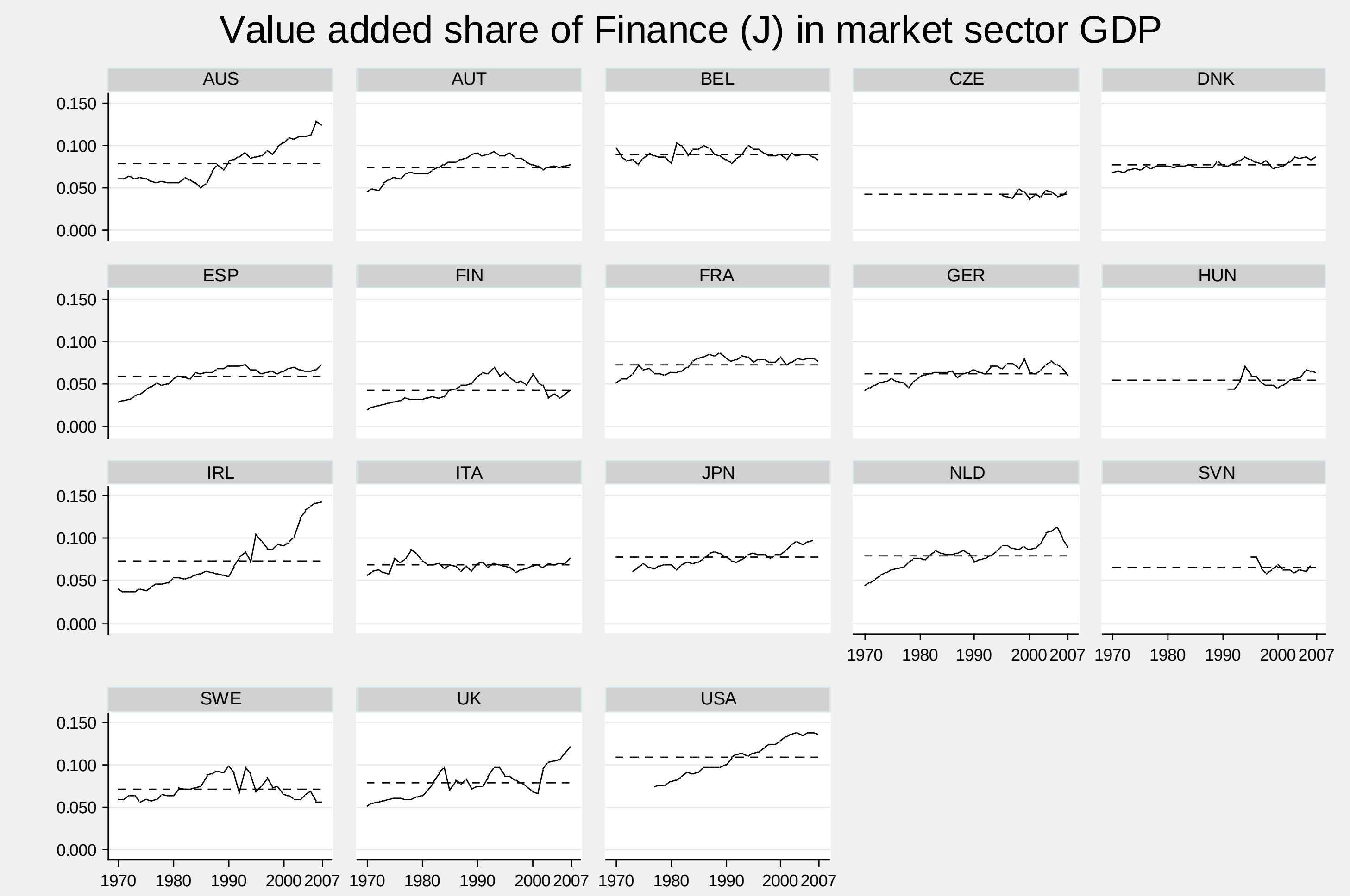


Chart 2 (continued)



Source: EU KLEMS. Note: Dashed lines denote country means.

Chart 2 (continued)

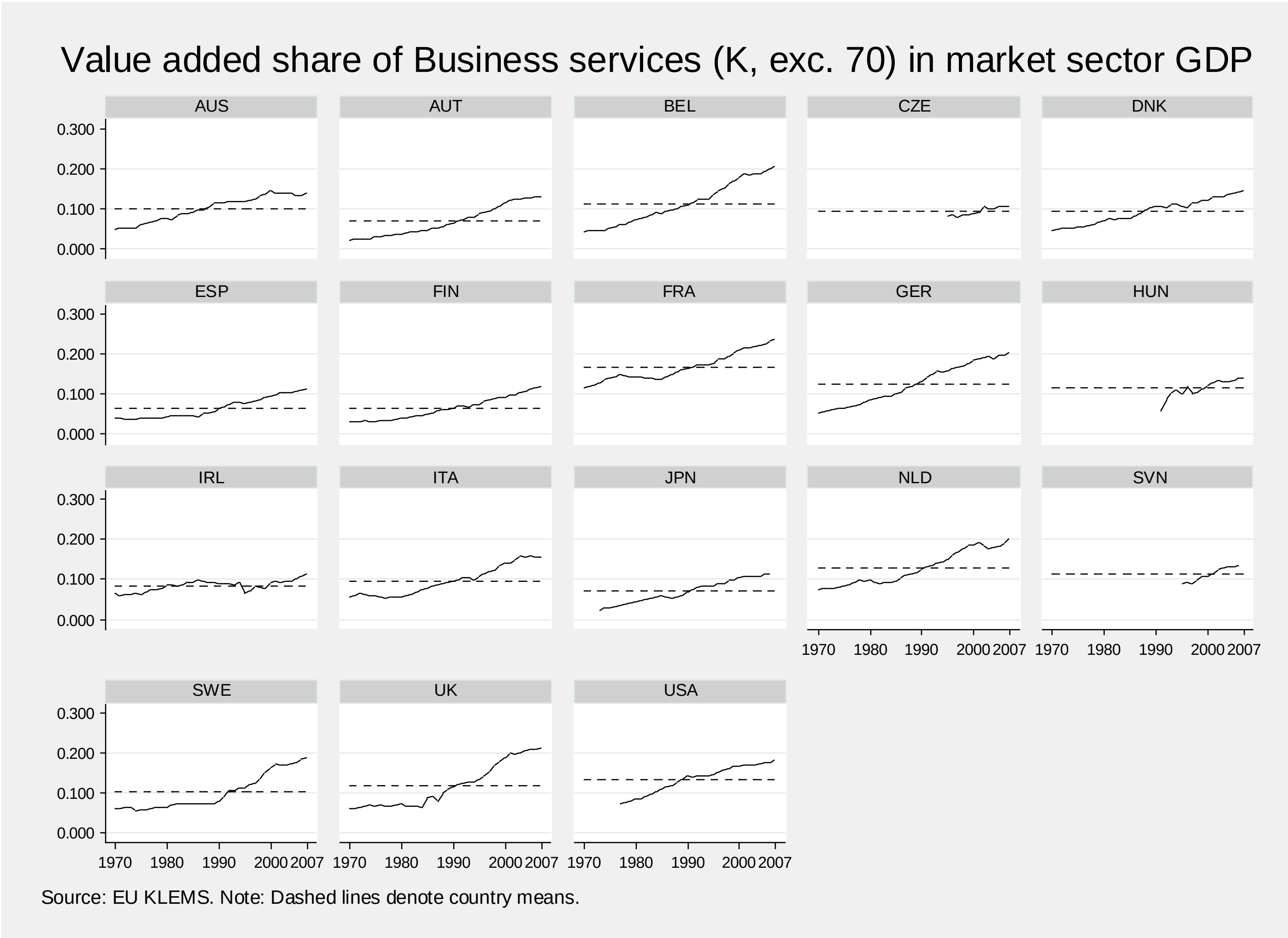
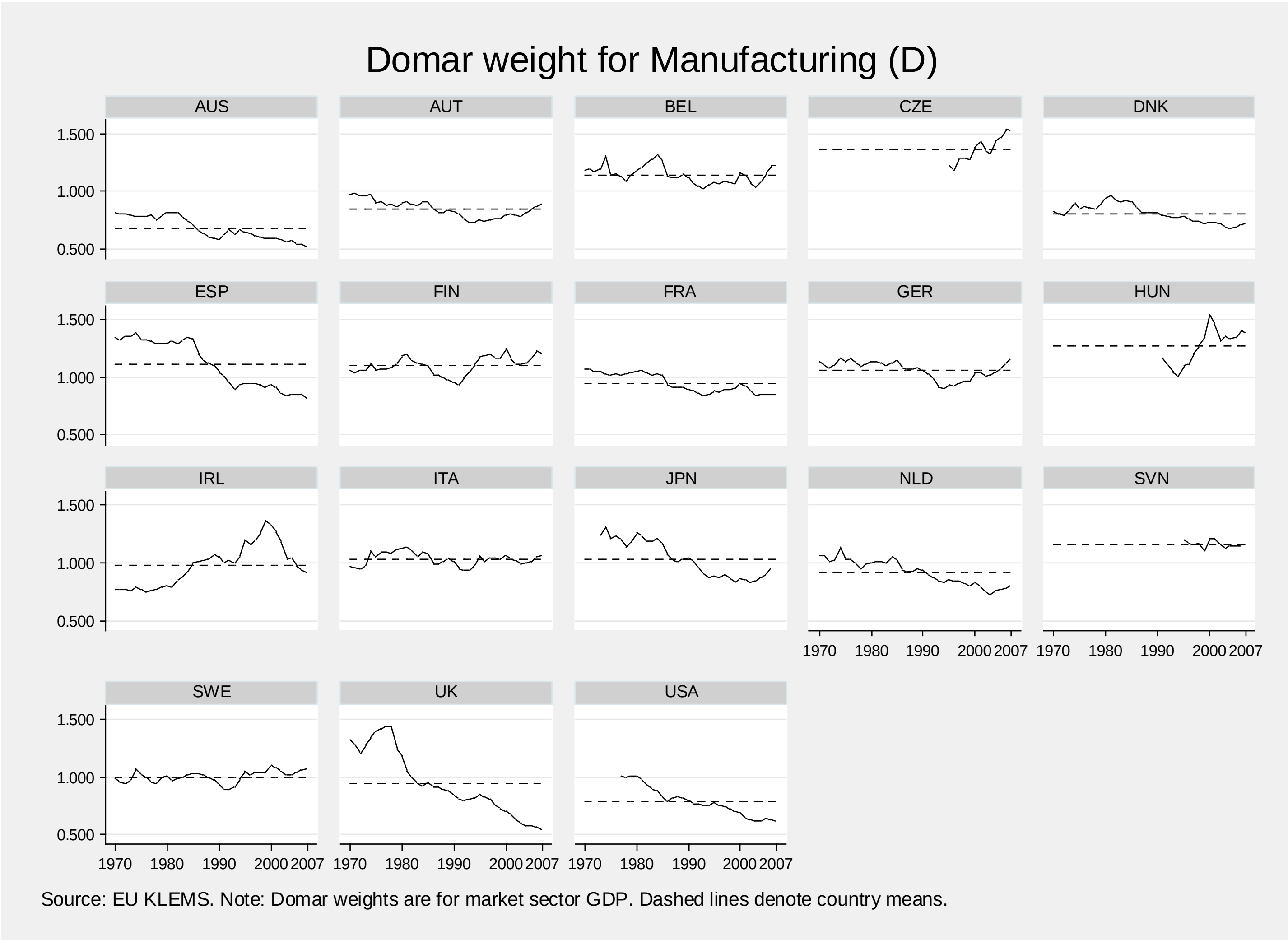
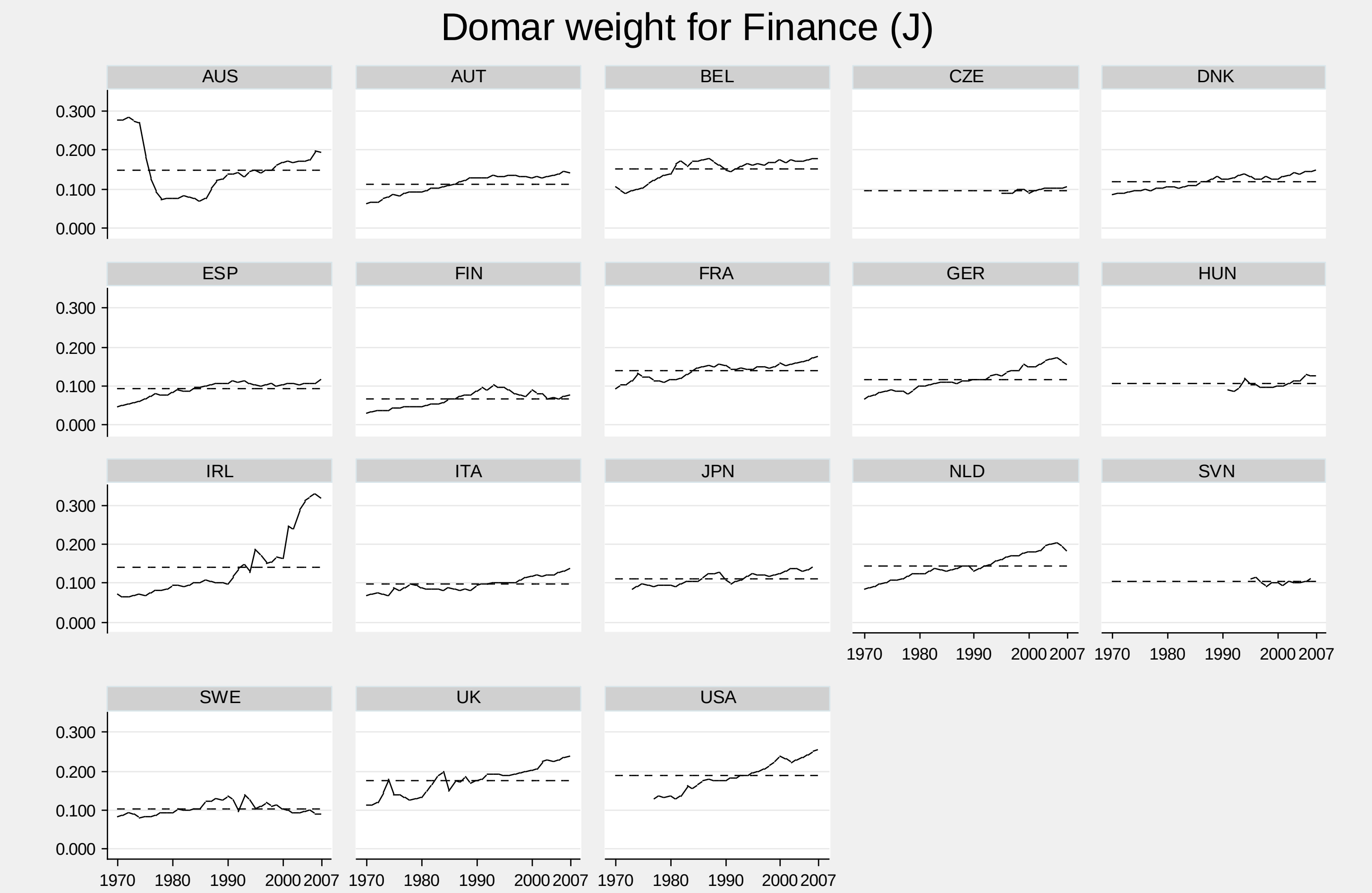


Chart 3



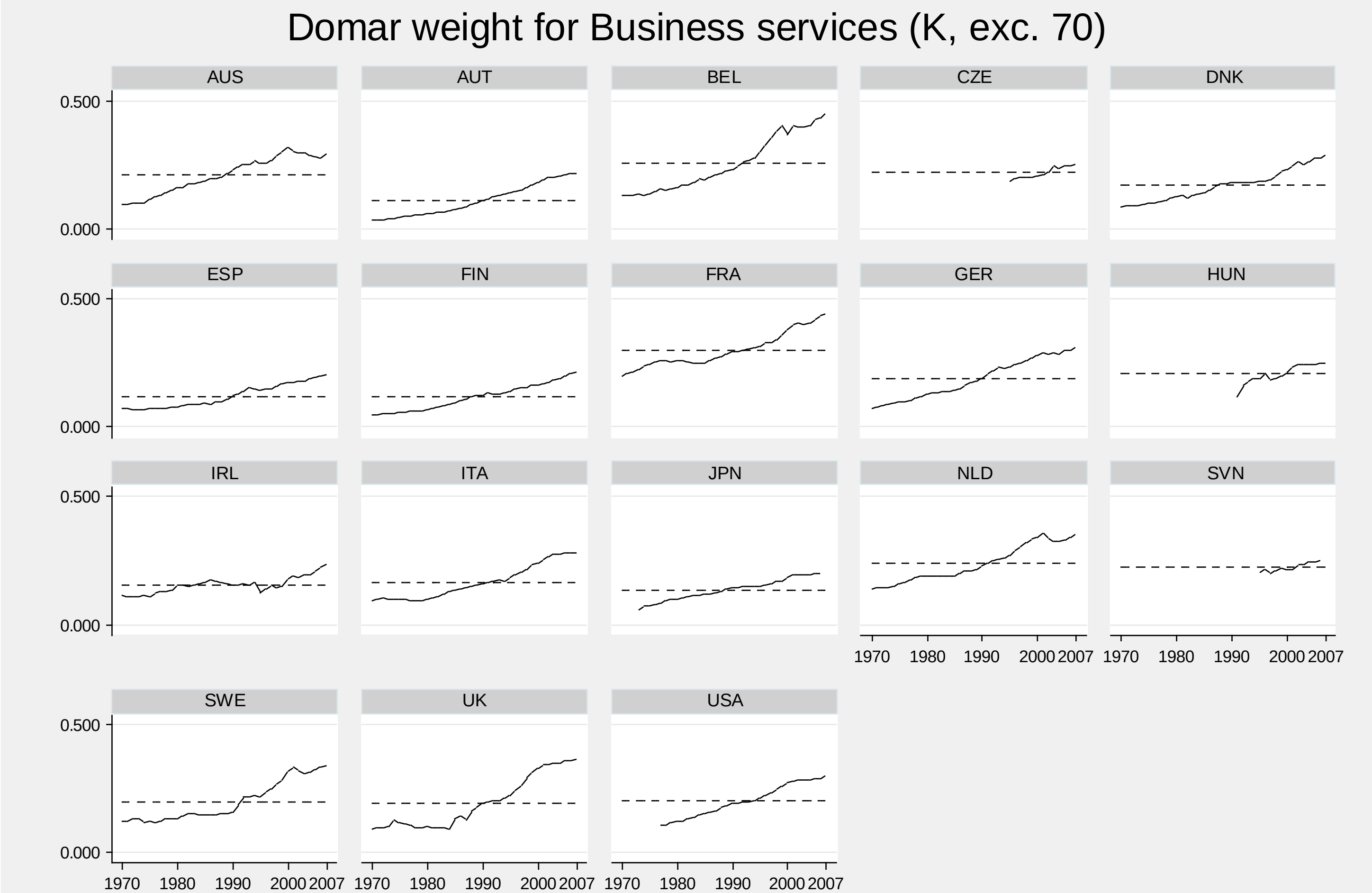
Domar weight for Manufacturing (D)
AUS
AUT
BEL
CZE
DNK
ESP
FIN
FRA
GER
HUN
IRL
ITA
JPN
NLD
SVN
SWE
UK
USA
1.500
1.000
0.500
1970
1980
1990
2000
2007
Source: EU KLEMS. Note: Domar weights are for market sector GDP. Dashed lines denote country means.

Chart 3 (continued)



Source: EU KLEMS. Note: Domar weights are for market sector GDP. Dashed lines denote country means.

Chart 3 (continued)



Source: EU KLEMS. Note: Domar weights are for market sector GDP. Dashed lines denote country means.

Decomposing Multifactor Productivity Growth in Canada by Industry and Province, 1997-2014

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Finance Canada

Alexander Murray
Centre for the Study of Living Standards[1]

ABSTRACT

Between 1997 and 2014, multifactor productivity (MFP) in Canada's business sector industries grew at an annual rate of 0.02 per cent per year - essentially zero. In this article, we decompose aggregate MFP growth into contributions by industry and province. Two sets of results are presented: one based on the generalized exactly additive decomposition (GEAD) and one based on the CSLS decomposition. The two decomposition methods lead to very different conclusions. The GEAD suggests that the reallocation of inputs to the mining and oil and gas extraction industry in the oil-rich provinces were the primary drivers of MFP growth in Canada while the manufacturing sector, concentrated in Ontario and Quebec, dragged MFP growth down. The CSLS decomposition suggests precisely the opposite: mining and oil and gas was the main hindrance to Canada's MFP performance while manufacturing was the major driver of MFP growth. The disagreement between the two methods is primarily attributable to the fact that the large increase in commodity prices (especially oil prices) over the 1997-2014 period increases the mining and oil and gas industry's contribution to MFP growth according to the GEAD while the CSLS decomposition does not treat such relative price effects as contributors to productivity growth.

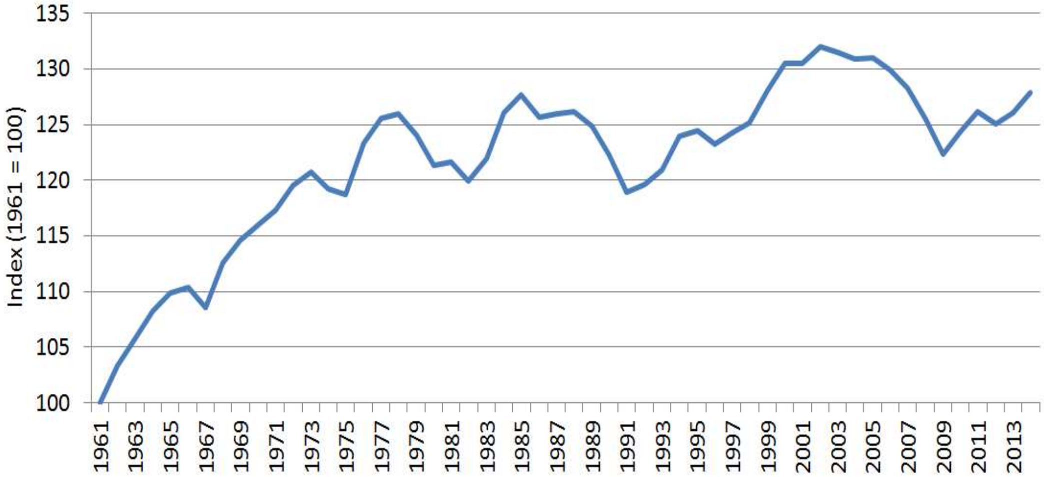
Introduction

Multifactor productivity (MFP) is defined as the quantity of output produced per unit of "aggregate input" used in production.[2] While MFP growth is often treated as synonymous with technological progress, it also reflects other factors such as allocative efficiency, returns to scale, and capacity utilization. An

1 Matthew Calver is an economist at Finance Canada and Alexander Murray is an economist at the Centre for the Study of Living Standards (CSLS). Calver undertook the research for this article while employed at the CSLS. This article was written under the supervision of CSLS Executive Director Andrew Sharpe. It is an abridged version of Calver and Murray (2016). An earlier version was presented at the Michael Denny Memorial Session at the annual meeting of the Canadian Economics Association, University of Ottawa, June 3-5, 2016. The authors thank discussant Shutao Cao for comments and session organizer Erwin Diewert for the invitation to present the paper as well as useful comments. Emails: matthewcalver449@hotmail.com; alexander.murray@csls.ca.

2 MFP is commonly referred to as total factor productivity (TFP). The two terms are synonymous. Since this article is based on Statistics Canada MFP estimates, we use that term.

Chart 1
Multifactor Productivity, Canada, Business Sector, 1961 = 100, 1961-2014



Source: Statistics Canada, CANSIM Table 383-0021

economy with a higher level of MFP is able to produce a higher level of output for a given amount of input, resulting in a higher standard of living for the population. For this reason, policymakers are interested in monitoring trends in MFP and adopting policies which promote MFP growth.[3]

MFP growth in Canada has been disappointing in recent decades. Chart 1 displays Statistics Canada's official index of the level of MFP in the Canadian business sector between 1961 and 2014. Over the entire period, MFP grew at a compound annual rate of 0.5 per cent. There was a clear decline in the trend growth rate in the late 1970s. MFP rose by 26 per cent between 1961 and 1978, but by only 1.5 per cent between 1978 and 2014 (although it had been as high as 4.8 per cent above the 1978 level at its peak in 2002).

The negligible growth of MFP in Canada since the late 1970s has been of major concern to policymakers and is still not well understood. This article shines new light on the modest MFP growth observed in Canada from 1997 to 2014 by quantifying the specific contributions of each province and industry to Canada's overall MFP growth rate. This allows for the identification of sectors that have driven MFP growth in Canada and sectors that have acted as a drag on growth. The existing literature contains similar decompositions using labour productivity growth (Sharpe, 2010; Sharpe and Thomson, 2010; Almon and Tang, 2011; Baldwin and Willox, 2016). However, labour productivity is not as comprehensive a measure of an economy's overall productivity as MFP because labour productivity only considers one input (labour) while MFP is based upon a composite input of labour and capital.[4]

We use two different approaches from the literature in order to decompose aggregate MFP growth into provincial and industry contributions. The first is the generalized exactly additive decomposition (GEAD), developed by

3 See Oulton (2016) and Murray (2016) in this issue of the *International Productivity Monitor* for discussions of the factors that influence MFP.

4 See Murray (2016) for a comprehensive review of the relative strengths and weaknesses of MFP and partial productivity measures.

Tang and Wang (2004) for labour productivity growth and adapted for MFP growth by Diewert (2015). The second is the CSLS decomposition, developed by Sharpe (2009 and 2010) for labour productivity growth and adapted here for use with MFP growth.

There are three key differences between these two approaches. First, the industry contributions in the GEAD are influenced by changes in sectors' relative input and output prices while those in the CSLS decomposition are not. Second, an increase in a sector's share of aggregate inputs always increases that sector's contribution to aggregate MFP growth according to the GEAD, while according to the CSLS decomposition this is only true if the sector in question has an above-average productivity level. Third, the GEAD is exactly additive while the CSLS decomposition is not.[5]

We view the two approaches as complementary rather than competing. Some researchers have criticized the GEAD for the inclusion of relative price effects and for the failure of its reallocation effects to account for the influence of relative productivity levels (de Avillez, 2012; Reinsdorf, 2015). The CSLS decomposition overcomes these criticisms, but at the cost of exact additivity. Which approach is more appropriate depends upon what a researcher is interested in learning. As we will see, the two decomposition formulas lead to radically different conclusions regarding the sources of MFP growth in Canada.

The remainder of the article is organized as follows. In Section II, we provide an overview of the decomposition methods and describe the data. In Section III, we present the results of the MFP growth decomposition exercises, which have not previously been performed using Canadian data. Section IV concludes.

Methodology and Data

We implement two decompositions of MFP growth in this article: the generalized exactly additive decomposition (GEAD) and the CSLS decomposition. In this section, we provide a brief description of each decomposition method. We forego a thorough derivation of the decomposition formulas; those details can be found in Calver and Murray (2016). The section ends with a discussion of the data.

Generalized Exactly Additive Decomposition (GEAD)

The GEAD was developed by Tang and Wang (2004) to address a problem of non-additivity of contributions in the traditional decomposition formula of Denison (1962). The traditional decomposition depends on the additivity of real volume measures; it requires that real aggregate output (or input) be equal to the sum of the real sectoral outputs (or inputs). Additivity always holds in nominal terms, but it does not hold in real terms when chained indexes or Fisher quantity measures are used.[6] To address this problem, Tang and Wang modified the traditional decomposition of labour productivity so that it depends on nominal additivity rather than real additivity. As a result, changes in relative prices of sectoral outputs enter the decomposition formula. The influence

5 In the GEAD, the sectoral contributions sum exactly to the growth of aggregate MFP by construction. In the CSLS decomposition, there is a small discrepancy between aggregate MFP growth and the sum of the sectoral contributions. This is discussed in greater detail below.

6 In the past, non-additivity did not arise because most statistical agencies produced output estimates using constant dollar Laspeyres volume measures. Constant dollar Laspeyres measures have the property that real aggregate output is equal to the sum of real sectoral outputs. Non-additivity became problematic as chained Fisher measures became common.

of relative prices is the core distinction between the GEAD and the traditional approach.

Tang and Wang applied their decomposition to labour productivity growth. Diewert (2015) devised a version of the GEAD for MFP growth, and that is the version we use in this article. Define N sectors over two periods ($t \varepsilon \{0,1\}$). For our application, a sector will correspond to an industry-province pair. Let γ denote aggregate MFP growth between time 0 and time 1. The GEAD decomposition formula is:

$$\gamma = \sum_{n=1}^{N} s_{Yn}^{0} \left\{[1+\gamma_n][1+\rho_n][1+\omega_n][1+\sigma_n]-1\right\} \quad (1)$$

Here, s_{Yn}^{0} is the nominal output share of sector n at time 0. The other terms are defined as follows:

Rate of output price growth:

$$\rho_n = (p_n^1 / p_n^0) - 1$$

Rate of (inverse) relative input price growth:

$$\omega_n = (w_n^0 / w_n^1) - 1$$

Rate of within-sector MFP growth:

$$\gamma_n = (X_n^1 / X_n^0) - 1$$

Rate of nominal input cost share growth:

$$\sigma_n = (s_{zn}^1 / s_{zn}^0) - 1$$

where p_n^t is the relative price of the output of sector n at time t, w_n^t is the relative price of the bundle of inputs used in sector n at time t, X_n^t is the index of MFP in sector n at time t, and s_{zn}^t is sector n's share of aggregate nominal input expenditures at time t.

Expanding equation (1) reveals that the contribution of each sector is driven by the growth rates of each of our four factors plus their interaction terms. Generally, the interaction terms will be relatively small. We do not want to assess the fifteen additive terms within each sector in our analysis as this would become quite tedious. Following Diewert (2015), we instead allocate each interaction term equally among its component factors. For example, the contribution of sector n's within-sector MFP growth to aggregate MFP growth can be estimated as:

$$\Delta X_n = s_{Yn}^{0}\gamma_n \left\{1 + \frac{(\rho_n + \omega_n + \sigma_n)}{2} + \frac{(\rho_n\omega_n + \rho_n\sigma_n + \omega_n\sigma_n)}{3} + \frac{(\rho_n + \omega_n + \sigma_n)}{4}\right\} \quad (2)$$

Analogous expressions are used for the contributions of output price growth (Δp_n), (inverse) input price growth (Δw_n), and input cost share growth (Δs_{zn}). Then aggregate MFP growth is given by:

$$\gamma = \sum_{n=1}^{N}\left[\Delta X_n + \Delta p_n + \Delta w_n + \Delta s_{zn}\right] \quad (3)$$

CSLS Decomposition

A weakness of the GEAD is that the apportionment of the total reallocation effect across sectors is problematic. There are two reasons for this. First, the industry contributions in the GEAD are influenced by changes in sectors' relative input prices and relative output prices even when all sectors' productivities and input shares remain unchanged. This is inconsistent with an interpretation of productivity growth as an outward shift of the production possibilities frontier as a result of technological improvements (Reinsdorf, 2015). Second, an increase in a sector's share of aggregate inputs always increases that sector's contribution to aggregate MFP growth according to the GEAD. That an increase in an industry's share of inputs at the expense of other industries with higher productivity levels is counted as a positive contribution by the industry to aggregate productivity growth is highly counterintuitive.

The CSLS decomposition proposes an alternative definition of sectoral reallocation effects that addresses these weaknesses. In our view, the resulting sectoral contributions to productivity growth are more consistent with economic intuition than the contributions generated by the GEAD. Sharpe (2009), Sharpe (2010) and de Avillez (2012) applied the CSLS decomposition to Canadian labour productivity growth. We adapt the CSLS decomposition for the analysis of MFP growth.

$$\hat{\gamma} = \sum_{n=1}^{N}\left[\hat{s}^{0}_{Yn}\hat{\gamma}_n + \left(\frac{\hat{X}^{0}_{n} - \hat{X}^{0}}{\hat{X}^{0}}\right)\left(\hat{s}^{1}_{Zn} - \hat{s}^{0}_{Zn}\right) + \left(\frac{\left(\hat{X}^{1}_{n} - \hat{X}^{0}_{n}\right) - \left(\hat{X}^{1} - \hat{X}^{0}\right)}{\hat{X}^{0}}\right)\left(\hat{s}^{1}_{Zn} - \hat{s}^{0}_{Zn}\right)\right] \quad (4)$$

Here, $\hat{s}^{0}_{Yn}$ is sector *n*'s share of real output at time 0, $\hat{s}^{t}_{Zn}$ is sector *n*'s share of real inputs at time *t*, $\hat{\gamma}_n$ is the within-sector MFP growth of sector *n*, and $\hat{X}^{t}_{n}$ and $\hat{X}^{t}$ are the MFP indexes at date *t* for sector *n* and for the aggregate economy, respectively.

The first term on the right-hand side of equation (4) is the contribution to aggregate MFP growth of within-sector MFP growth in sector n. The second term is the reallocation level effect. When an industry's share of real inputs rises, its reallocation level effect is positive if and only if its productivity level is above average. The third term is the reallocation growth effect. When an industry's share of real input rises, its reallocation growth effect is positive if and only if its productivity growth rate is above average. The CSLS decomposition thus embodies the idea that the sign of an industry's reallocation effect should reflect the productivity performance of that industry relative to the other industries from which it is gaining (or to which it is losing) input share.[7]

The fact that the output and input shares ($\hat{s}^{t}_{Yn}$ and $\hat{s}^{t}_{Zn}$) are defined in real terms rather than in nominal terms introduces the problem of non-additivity. Like the traditional decomposition of Denison (1962), the CSLS decomposition depends on the additivity of real volume measures; it requires that real aggregate output (or input) be equal to the sum of the real sectoral outputs (or inputs). Additivity always holds in nominal terms, but it does not hold in real terms when chained indexes or Fisher quantity measures are used. Non-additivity introduces a discrepancy between the sum of the sectoral contributions, $\hat{\gamma}$, and actual aggregate MFP growth, γ. As we will show, the discrepancy turns out to be small.

Data

We implement the GEAD and the CSLS decomposition for "business sector industries" in Canada over the 1997-2014 period.[8] The decompositions yield contributions from each combination of the ten provinces and fifteen two-digit NAICS business sector industries - 150 industry-province pairs in total.

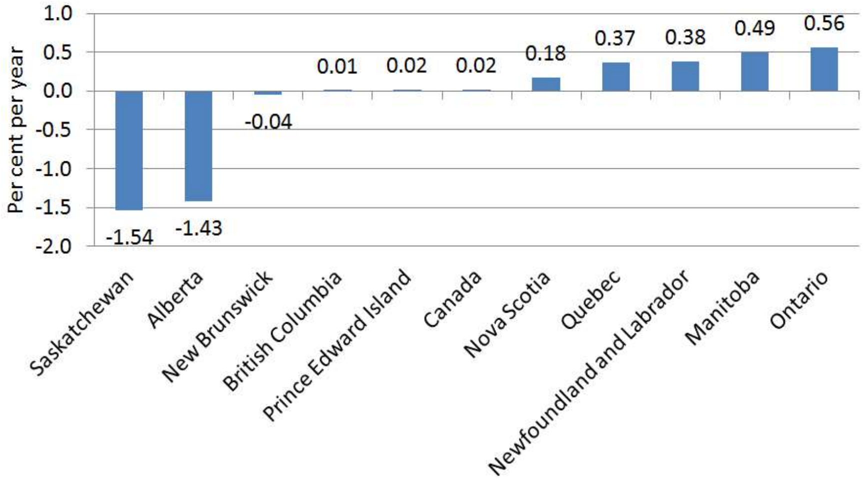
All the data for the decomposition exercises are drawn from Statistics Canada's CANSIM Table 383-0026. We use the annual series on nominal GDP, real GDP, real capital services input, real labour input, nominal labour compensation, and nominal capital costs.[9] Using these data at the industry-province level, we construct aggregates at the provincial level (i.e.

7 One interpretation of the reallocation effects in the CSLS decomposition, due to Reinsdorf and Yuskavage (2010), is that input share 'released' by one industry goes into a common pool from which all other industries can draw. The opportunity cost of inputs in this pool is the average productivity level of the economy. Baldwin and Willox (2016) propose a labour productivity decomposition in which an increase in an industry's labour share is assumed to be drawn from all other industries in proportion to those industries' initial labour shares. It turns out that this decomposition yields a total reallocation effect that is, to a close approximation, a version of the reallocation level effect from the CSLS decomposition. Hence, they provide an alternative motivation for the CSLS decomposition.

8 Business sector industries exclude the public administration, education, and health industries, but the data capture the activities of non-business establishments in the business sector industries. In practice, almost all establishments in our business sector industries are business establishments, so we will sometimes refer to this as 'the business sector.'

9 Nominal GDP is available up to 2012. We extend the series to 2014 using the growth rate of total nominal input costs (i.e. labour compensation plus capital cost). All other series are available to 2014 from CANSIM. The labour input index accounts for the effect of changes in labour quality over time.

Chart 2
Multifactor Productivity Growth in Canada and the Provinces, Business Sector Industries, Per Cent per Year, 1997-2014



Source: Authors' calculations based on data from CANSIM Table 383-0026.

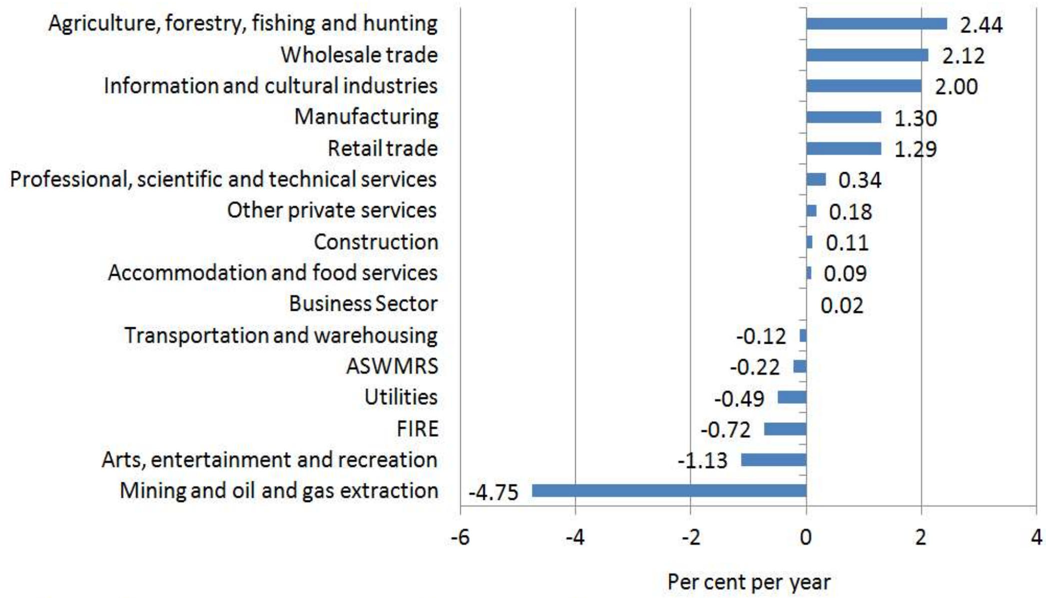
aggregating across all industries), the industry level (i.e. aggregating across all provinces), and the 'national' level (i.e. aggregating across all provinces and industries). Note that these 'national' aggregates do not include the territories. The nominal aggregates are obtained by summing the underlying province-industry sectoral data, while the real aggregates are chained Fisher aggregates as outlined by Landefeld *et al.* (2003). All real quantities are expressed in chained 2007 dollars.

Growth rates of output and aggregate input prices are measured using implicit price deflators. The growth rates of aggregate input prices in each sector are calculated as the growth rates of the implicit input price deflator (with nominal input measured as the sum of labour compensation and capital cost).[10] Similarly, the growth rates of aggregate output prices in each sector are calculated as the growth rates of the implicit output price deflator.

Finally, some conceptual difficulties arise in measuring the relative MFP levels of each sector for the CSLS decomposition. MFP levels for each sector are measured as a unit-free index normalized to 100 in the base year 2007. By construction, all sectors have the same MFP level in the base year. Away from the base year, intersectoral differences in MFP levels arise over time due to differential MFP growth rates in the sectors. We could have constructed an alternative measure of real input by applying the same national prices of capital and labour in constructing aggregate input for each industry-province pair. This would lead to different MFP levels across industries and provinces even in the reference year, with all MFP levels expressed relative to the MFP level of the national aggregate in the reference year. While an approach that generates differing MFP levels in the reference year is desirable, we opt to take the simpler approach here.[11]

10 Note that we do not assume that a sector's total nominal input costs are equal to its total nominal output. Statistics Canada estimates capital costs via a hybrid method that uses both internal and external rates of return. As a result, total nominal input costs are in general not equal to nominal output. The discrepancy may reflect factors such as imperfect competition and non-constant returns to scale. See Baldwin *et al.* (2014) for a discussion. In any event, the decomposition formulas we apply do not depend on the equivalence of nominal output and nominal inputs.

Chart 3
Multifactor Productivity Growth by Business Sector Industry, Canada, Per Cent per Year, 1997-2014



Source: Authors' calculations based on data from CANSIM Table 383-0026.
Note: FIRE = Finance, insurance, and real estate. ASWMRS = administration and support, waste management and remediation services.

Results

Overview of MFP Growth by Province and Industry

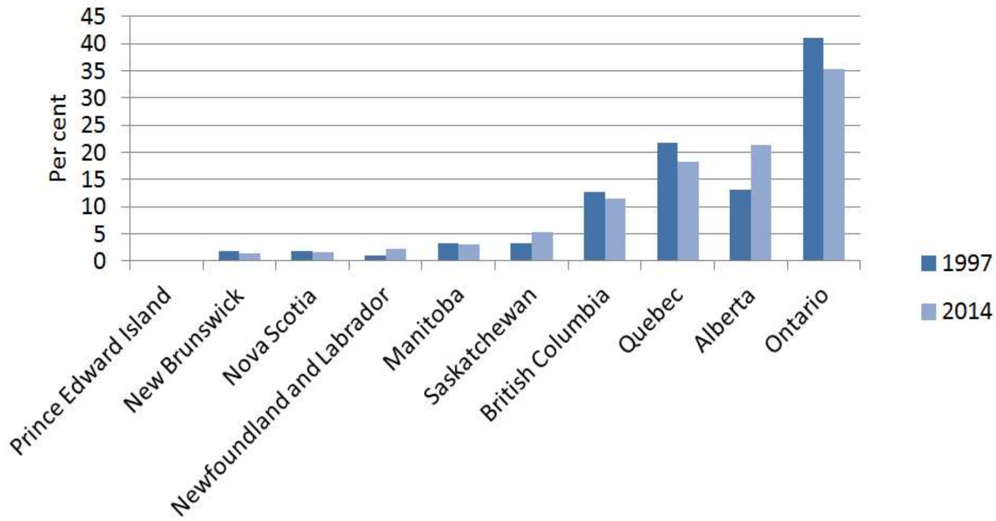
Before presenting the results of our decompositions, it is informative to discuss the underlying trends in each sector (industry-province pair) of the economy. Since the GEAD breaks MFP growth into contributions related to changes in MFP within each sector, the input and output prices of the sector, and the inputs shares of each sector, an understanding of how these factors have changed across industries will provide some insight into what drives the decomposition results.

We begin with aggregate MFP growth. Between 1997 and 2014, our estimates show that cumulative growth in MFP in Canada's business sector industries was 0.28 per cent. This amounts to a growth rate of 0.02 per cent per year - essentially zero (Chart 2). Statistics Canada's official estimates for the aggregate business sector (depicted in Chart 1 at the beginning of this article) put national MFP growth over the 1997-2014 period at 2.9 per cent cumulatively, or 0.16 per cent per year. The 0.14 percentage-point discrepancy between the annual growth rates may reflect differences in geographic coverage (i.e. the exclusion of the territories from our 'national' estimates) and small methodological differences between Statistics Canada's provincial and national MFP databases.[12]

11 We have experimented with generating results using national input prices to obtain differential MFP levels in the reference year. Doing so does not seem to significantly change our conclusions, although the magnitudes of aggregate MFP growth and the contributions associated with each industry change.

12 In particular, the national MFP program includes land and inventories as components of the capital stock and accounts for tax parameters in the estimation of user costs. The provincial capital services data do not account for these factors. See Gu and Lee (2013).

Chart 4
Distribution of Nominal Input Costs Across Provinces, Per Cent, 1997 and 2014



Source: Authors' calculations based on data from CANSIM Table 383-0026.

Over the 1997-2014 period, MFP declined in three provinces: Saskatchewan (-1.54 per cent per year), Alberta (-1.43 per cent per year), and New Brunswick (-0.04 per cent per year). Five provinces exhibited non-negligible positive MFP growth. The fastest growth was in Ontario, at 0.56 per cent per year.[13]

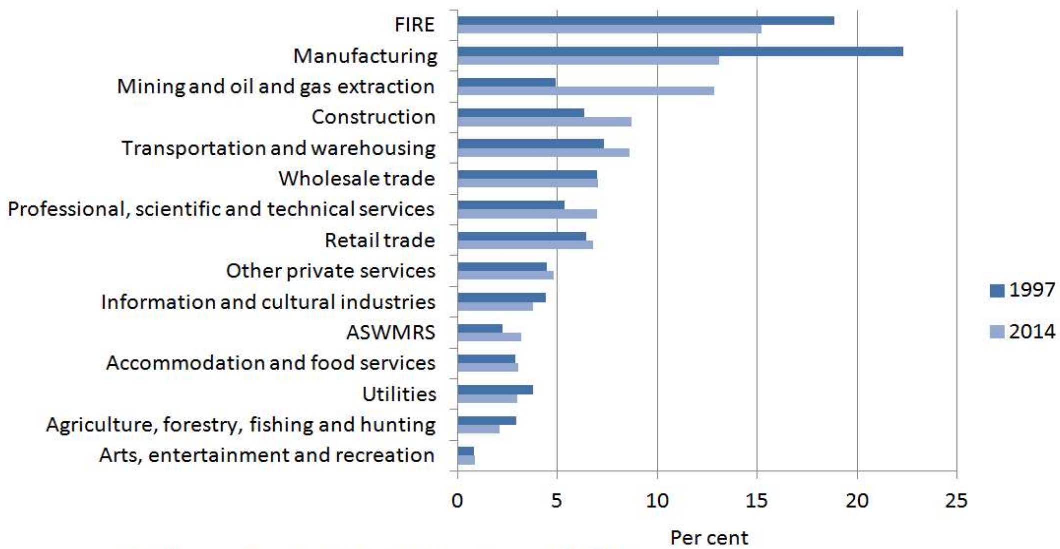
Given that Saskatchewan and Alberta both experienced significant growth in their natural resource sectors over the period, their declining MFP was likely linked to the oil and gas sector tapping into more marginal resources as soaring prices made them financially viable. However, the third major oil producing province, Newfoundland and Labrador, experienced positive MFP growth over the period. This suggests that the effects of the oil and gas boom are more nuanced.[14]

The notion that the oil and gas sector played a significant role in the poor productivity growth observed in Alberta and Saskatchewan is supported by Chart 3, which reveals that the mining and oil and gas extraction industry had by far the worst MFP growth of all business sector industries from 1997 to 2014 (-4.75 per cent per year). Substantial MFP declines also occurred in arts, entertainment and recreation (-1.13 per cent per year); finance, insurance, real estate, and leasing (FIRE) (-0.72 per cent per year); and utilities (-0.49 per cent per year). Three industries exhibited MFP growth of

13 Our provincial estimates of MFP growth are very similar to the official Statistics Canada estimates. Across provinces, the correlation of our compound annual MFP growth estimates for 1997-2014 with the estimates of Statistics Canada is 0.995.

14 Productivity growth in the oil and gas industry in Newfoundland and Labrador is linked to the nature of offshore oil production. Several offshore oil wells began operating in the province in the late 1990s. These offshore wells represented the major capital inputs to the industry in the province, and the capital stock expanded at a much slower pace than that observed in Alberta and Saskatchewan over the 1997-2014 period. MFP growth was strong in mining and oil and gas extraction in the province because capital input growth was limited while output significantly increased, likely due to increased capacity utilization of the new offshore wells. For a detailed discussion of how rising oil and gas prices affected the labour productivity of the three major oil producing provinces directly and indirectly, see Sharpe and Waslander (2014). For an analysis of the overall productivity performance of Newfoundland and Labrador since 1997, see Grand'Maison and Sharpe (2013).

Chart 5
Distribution of Nominal Input Costs Across Business Sector Industries, Per Cent, 1997 and 2014



Source: Authors' calculations based on data from CANSIM Table 383-0026.
Note: FIRE = Finance, insurance, and real estate. ASWMRS = administration and support, waste management and remediation services.

2.0 per cent per year or more: agriculture, forestry, fishing and hunting (2.44 per cent per year); wholesale trade (2.12 per cent per year); and information and cultural industries (2.00 per cent per year). MFP growth in manufacturing, at 1.30 per cent per year, was also well above the business sector average.

Sectoral contributions to aggregate productivity growth also depend on the sectors' relative sizes. Chart 4 and Chart 5 show the relative sizes of the provinces and industries in terms of nominal input costs in both 1997 and 2014.[15]

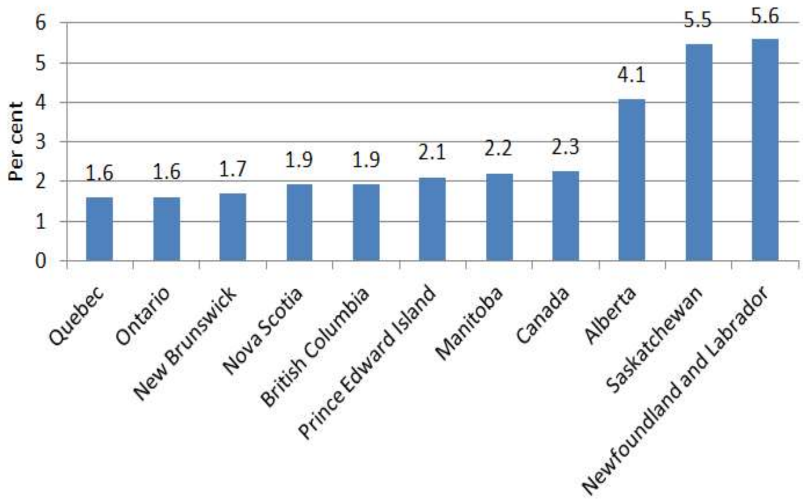
The most notable feature of Chart 4 is that Alberta, Saskatchewan, and Newfoundland and Labrador have experienced significant growth in the sizes of their economies relative to the other provinces, while Ontario, Quebec, and British Columbia have experienced relative declines in size. Ontario's share of nominal input costs in the business sector industries fell from 41.1 per cent in 1997 to 35.4 per cent in 2014 while Alberta's rose from 13.0 per cent to 21.3 per cent.

Several industries experienced large changes in their shares of aggregate input costs between 1997 and 2014. Manufacturing's share of total input costs fell from 22.3 per cent in 1997 to 13.1 per cent in 2014, and FIRE's share fell from 18.9 per cent to 15.2 per cent over the period. Meanwhile, mining and oil and gas extraction's share rose from 4.9 per cent to 12.9 per cent and construction's share rose from 6.3 per cent to 8.7 per cent. Given the geographic concentrations of mining and oil and gas and manufacturing, the developments in these industries are closely related to the provincial trends observed in Chart 4.

Overall, these patterns suggest that economic resources have been reallocated toward the mining and oil and gas extraction industries in Alberta, Saskatchewan, and Newfoundland and Labrador - industries with falling MFP levels.

15 Constructing these charts using nominal GDP rather than nominal input costs would not alter any conclusions about the relative sizes of industries or provinces.

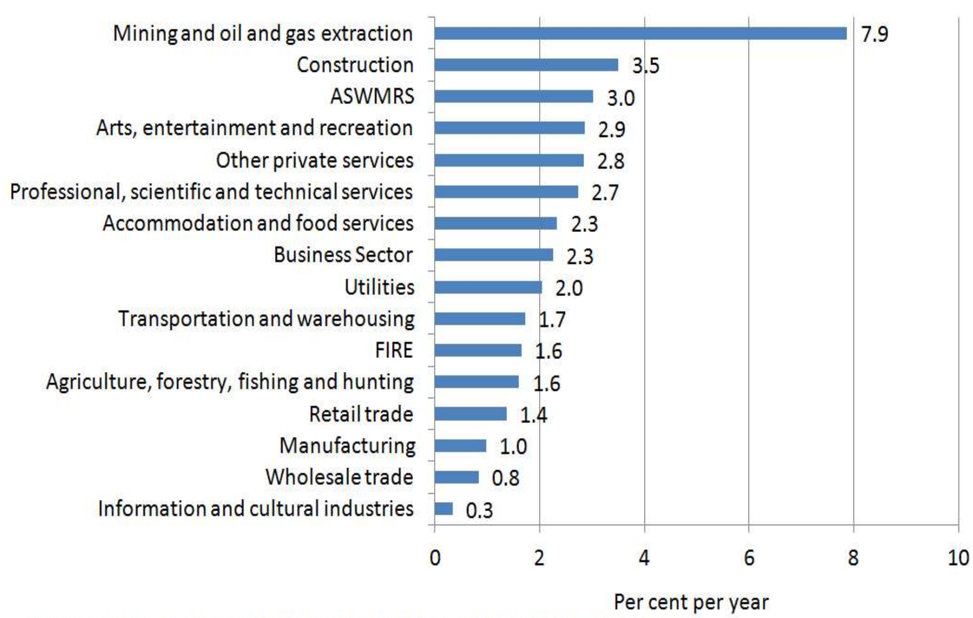
Chart 6
Growth of the GDP Deflator in Canada and the Provinces, Business Sector Industries, Per Cent per Year, 1997-2014



Source: Authors' calculations based on data from CANSIM Table 383-0026.

Resources have been reallocated away from the manufacturing industry in Ontario and Quebec - an industry with rising MFP. Everything else being equal, this should lead to lower aggregate MFP growth.[16] In the GEAD, the rising relative price of mining and oil and gas sector output and the falling relative price of manufacturing sector

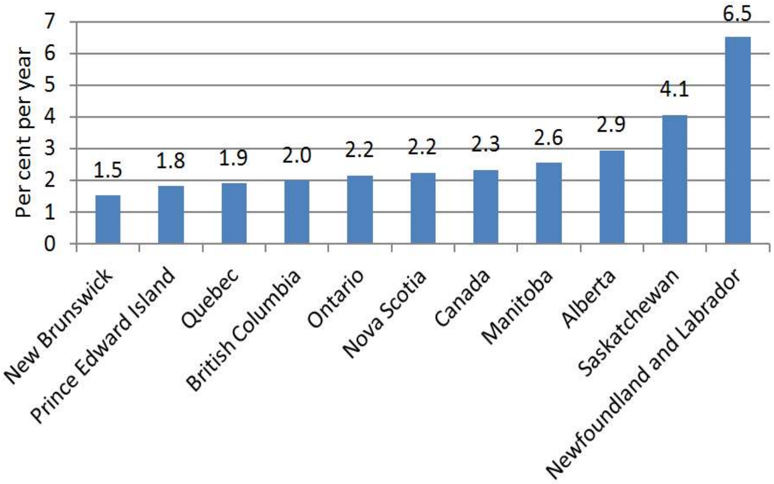
Chart 7
Growth of the GDP Deflator by Business Sector Industry, Canada, Per Cent per Year, 1997-2014



Source: Authors' calculations based on data from CANSIM Table 383-0026.
Note: FIRE = Finance, insurance, and real estate. ASWMRS = administration and support, waste management and remediation services.

16 In principle, this reallocation of resources could yield faster aggregate MFP growth through a strong reallocation level effect if the MFP level of mining and oil and gas is very high relative to that of manufacturing.

Chart 8
Growth of the Implicit Input Price Deflator in Canada and the Provinces, Business Sector Industries, Per Cent per Year, 1997-2014



Source: Authors' calculations based on data from CANSIM Table 383-0026.

output will provide a countervailing force. We now examine these price changes in more detail.

Output and Input Prices

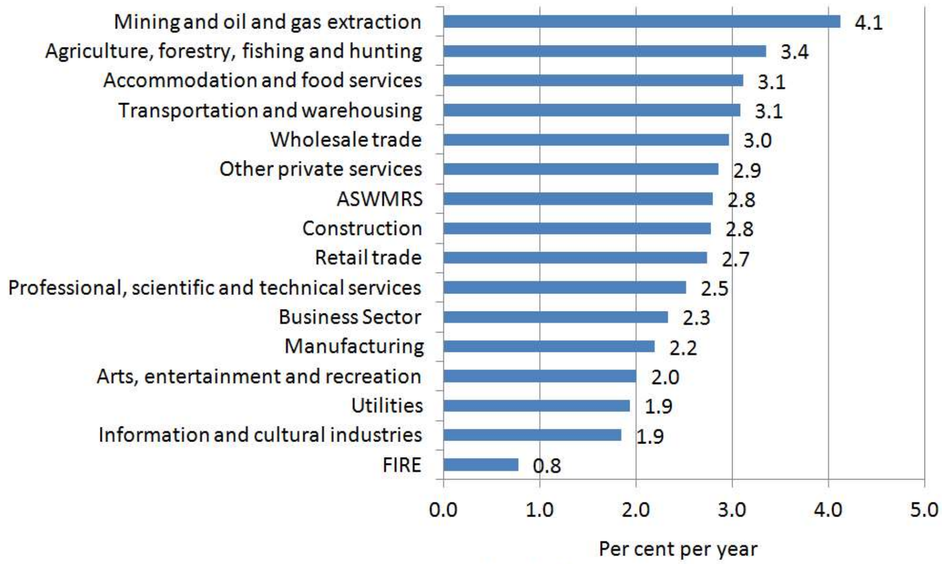
If the output of a sector becomes more valuable relative to that of other sectors over time, reflected in a rising relative price of the output of the sector, then the GEAD ascribes a larger MFP contribution to that sector. The price of the aggregate output of the business sector across all provinces grew by 2.3 per cent per year over the 1997-2014 period (Chart 6). Three provinces experienced significantly above average output price growth: Newfoundland and Labrador (5.6 per cent per year), Saskatchewan (5.5 per cent per year), and Alberta (4.1 per cent per year). This reflects the effects of rising natural resource prices, especially oil prices. Price growth was relatively modest in the other provinces. The lowest rates of output price growth were in Quebec and Ontario, each at 1.6 per cent per year.

At 7.9 per cent per year, output price growth in mining and oil and gas extraction was more than double the next highest output price growth rate among the fifteen business sector industries over the 1997-2014 period (Chart 7). As we shall see, this will translate into large MFP growth contributions from the mining and oil and gas extraction industry under the GEAD but not under the CSLS decomposition. Construction had the second-highest output price growth rate, at 3.5 per cent per year. Output price growth was lowest in information and cultural industries (0.3 per cent per year) and in wholesale trade (0.8 per cent per year).

The GEAD framework also accounts for changes in relative input prices. If a sector's bundle of inputs grows more expensive relative to the bundle of inputs used in the economy as a whole, that sector's contribution to MFP growth declines; the rising real value of inputs (everything else being equal) reduces the value of the sector's output relative to its inputs. Changes in input prices may reflect changes in the quality of the inputs or changes in the opportunity cost of using the input (i.e. firms could substitute a greater quantity of other inputs which have become relatively cheaper).

Chart 8 displays the rates of input price growth by province for the 1997-2014 period. As in the case of output price growth, the three

Chart 9
Growth of the Implicit Input Price Deflator by Business Sector Industry, Canada, Per Cent per Year, 1997-2014



Source: Authors' calculations based on data from CANSIM Table 383-0026.
Note: FIRE = Finance, insurance, and real estate. ASWMRS = administration and support, waste management and remediation services.

highest rates of input price growth over the 1997-2014 period were in Newfoundland and Labrador (6.5 per cent per year), Saskatchewan (4.1 per cent per year), and Alberta (2.9 per cent per year). This is not too surprising because rising output growth in a sector raises demand for the inputs of that sector, which in turn raises the prices of those inputs. Thus, to some extent, the effects of changing relative output prices should be expected to be offset by those of changing input prices in the GEAD. The lowest input price growth rates were in New Brunswick (1.5 per cent per year) and Prince Edward Island (1.8 per cent per year).

Given the provincial patterns, it is unsurprising that the fastest input price growth among industries occurred in mining and oil and gas extraction, at 4.1 per cent per year (Chart 9). The slowest input price growth over the 1997-2014 period was in FIRE (0.8 per cent per year).

Decomposition Results: GEAD

Table 1 summarizes the MFP growth decomposition for the 1997-2014 period based on the GEAD. The contributions of each province and industry to overall MFP growth are expressed in percentage points. The total contribution of each industry or province is the sum of four effects primarily associated with four factors: within-sector MFP growth, growth in relative output prices, (inverse) growth in relative input prices, and growth in the sector's share of total input costs.[17]

First, consider the four factors at the aggregate level. Within-sector MFP growth contributed 0.14 percentage points to aggregate MPF growth. This amounts to 50 per cent of Canada's 0.28 per cent cumulative MFP growth over the 1997-2014 period. Each of the other three effects is much larger in absolute value than the within-sector MFP growth effect: relative out-

17 Recall that each of the four components contains an equal share of the factor's interaction effects with the other factors.

Table 1
Contributions by Provinces and Business Sector Industries to Multifactor Productivity Growth in Canada, GEAD, Percentage Points, 1997-2014

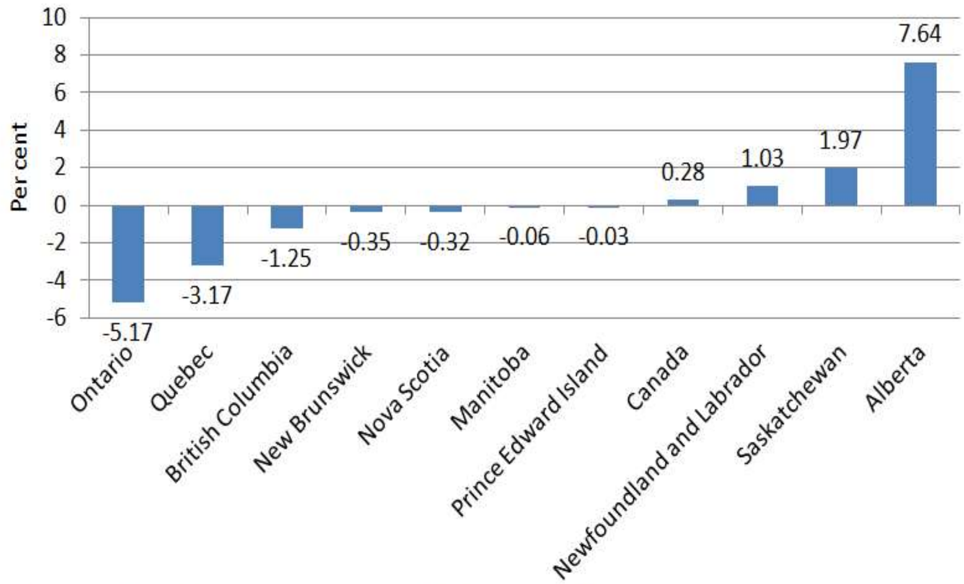
	Within-Sector MFP Growth	Relative Output Price Growth	(Inverse) Relative Input Price Growth	Input Share Growth	Total Effect
Total	0.14	1.91	-3.15	1.38	0.28
Province					
Alberta	-4.11	5.35	-2.61	9.00	7.64
British Columbia	0.13	-0.66	0.65	-1.37	-1.25
Manitoba	0.24	0.03	-0.20	-0.13	-0.06
New Brunswick	-0.03	-0.13	0.20	-0.39	-0.35
Newfoundland and Labrador	0.75	1.04	-2.26	1.50	1.03
Nova Scotia	0.03	-0.11	0.06	-0.30	-0.32
Ontario	3.89	-4.25	1.15	-5.96	-5.17
Prince Edward Island	0.00	-0.01	0.03	-0.05	-0.03
Quebec	1.19	-2.16	1.41	-3.61	-3.17
Saskatchewan	-1.95	2.80	-1.56	2.69	1.97
Industry					
Accommodation and food services	0.04	0.04	-0.37	0.15	-0.15
ASWMRS	-0.10	0.41	-0.29	1.13	1.15
Agriculture, forestry, fishing and hunting	1.07	-0.26	-0.45	-0.86	-0.51
Arts, entertainment and recreation	-0.17	0.09	0.05	0.04	0.01
Construction	0.17	1.87	-0.86	2.95	4.13
FIRE	-2.23	-1.80	4.66	-3.74	-3.11
Information and cultural industries	1.37	-1.29	0.30	-0.63	-0.24
Manufacturing	3.95	-3.88	0.53	-9.57	-8.96
Mining and oil and gas extraction	-8.11	9.01	-4.28	9.25	5.88
Other private services	0.17	0.50	-0.48	0.42	0.62
Professional, scientific and technical services	0.42	0.49	-0.27	1.71	2.35
Retail trade	1.42	-0.97	-0.44	0.36	0.37
Transportation and warehousing	-0.06	-0.52	-0.72	0.88	-0.41
Utilities	-0.31	-0.11	0.24	-0.79	-0.98
Wholesale trade	2.52	-1.66	-0.77	0.07	0.15

Source: Authors' calculations based on data from CANSIM Table 383-0026.
Note: FIRE = Finance, insurance, and real estate. ASWMRS = administration and support, waste management and remediation services.

put price growth contributed 1.91 percentage points, (inverse) relative input price growth contributed -3.15 percentage points, and input share growth contributed 1.38 percentage points. As shown by Diewert (2016), however, these three effects are approximately offsetting in the aggregate. In total they contributed just 0.14 percentage points to cumulative MFP growth.

It is important to emphasize that the small combined contribution of the price and reallocation effects to aggregate MFP growth is a mathematical result that should always hold (to a close approximation, at least) while the small

Chart 10
Contributions by Provinces to Multifactor Productivity Growth in Canada, GEAD, Percentage Points, 1997-2014



Source: Authors' calculations based on data from CANSIM Table 383-0026.

contribution of within-sector MFP growth is an empirical result that could have been different if Canada's productivity performance over the 1997-2014 period had been better.

While the price and reallocation effects are approximately offsetting in the aggregate, they do have a substantial effect on the province and industry contributions. We turn to these contributions now.

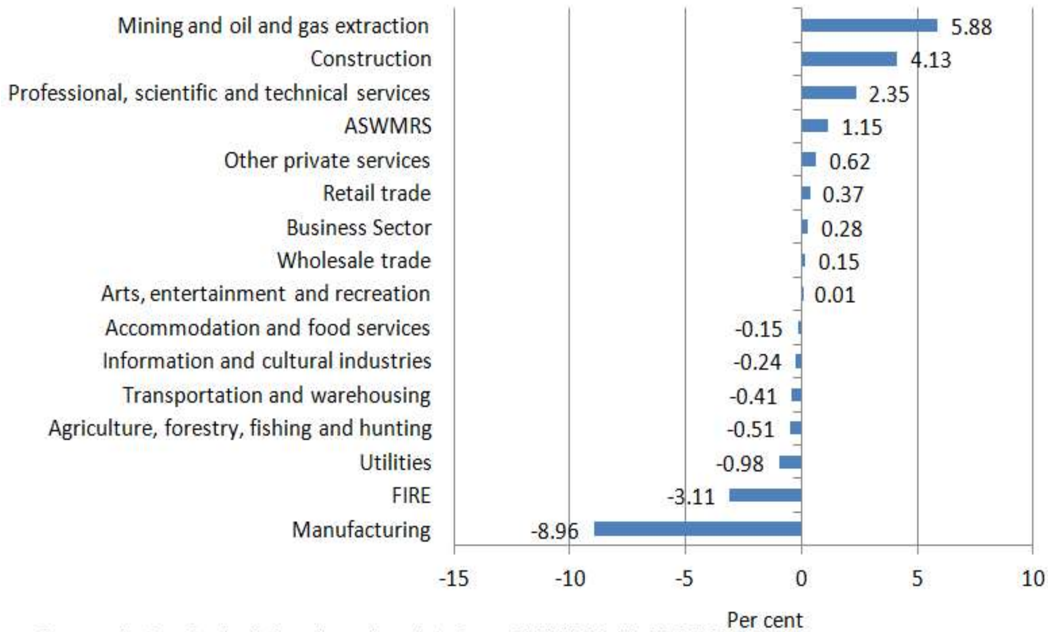
Among the provinces, Alberta made by far the largest contribution to aggregate MFP growth, at 7.6 percentage points (Chart 10). Saskatchewan (at 2.0 percentage points) and Newfoundland and Labrador (at 1.0 percentage points) also made positive contributions. The largest negative contributions were from Ontario (-5.2 percentage points) and Quebec (-3.2 percentage points).

The positive contributions of Alberta and Saskatchewan to overall MFP growth were entirely attributable to large relative output price growth effects and input share growth effects experienced in those two provinces. Both provinces exhibited negative within-sector MFP growth, but the output price and input share effects swamped the direct within-sector MFP growth effects. The same explanation applies in Quebec and Ontario with the signs reversed; both had positive within-sector MFP growth, but large negative output price and input share effects led to negative total contributions.

Given the provincial decomposition, it is not surprising that the mining and oil and gas extraction industry was the largest contributor to aggregate MFP growth (Chart 11). The industry contributed 5.9 percentage points to overall MFP growth over the 1997-2014 period. Negative within-sector MFP growth contributed -8.1 percentage points, while rising relative input prices in the industry made a further contribution of -4.3 percentage points. These negative effects were more than offset by large positive contributions from relative output price growth (9.0 percentage points) and input share growth (9.3 percentage points).

Manufacturing made by far the smallest (i.e. most negative) contribution to overall MFP

Chart 11
Contributions by Business Sector Industries to Multifactor Productivity Growth in Canada, GEAD, Percentage Points, 1997-2014



Source: Authors' calculations based on data from CANSIM Table 383-0026.
Note: FIRE = Finance, insurance, and real estate. ASWMRS = administration and support, waste management and remediation services.

growth, at -9.0 percentage points. Again, the total effect differs in sign from the direct within-sector MFP growth effect. Manufacturing's positive MFP growth contributed 4.0 percentage points to overall MFP growth, while relative input price changes contributed a further 0.5 percentage points. However, these effects were more than offset by the negative contributions from relative output price growth (-3.9 percentage points) and input share growth (-9.6 percentage points).

Clearly, the provincial patterns displayed in Chart 10 and the industry patterns in Chart 11 are related. The large increase in commodity prices over the 1997-2014 period resulted in a substantial expansion of economic activity in the mining and oil and gas industry, which is concentrated in Alberta, Saskatchewan and Newfoundland and Labrador. At the same time, the opposite was occurring in the manufacturing sector, which is concentrated in Ontario and Quebec. These price growth and input reallocation effects dominated the effect of within-sector MFP growth, which was positive in manufacturing and negative in mining and oil and gas.

Among the remaining industries, significant positive contributions to overall MFP growth came from construction (4.1 percentage points) and professional, scientific and technical services (2.4 percentage points). The FIRE industry made a significant negative contribution of -3.1 percentage points.

We can compare our main results with those of Diewert (2015), who decomposed MFP growth in Australia over the 1995-2012 period. Diewert finds that the contribution to MFP growth from the mining industry exceeds the average MFP growth in the total economy so that mining is the most important positive contributor to an even greater extent than we estimate in Canada. Similar to our findings, output

Table 2

Ten Largest Positive and Negative Province-Industry Contributions to Multifactor Productivity Growth in Canada, GEAD, Percentage Points, 1997-2014

Province	Industry	Within-Sector MFP Growth	Relative Output Price Growth	(Inverse) Relative Input Price Growth	Input Share Growth	Total Effect
Ontario	Manufacturing	2.39	-2.47	0.48	-6.09	-5.69
Quebec	Manufacturing	0.69	-1.11	0.49	-2.56	-2.50
Quebec	FIRE	-0.49	-0.69	1.32	-1.29	-1.14
British Columbia	FIRE	-0.75	-0.22	1.02	-0.93	-0.88
Ontario	FIRE	-0.23	-0.61	1.19	-1.01	-0.65
British Columbia	Manufacturing	0.55	-0.45	0.02	-0.75	-0.63
Ontario	Utilities	0.03	-0.25	0.09	-0.47	-0.60
British Columbia	Agriculture, forestry, fishing and hunting	0.21	-0.19	0.03	-0.39	-0.34
Quebec	Utilities	0.15	-0.12	-0.08	-0.26	-0.31
Quebec	Information and cultural industries	0.36	-0.39	0.07	-0.32	-0.28
Alberta	Wholesale trade	0.18	0.02	-0.13	0.36	0.42
Quebec	Professional, scientific and technical services	-0.03	0.10	0.07	0.30	0.44
Quebec	Construction	0.09	0.24	-0.01	0.25	0.57
Alberta	Professional, scientific and technical services	0.26	0.24	-0.26	0.55	0.78
Ontario	Professional, scientific and technical services	0.07	0.06	0.05	0.63	0.80
Ontario	Construction	-0.32	0.67	0.18	0.32	0.85
Newfoundland and Labrador	Mining and oil and gas extraction	0.61	1.01	-2.08	1.36	0.91
Saskatchewan	Mining and oil and gas extraction	-2.40	2.35	-0.73	1.96	1.17
Alberta	Construction	0.32	0.51	-0.74	1.75	1.84
Alberta	Mining and oil and gas extraction	-5.00	4.22	-0.70	4.36	2.88

Source: Authors' calculations based on data from CANSIM Table 383-0026.

Note: FIRE = Finance, insurance, and real estate. ASWMRS = administration and support, waste management and remediation services.

prices and reallocation for mining are found to have made large positive contributions, while within sector MFP growth had a large negative effect. Rising input prices in mining are also found to have had a negative effect, but it is relatively small compared to that which we estimated in Canada. Diewert also estimate a large negative contribution from manufacturing due to falling output prices and a large negative reallocation effect, offset to a limited degree by falling input prices. This is also in line with our results, although we find that there is a significant positive within-sector contribution from manufacturing in Canada while within-sector MFP growth had almost no effect in Australia.

The major trends are clear, but our decomposition at the industry-province level allows for a more disaggregated analysis of the most important contributions within the most important industries and provinces. Table 2 presents the ten industry-province pairs with the largest positive contributions and the ten with the largest negative contributions to aggregate MFP growth between 1997 and 2014. The two largest negative contributions were made by the manufacturing industries of Ontario and Quebec, at -5.7 percentage points and -2.5 percentage points, respectively. Manufacturing accounts for three of the ten largest negative contributions, while FIRE accounts for an additional three. In the manufacturing cases, positive within-sector MFP growth was more than offset by negative output price growth effects and input share growth effects. In the FIRE cases, within-sector MFP growth also made negative contributions.

The largest positive contribution was from Alberta's mining and oil and gas extraction industry, at 2.9 percentage points. The mining and oil and gas extraction industry accounted for three of the four largest positive contributions to overall MFP growth over the 1997-2014 period, with construction and professional, scientific and technical services each accounting for three of the top ten. The positive contributions of mining and oil and gas extraction were mainly driven by relative output price growth and input share growth, although the industry did exhibit a positive within-sector MFP growth effect in Newfoundland and Labrador.

Finally, we consider detailed breakdowns of the contributions of Alberta and Ontario, the two provinces with the largest impacts on national MFP growth, and of manufacturing and mining and oil and gas extraction, the two industries with the largest impacts on national growth. This will allow us to obtain a sense of whether contributions were broad-based within these categories or concentrated in a few subsectors.

The positive productivity contribution of Alberta is not entirely attributable to the mining and oil and gas extraction and construction industries. These two industries are responsible for 61.8 per cent of Alberta's total contribution. Every other industry in the province also made a positive contribution to overall MFP growth over the 1997-2014 period. Many of the industries made positive contributions via the within-sector MFP growth effect, although the input share growth effect was typically larger.

In contrast, the negative contribution of Ontario is entirely accounted for by the manufacturing industry. Manufacturing's negative contribution accounted for 110 per cent of Ontario's overall MFP growth contribution. That being said, nine of the fifteen industries in Ontario made negative contributions to Canada's MFP growth while six made positive contributions. The largest positive contributions were from construction and professional, scientific and technical services at -16.4 per cent and -15.4 per cent of Ontario's total contribution, respectively.[18] In both cases, the contributions were driven mainly by relative output price growth and input share growth (although professional, scientific and technical services also made a positive within-sector MFP contribution).

Within the manufacturing industry, we find that the negative contribution is concentrated in Ontario and Quebec, which together account for 91.4 per cent of the total contribution of the industry. The manufacturing industries in Saskatchewan and Alberta made positive contributions to overall MFP growth over the 1997-2014 period; they accounted for -1.3 per cent and -0.5 per cent of the industry's total contribution, respectively. In every other province, manufacturing's contribution was negative. The within-sector MFP growth effect made a positive contribution to aggregate MFP growth in every province but New Brunswick, but in most provinces this was swamped by the output price growth and input share growth effects.

The positive contribution of the mining and oil and gas extraction industry is concentrated in Alberta, Saskatchewan and Newfoundland and

18 Remember, Ontario's total contribution was negative. Thus, having accounted for -16.4 per cent of Ontario's total contribution means that the construction industry in Ontario made a positive contribution.

Table 3
Contributions by Provinces and Business Sector Industries to Multifactor Productivity Growth, CSLS Decomposition, Percentage Points, 1997-2014

	Within-Sector MFP Growth	Reallocation Level Effect	Reallocation Growth Effect	Total Effect
Total	2.19	8.05	-11.32	-1.09
Province				
Alberta	-4.01	5.13	-5.76	-4.64
British Columbia	0.34	0.60	-1.00	-0.05
Manitoba	0.27	0.07	-0.15	0.19
New Brunswick	-0.01	0.04	-0.05	-0.02
Newfoundland and Labrador	0.43	-0.30	0.03	0.16
Nova Scotia	0.09	0.05	-0.08	0.06
Ontario	4.33	0.97	-1.99	3.31
Prince Edward Island	0.01	0.01	-0.01	0.01
Quebec	1.45	0.38	-0.62	1.21
Saskatchewan	-0.71	1.10	-1.70	-1.31
Industry				
Accommodation and food services	0.04	0.00	-0.01	0.04
ASWMRS	-0.08	-0.01	-0.03	-0.13
Agriculture, forestry, fishing and hunting	1.16	0.33	-0.50	0.98
Arts, entertainment and recreation	-0.15	0.04	-0.04	-0.16
Construction	0.13	-0.21	0.11	0.02
FIRE	-2.00	0.14	-0.11	-1.97
Information and cultural industries	1.26	0.07	-0.16	1.17
Manufacturing	4.61	1.04	-1.95	3.69
Mining and oil and gas extraction	-7.09	6.17	-7.92	-8.84
Other private services	0.16	-0.01	0.01	0.16
Professional, scientific and technical services	0.36	-0.04	0.07	0.39
Retail trade	1.39	0.00	0.00	1.39
Transportation and warehousing	0.00	0.05	-0.14	-0.09
Utilities	-0.13	0.23	-0.27	-0.17
Wholesale trade	2.54	0.25	-0.36	2.43

Source: Authors' calculations based on data from CANSIM Table 383-0026.
Note: FIRE = Finance, insurance, and real estate. ASWMRS = administration and support, waste management and remediation services.

Labrador, which together account for 84.4 per cent of the industry's total effect. The industry's contribution was positive in every province except for Nova Scotia. The within-sector MFP growth effect was negative in every province except for Nova Scotia and Newfoundland and Labrador; the positive total contributions from mining and oil and gas extraction in most provinces were driven by the output price growth effect and the input share growth effect.

Decomposition Results: CSLS Decomposition

Table 3 summarizes the MFP growth decomposition for the 1997-2014 period based on the CSLS decomposition. The contributions of each province and industry to overall MFP growth are expressed in percentage points. The total contribution of each industry or province is the sum of three effects: within-sector MFP growth, the reallocation of inputs into sectors with above-average MFP levels, and the reallocation of inputs into sectors with above-average MFP growth rates.

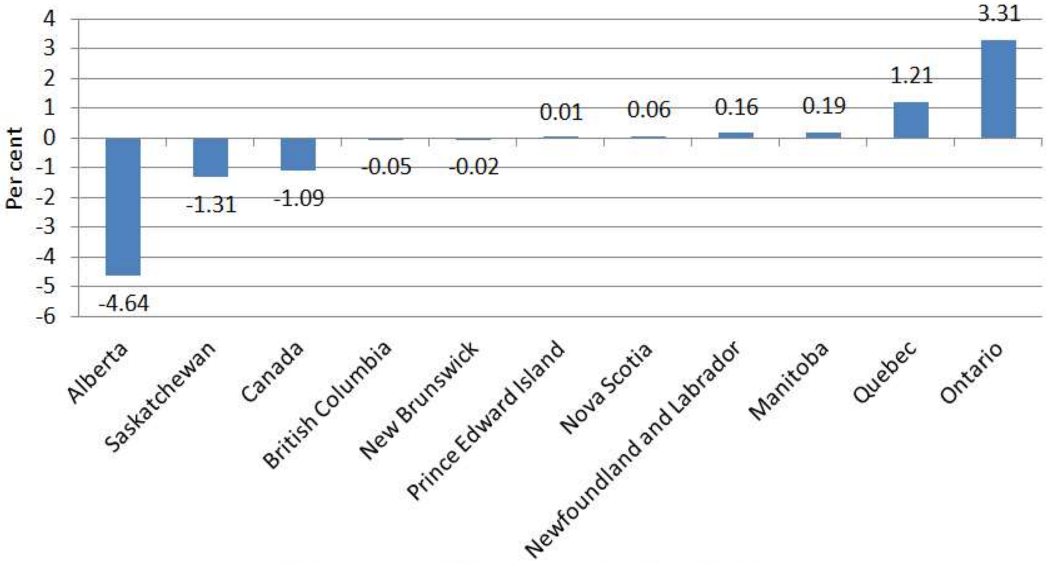
The CSLS decomposition differs from the GEAD decomposition in two important ways. First, the CSLS decomposition does not include changes in relative output or input prices when assessing a sector's contribution to productivity growth. If one is concerned about the value of output generated per (price-adjusted) unit of aggregate input, then the GEAD may be the preferred approach. But, from a traditional perspective of productivity growth representing an outward shift of the production possibilities frontier, it may be preferable to exclude changes in relative prices when assessing the sources of MFP growth by industry and province. Second, the CSLS decomposition only counts reallocation of resources toward a sector as a positive contribution to productivity growth from the sector if the sector has an above average productivity level. We argue that this is more sensible than counting input growth in a sector as a positive contribution from that sector regardless of its productivity level. These two differences lead to extremely different conclusions regarding which provinces and industries generated productivity growth in Canada.

First, we consider MFP growth at the aggregate level.[19] Within-sector MFP growth contributed 2.2 percentage points to overall MFP growth. An additional contribution of 8.1 percentage points arose from the reallocation level effect. This reflects the movement of resources into Canada's mining and oil and gas industry, which has a high productivity level. These positive effects were offset by a negative reallocation growth effect; the movement of resources out of manufacturing (with high MFP growth) and into mining and oil and gas (with negative MFP growth) put downward pressure on overall MFP growth via this channel.

The results based on the GEAD suggested that the mining and oil and gas extraction industry in Alberta, Saskatchewan and Newfoundland and Labrador was the key driver of Canada's MFP growth while the manufacturing industry in Ontario and Quebec was the largest drag on overall MFP growth. The CSLS decomposition suggests precisely the opposite. Under the CSLS decomposition, the two provinces with the largest negative contributions to MFP growth are Alberta and Saskatchewan, at -4.6 percentage points and -1.3 percentage points, respectively (Chart 12). The provinces with the largest positive contributions are Ontario (3.3 percentage points) and Quebec (1.2 percentage points). The provincial patterns reflect the industry patterns. The industry with the largest positive contribution to overall MFP growth is

19 Note that the economy-wide total MFP effect in Table 3 is -1.09 per cent between 1997 and 2014. This differs from the cumulative aggregate MFP growth of 0.28 per cent displayed in Table 1 and in Chart 2. This discrepancy arises from the fact that the CSLS decomposition does not satisfy exact additivity; see the discussion in Section II. Relative to the GEAD, the CSLS decomposition sacrifices exact additivity in exchange for the elimination of price effects and a different (and in our view more sensible) apportionment of the aggregate effect of resource reallocation across industries. The error that arises from non-additivity turns out to be very small. Cumulative changes of 0.28 per cent and -1.09 per cent between 1997 and 2014 amount to annual growth rates of 0.016 and -0.064 per cent per year, respectively. Thus, the annual growth discrepancy is 0.081 percentage points; non-additivity introduces an error of less than one tenth of a percentage point per year.

Chart 12
Contributions by Provinces to Multifactor Productivity Growth, CSLS Decomposition, Percentage Points, 1997-2014



Source: Authors' calculations based on data from CANSIM Table 383-0026.

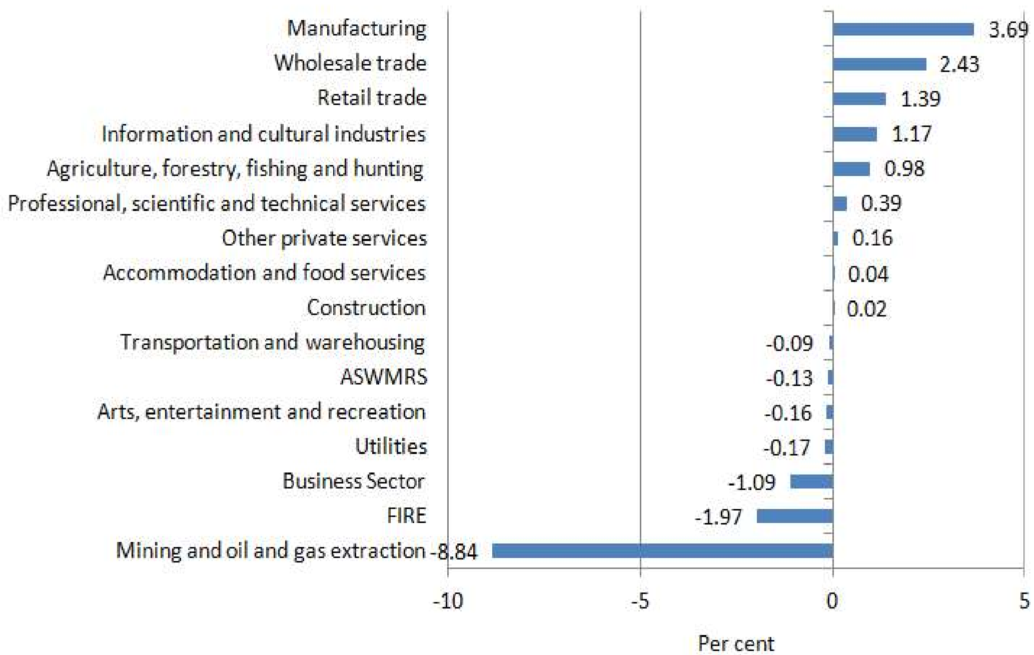
manufacturing, at 3.7 percentage points, while the industry with the largest negative contribution by far is mining and oil and gas extraction at -8.8 percentage points (Chart 13).

As Table 3 indicates, these contributions are mainly driven by within-sector MFP growth. In both manufacturing and mining and oil and gas extraction, and in all the provinces in which those industries are concentrated (Ontario, Quebec, Alberta, and Saskatchewan), the two reallocation effects are more or less offsetting. This leaves the within-sector effect to drive the total contributions. The within-sector MFP growth contribution was -4.0 percentage points in Alberta and -0.7 percentage points in Saskatchewan; both reflect the -7.1 percentage-point contribution of the mining and oil and gas industry. On the other hand, the within-sector MFP growth contribution was 4.3 percentage points in Ontario and 1.5 percentage points in Quebec, with both reflecting the 4.6 percentage-point within-sector effect of the manufacturing industry.

The within-sector effects generated by the CSLS and GEAD decompositions are relatively similar in absolute terms. The large differences in the total contributions assigned to each sector by the two decomposition formulas arise from two sources. First, changes in prices have a large effect if included; they are in the GEAD but not in the CSLS decomposition. Second, the CSLS decomposition's approach to reallocation effects only considers reallocation to make a positive contribution to the extent that a sector's productivity level is above average. This significantly reduces the effects associated with the large reallocation of employment out of manufacturing (Ontario) and into mining and oil and gas extraction (Alberta).

While mining and oil and gas extraction made by far the largest negative contribution among the industries, FIRE also made a significant negative contribution of -2.0 percentage points (Chart 13). This was driven entirely by a -2.0 percentage-point within-sector MFP growth effect. The total contribution of FIRE was negative according to both the GEAD and the

Chart 13
Contributions by Business Sector Industries to Multifactor Productivity Growth, CSLS Decomposition, Percentage Points, 1997-2014



Source: Authors' calculations based on data from CANSIM Table 383-0026.
Note: FIRE = Finance, insurance, and real estate. ASWMRS = administration and support, waste management and remediation services.

CSLS decomposition; the two decompositions do not disagree about FIRE as they do in the cases of manufacturing and mining and oil and gas extraction.

Table 4 displays the province-industry pairs with the ten largest negative and ten largest positive contributions to overall MFP growth over the 1997-2014 period according to the CSLS decomposition. In terms of the largest negative contributions, the mining and oil and gas extraction industry accounts for four of the top five and five of the top ten. The negative contribution of Alberta's mining and oil and gas extraction sector, at -5.4 percentage points, is by far the largest negative contribution among the 150 province-industry pairs. It was driven by the sector's substantial negative within-sector MFP growth effect, with the two reallocation effects largely offsetting one another. Aside from mining and oil and gas, the FIRE industry accounts for three of the ten largest negative contributions.

Ontario manufacturing made the largest positive contribution to overall MFP growth over the 1997-2014 period, at 2.1 percentage points. It was followed by Ontario wholesale trade at 1.4 percentage points. Positive contributions are less concentrated in specific industries than the negative contributions. Manufacturing and retail trade each accounts for three of the top ten largest positive contributions, while wholesale trade and information and cultural industries each accounts for two. In every case, the positive total contributions were driven by within-sector MFP growth.

Alberta's substantial negative contribution to Canada's MFP growth over the 1997-2014 period was entirely attributable to the mining and oil and gas industry.[20] The next largest contribution in the province was from FIRE, which

Table 4
Ten Largest Positive and Negative Province-Industry Contributions to Multifactor Productivity Growth, CSLS Decomposition, Percentage Points, 1997-2014

Province	Industry	Within-Sector MFP Growth	Reallocation Level Effect	Reallocation Growth Effect	Total Effect
Alberta	Mining and oil and gas extraction	-4.88	5.11	-5.61	-5.38
Saskatchewan	Mining and oil and gas extraction	-1.16	1.05	-1.61	-1.72
British Columbia	FIRE	-0.71	0.01	-0.01	-0.71
British Columbia	Mining and oil and gas extraction	-0.38	0.21	-0.48	-0.65
Ontario	Mining and oil and gas extraction	-0.54	0.08	-0.17	-0.62
Quebec	FIRE	-0.45	0.00	0.00	-0.45
Alberta	FIRE	-0.37	0.12	-0.10	-0.35
Ontario	Construction	-0.27	-0.04	-0.04	-0.35
Alberta	Utilities	-0.21	0.13	-0.19	-0.26
Quebec	Mining and oil and gas extraction	-0.20	0.03	-0.08	-0.24
Quebec	Retail trade	0.24	0.01	-0.01	0.24
British Columbia	Wholesale trade	0.25	0.03	-0.04	0.24
Quebec	Information and cultural industries	0.35	0.05	-0.10	0.30
Alberta	Retail trade	0.31	-0.03	0.04	0.32
Ontario	Retail trade	0.43	0.01	-0.01	0.42
Ontario	Information and cultural industries	0.49	0.00	0.01	0.50
British Columbia	Manufacturing	0.61	0.20	-0.24	0.57
Quebec	Manufacturing	0.78	0.22	-0.27	0.72
Ontario	Wholesale trade	1.50	0.14	-0.24	1.40
Ontario	Manufacturing	2.88	0.63	-1.37	2.13

Source: Authors' calculations based on data from CANSIM Table 383-0026.
Note: FIRE = Finance, insurance, and real estate. ASWMRS = administration and support, waste management and remediation services.

accounted for just 7.5 per cent of Alberta's total contribution. Ten of the fifteen industries in Alberta made positive contributions to aggregate MFP growth over the 1997-2014 period, but these contributions were swamped by the mining and oil and gas sector.

In contrast, Ontario's positive contribution to overall MFP growth was not concentrated in one industry alone. Manufacturing accounted for 64.5 per cent of Ontario's total contribution, but five other industries made contributions (either positive or negative) that amounted to at least ten per cent of Ontario's total in absolute value. In particular, Ontario's wholesale trade industry contributed 42.5 per cent of the provincial total. In every case, the within-sector productivity growth effect was the largest component of the sector's total effect.

The manufacturing industries in every province except New Brunswick made positive con-

20 See Calver and Murray (2016) for a more detailed discussion of industry contributions for Alberta and Ontario and contributions by province for mining, oil and gas, manufacturing, and FIRE.

tributions to Canada's MFP growth over the 1997-2014 period. Quebec and Ontario together accounted for 77.4 per cent of the industry's total contribution, and British Columbia accounted for another 15.4 per cent. The contributions from manufacturing in all the other provinces were small. In Ontario, Quebec and British Columbia, resource reallocation made a small negative contribution on balance as the reallocation level and growth effects largely offset each other. Within-sector MFP growth was the key driver of the industry's contributions in each province.

The negative contribution of the mining and oil and gas industry to Canada's MFP growth over the 1997-2014 period was concentrated in Alberta and Saskatchewan; those two provinces accounted for 80.3 per cent of the industry's total contribution. The industry made a negative contribution in every province except Nova Scotia and Newfoundland and Labrador. The latter is especially notable. Unlike Alberta and Saskatchewan, Newfoundland and Labrador exhibited positive MFP growth in its mining and oil and gas extraction industry over the 1997-2014 period.

The contribution of FIRE was negative in every province except Saskatchewan, where it was close to zero. The reallocation effects were quite small in most provinces; the exception is Alberta, but even there the two reallocation effects largely offset one another. The total MFP growth contributions were driven by within-sector MFP growth. British Columbia accounted for 36.2 per cent of the aggregate contribution. That province together with Quebec, Alberta and Ontario accounted for 87.1 per cent of the industry's contribution.

Conclusion

Between 1997 and 2014, multifactor productivity (MFP) in Canada's business sector industries grew by 0.28 per cent cumulatively, or 0.02 per cent per year - essentially zero. In this article, we performed two decomposition exercises to identify how different sectors of the economy contributed to this overall performance. The results consistently indicate that Alberta (the mining and oil and gas extraction industry) and Ontario (the manufacturing industry) were the major contributors to aggregate MFP growth over the 1997-2014 period. However, the two decomposition formulas we employ disagree about which of these sectors generated productivity growth and which hindered it.

The generalized exactly additive decomposition (GEAD) includes the effects of changes in relative prices of inputs and outputs. It also assigns compositional effects from resource reallocation in such a way that reallocation of resources to a sector is considered to result in a positive contribution to productivity growth from the sector even if the sector has a below average productivity level. The GEAD finds that Alberta and the mining and oil and gas extraction industry were the major sources of MFP growth in Canada due to rising natural resource prices and reallocation of inputs to these sectors. The manufacturing sector experienced falling output prices and contracted significantly so that it reduced aggregate MFP growth. This negative effect from manufacturing was most highly concentrated in Ontario.

In contrast, the CSLS decomposition excludes price effects and assigns a positive contribution to an industry with a rising input share only to the extent that the industry's productivity level exceeds the average. The CSLS decomposition has previously only been applied to labour productivity; a methodological innovation of this article is the adaptation of the CSLS decomposition to MFP growth. The CSLS decomposition suggests that manufacturing was the largest contributor to the growth of MFP in Canada due to strong within-sector MFP growth. Fifty-eight per cent of manufacturing's contribution occurred in Ontario. On the other hand, Saskatchewan and Alberta are found to have lowered aggregate MFP growth because of very large declines in MFP within the mining and oil and gas extraction industry.

From a policymaker's point of view, the very different conclusions from the two decomposition methodologies may seem inconvenient. However, the results of both exercises can potentially be useful depending upon what one is interested in. Traditionally, productivity researchers have emphasized the importance of technological progress, which can be viewed as an outward expansion of the production possibilities frontier. Changes in prices should be ignored when attempting to assess productivity from the standpoint of technological change. The CSLS decomposition may be better suited for assessing how provinces and industries are contributing to "real" productivity growth nationally. However, the ultimate goal of public policy is not to maximize physical productivity growth, but the total value of production. From this point of view, incorporating price changes may be more relevant for understanding how changes in the value of output per unit of input have contributed to rising living standards. The GEAD is better suited for this purpose. However, the CSLS decomposition can provide valuable insights to policymakers seeking to identify opportunities to improve "real" productivity, which is an important factor in determining aggregate living standards.

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Partial versus Total Factor Productivity Measures: An Assessment of their Strengths and Weaknesses

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Abstract

A partial productivity measure relates output to a single input. Total factor productivity (or TFP) relates an index of output to a composite index of all inputs. This article reviews the strengths and weaknesses of each type of productivity measure from theoretical and methodological perspectives. Different productivity measures may be useful for different analytical purposes, and no single measure provides a complete picture of an industry's productivity performance. We argue for a balanced, context-appropriate approach to productivity analysis that incorporates both productivity measures.

Productivity measures are often used to assess a country's economic performance. There are two types of productivity measure. A partial productivity measure relates output to a single input; examples include labour productivity (output per hour worked), capital productivity (output per unit of capital), and energy productivity (output per joule of energy used). Total factor productivity (or TFP) relates an index of output to a composite index of all inputs.

In studies of long-term growth, many analysts focus on TFP as the preeminent measure of productivity. TFP growth is commonly associated with innovation and technological change, the long-run drivers of per-capita income growth. Empirically, growth accounting exercises attribute 50 to 70 per cent of cross-country per-capita income level differences to differences in TFP (Hseih and Klenow, 2010). However, TFP is subject to many challenges in terms of both theoretical interpretation and empirical measurement.

Partial productivity measures have their own set of strengths and weaknesses. Such measures are of theoretical interest because of their close relationship to factor prices. From a practical perspective, a partial productivity measure may be more informative than TFP for certain analytical purposes because partial measures allow an analyst to zero in on the efficiency of the use of specific resources that are of special interest in a particular context.

1 Alexander Murray is an economist at the Centre for the Study of Living Standards (CSLS). This article is an abridged version of a report on productivity measures for natural resource industries prepared for the Smart Prosperity Institute (Murray and Sharpe, 2016). The author thanks Nicholas Oulton from the London School of Economics, Michelle Brownlee from the Smart Prosperity Institute, Andrew Sharpe, Bert Waslander, and officials from Natural Resources Canada and the Forest Products Association of Canada for helpful comments. E-mail: alexander.murray@csls.ca.

This article assesses the strengths and weaknesses of each type of productivity measure from both theoretical and methodological perspectives. It argues for a balanced, context-appropriate approach to productivity analysis that incorporates both types of measure. The first section of the article provides technical definitions of TFP and partial productivity and outlines the relationship between them. In the second section, we discuss the strengths and weaknesses of each type of productivity measure from both a theoretical perspective and a methodological perspective. Section three concludes.

Definitions of Partial and Total Factor Productivity, and the Relationship between Them

A firm uses inputs to produce output.[2] Intuitively, the ratio of the firm's output to its input is a definition of its productivity; a firm that produces more output per unit of input is more productive. But how should 'units of input' be measured, given that there are many types of input and each is measured in different units (hours of work, hectares of land, barrels of oil, and so on)? Different choices correspond to different notions of productivity.

Let us be precise. Let $X_{1,t}, \ldots X_{N,t}$ denote the real volumes of the N inputs used by the firm at date t, and let Q_t be the firm's real output. One way of assessing the firm's productivity growth between dates $t-1$ and t is to compare the growth of Q_t to that of each of the N inputs one at a time. Let $A_{i,t} = \frac{Q_t}{X_{i,t}}$ be the partial productivity of input i. Then the partial productivity growth of input i at time t is

$$\Delta \ln A_{i,t} = \Delta \ln Q_t - \Delta \ln X_{i,t}$$

where $\Delta \ln Q_t = \ln Q_t - \ln Q_{t-1}$ and so on. Positive partial productivity growth for input i indicates that the firm is able to produce more output per unit of input i it uses. The most common partial productivity measure is labour productivity, which is obtained when $X_{i,t}$ corresponds to the number of hours of labour used by the firm during period t. $\Delta \ln A_{i,t}$ then corresponds to growth in the firm's output per hour of labour input. In general, partial productivity can be computed for any input.

Each partial productivity measure provides an incomplete picture of the productivity with which the firm uses its inputs, and to keep track of the firm's partial productivity growth for all N inputs may be cumbersome. We may desire a single index of change in the productivity with which the firm uses all its inputs together. A reasonable way to combine the growth rates of the N inputs $X_{1,t}, \ldots X_{N,t}$ into a single composite input growth rate $\Delta \ln X_t$ is to use the following index:

$$\Delta \ln X_t = \sum_{i=1}^{N} \omega_{i,t} \Delta \ln X_{i,t}$$

where the weight $\omega_{i,t}$ is the average share of input i in total input costs in periods $t-1$ and t.[3] Then the firm's *total factor productivity growth* is defined as

$$\Delta \ln A_t = \Delta \ln Q_t - \Delta \ln X_t$$

Total factor productivity (TFP) growth measures changes in the amount of output the firm produces from given quantities of its full set of inputs, not just one input.

2 We will discuss productivity in terms of a firm, but in general the production unit could be an industry, a province, or a country.

3 This formula is called a Tornqvist index. The reasonableness of this approach can be defended on the grounds that the Tornqvist index is a discrete-time approximation of the ideal continuous-time index that can be derived from a production function under the assumption that an input's price is equal to its marginal product. See Hulten (2001) for a comprehensive discussion. In practice, Statistics Canada constructs volume and price measures using a different method, the chained Fisher index. It can be shown that the numerical discrepancy between Fisher and Tornqvist indexes is small.

There is a well-known relationship between the firm's TFP growth rate and its partial productivity growth rates. It is usually the case that $\sum_{i=1}^{N} \omega_{i,t} = 1$.[4] If this is true, then the expressions above can be combined to yield

$$\Delta \ln A_t = \sum_{i=1}^{N} \omega_{i,t} (\Delta \ln Q_t - \Delta \ln x_{i,t})$$
$$= \sum_{i=1}^{N} \omega_{i,t} \Delta \ln A_{i,t}$$

Thus, TFP growth is the weighted sum of the partial productivity growth rates for all the inputs, where the weights are the inputs' cost-share weights.

The expressions for TFP growth, partial productivity growth, and the relationship between them yield several insights about the various productivity measures. First, the data requirements for TFP measurement are burdensome relative to the data requirements for a given partial productivity measure. Measurement of TFP growth requires time series measures of real output, all of the real inputs used by the firm, and the nominal cost shares necessary to compute the weights. The need for data on *all* inputs can pose a problem if the firm uses some inputs that are unobserved or non-marketed. Second, the fact that the composite input X_t is a unit-free growth index implies that TFP can be measured only in growth rates; we do not have a meaningful measure of the absolute level of TFP.[5] Third, the complexity of TFP may make it difficult to explain to non-experts. By contrast, a partial productivity measure is relatively easy to compute and to explain to non-experts, and it can be measured in both levels and growth rates.

In addition to posing different practical challenges for measurement, TFP and partial productivity measures have different connections to economic theory. These points and others are discussed in the next section, which outlines the strengths and weaknesses of partial productivity measures and TFP.

Strengths and Weaknesses of the Productivity Measures

Theoretical Considerations

TFP in Economic Theory

An analyst's choices about what to measure are guided by the implications of theory about what it is important to measure. The main merit of TFP is its importance in economic growth theory. Among economists, the dominant framework for thinking about economic growth is the neoclassical growth model pioneered by Solow (1956; 1957). In that framework, TFP growth is the ultimate source of long-run economic growth.

Suppose the relationship between the firm's output Q_t and its N inputs is described by the production function

$$Q_t = F(X_{1,t}, \ldots X_{N,t}; A_t)$$

Output depends on the input quantities $X_{1,t}, \ldots X_{N,t}$, which are controlled by the firm, and on a scaling factor A_t that the firm takes as given. When A_t increases, the firm can produce more output for any given amount of

4 In theory, the weights sum to one if the firm's production function exhibits constant returns to scale (and input prices equal marginal products, as has already been assumed). The sum of the weights would exceed one under increasing returns to scale. In practice, the input cost shares are almost always constructed in a way that implies that they sum to one.

5 It is possible to measure the relative TFP levels of two firms (or industries or countries). Essentially, this can be done by using the above formulas but measuring the log-differences as differences between firms at a point in time rather than changes within a firm over time. We do not pursue this issue further here. See Uguccioni (2016a) for an example of relative TFP level measurement in the context of the Canadian railway industry.

inputs. Taking the total logarithmic differential of this function, and assuming that markets are competitive, we obtain

$$\frac{\dot{A}_t}{A_t} = \frac{\dot{Q}_t}{Q_t} - \sum_{i=1}^{N} \omega_{i,t} \frac{\dot{X}_{i,t}}{X_{i,t}}$$

where $\dot{A}_t/A_t$, $\dot{Q}_t/Q_t$ and $\dot{X}_{i,t}/X_{i,t}$ denote the growth rates of A_t, Q_t and $X_{i,t}$, respectively, and $\omega_{i,t}$ is the cost share of input *i* as defined earlier.[6] If we use log differences as discrete-time approximations of the instantaneous growth rates in this equation, we obtain the index number for TFP growth, $\Delta ln A_t$, given in the previous section. Thus, the empirical TFP measure corresponds to the production function scale term in neoclassical growth theory.

Why are economists so interested in measuring the production function scale term A_t? Because in neoclassical growth theory, growth of A_t is the fundamental determinant of all per capita output growth. Hulten (1978) shows that, within this framework, aggregate TFP growth is interpretable as an outward shift in the economy's production possibilities frontier. Basu *et al.* (2013b) argue that the growth rates of TFP and of the per-capita capital stock provide, to a first order of approximation, a complete summary of changes in consumer welfare irrespective of the form of the production technology or the degree of competitiveness of product markets.

Within this framework, growth of partial productivity measures is driven by TFP growth in the long run. It is common to use the neoclassical growth accounting framework to decompose the partial productivity measure for one input into two proximate sources: TFP growth and factor deepening (that is, increases in the quantity of other inputs relative to the one input for which the productivity measure is being measured). An analyst who is firmly committed to the neoclassical theory, however, would claim that TFP growth is the only source of growth; if TFP growth were to cease, then the accumulation of producible factors would eventually stop as well. The implications of this point for assessing the 'importance' of TFP growth are discussed by Hulten (1979).

For concreteness, consider a two-input model with $Q_t = A_t F(K_t, L_t)$, where K_t is physical capital and L_t is labour. Using the accounting relationships discussed earlier, it can be shown that the growth rate of the partial productivity of labour may be expressed as

$$\Delta ln A_{L,t} = \Delta ln A_t + \omega_{K,t} \Delta ln\left(\frac{K_t}{L_t}\right)$$

The two proximate causes of labour productivity growth are TFP growth, $\Delta ln A_t$, and capital deepening, $\Delta ln(K_t/L_t)$. But the neoclassical theory implies that the cessation of TFP growth would lead, in the long run, to the end of per-worker capital accumulation and, hence, to the end of growth in the partial productivity of labour. Thus, in a fundamental sense, it is incorrect to attribute any part of labour productivity growth to capital deepening. Capital deepening is a proximate source of labour productivity growth, but TFP growth is the only fundamental source.

The preceding discussion presents the traditional theoretical argument for focusing on TFP growth as the most important notion of productivity growth. It explains why TFP has interested economists from a theoretical perspective and why economists have been motivated to measure TFP in spite of many practical challenges. Before moving on to a detailed discussion of practical issues in pro-

6 For readers interested in the mathematical details see Murray and Sharpe (2016).

ductivity measurement, there remain five theory-based points worth noting.

Theory-dependent Interpretation

The first is that the central role of TFP in economic growth is theory-dependent. Exogenous growth in the production function scaling factor is the ultimate source of long-run growth in the basic neoclassical model. But in practice, few economists believe that the neoclassical theory provides a satisfying account of real-world economic growth. It has been acknowledged from the beginning that TFP is "a measure of our ignorance"; it is a 'black box', the residual part of output growth that we cannot yet explain (Abramovitz, 1956). Considerable subsequent research effort has aimed to explain it by building theories in which TFP growth is the endogenous result of actions taken by decision-makers.

In the endogenous growth model of Romer (1986), for example, the production function exhibits constant returns to scale in capital and labour from the perspective of an individual firm but increasing returns in the aggregate because capital accumulation produces positive externalities that firms do not take into account in their decisions.[7] One could still compute the TFP index for this economy, but it would capture the spillover effect from capital rather than (or in addition to) the growth of an exogenous production function shifter. The fundamental determinant of long-run growth is no longer exogenous TFP growth, as it is in the neoclassical model, but rather the set of parameters that govern capital investment behaviour and the positive externalities. Since TFP growth now follows capital accumulation rather than driving it, it is no longer a more fundamental measure of productivity than partial productivity measures (Sargent and Rodriguez, 2000).[8]

Sensitivity to Assumptions

The second point is that, even within the neoclassical paradigm, the interpretation of TFP (A_t) is sensitive to many assumptions including, but not limited to, assumptions about the competitiveness of markets, the rate of factor utilization, returns to scale in the production function, changes in the quality of inputs, and the manner in which technological change augments different factors of production. If factor or product markets are not competitive, if firms vary factor utilization rates over time in response to business conditions, if the production function does not exhibit constant returns to scale, if input quality changes are unmeasured, or if technological improvements augment the marginal products of different factors differently, then the clean identification of the TFP index with a production function scaling factor breaks down.[9]

Hulten (2001) provides a simple example in which capital and labour are augmented by separate exogenous scale factors. In this case, he shows that the usual TFP measure captures not only the growth rates of these scale

7 Here, 'capital' should be taken to include not only machines and buildings but also the stock of 'knowledge capital' that arises from R&D. The positive externality reflects the spillover of ideas across firms.

8 Using data from a set of OECD countries, Oulton (2016a) poses the following question: By how much would the elasticity of aggregate output with respect to aggregate capital have to exceed the capital share of output (i.e. the capital elasticity of output faced by a firm that ignores spillovers) in order for capital spillovers to fully explain measured TFP growth? He finds that in most countries, the elasticity would have to be more than twice as large as the observed capital share. He finds it implausible that spillover effects could be that large, and therefore concludes that capital spillovers alone cannot explain all of measured TFP growth. See Romer (1987) for a related analysis.

factors but also changes in the factor cost shares.

TFP Growth is Not a Measure of Technological Change

The third point is that, even leaving aside its sensitivity to assumptions, the interpretation of TFP as a measure of technical change is subtle. TFP growth is commonly equated with technological progress, but this is inappropriate. As Gordon (2016:569) emphasizes, "innovation is the ultimate source of all growth in output per worker-hour, not just the residual after capital investment is subtracted out." Many technological improvements are embedded in new forms of machinery and equipment, and firms adopt them by substituting these new types of capital for other inputs. This 'embodied' technical change is not captured in TFP (Jorgenson and Stiroh, 1999).

Moreover, even disembodied innovations (improved management practices, for example) that arise from R&D expenditures should, to the extent that the returns are captured by the investors, be included in the output and input payments of the firms that conduct the R&D. TFP grows only to the extent that the benefits of the innovation spill over to firms that did not pay for it; that is, TFP reflects only the costless component of technological change (Jorgenson and Griliches, 1967). Lipsey and Carlaw (2004) reiterate this point and show how the timing of technology diffusion and the associated output changes affect the way in which technical progress shows up in TFP indexes. Thus, the interpretation of TFP as a measure of technical progress is subject to significant caveats even if all the assumptions underlying its measurement are true.[10]

Partial Productivity Measures and Factor Prices

The fourth point is that partial productivity measures are also of theoretical interest because of their close relationship to factor prices. This is especially true of labour productivity, which has a robust theoretical connection to wages and, hence, to living standards. As noted earlier, the competitive firm will hire labour until the output elasticity of labour and the nominal output share of labour costs are equal.[11] Letting β_t denote the output elasticity of labour and w_t the real wage, this implies

$$w_t = \beta_t A_{L,t}$$

Thus, the average real wage is proportional to the partial productivity of labour, $A_{L,t}$. In the most common framework with Cobb-Douglas

9 Much of the cutting-edge research on TFP measurement focuses on disentangling these factors and isolating the technology growth component. Basu *et al.* (2006) construct a 'purified' measure of annual U.S. TFP growth that accounts for imperfect competition, variable factor utilization, input quality and non-constant returns to scale. Basu *et al.* (2013a) update the method and estimate measures of TFP growth for the consumption and investment goods sectors. Fernald (2014) provides estimates of consumption sector, investment sector, and total business sector TFP growth at a quarterly frequency, adjusted for input quality and variable factor utilization but not for non-constant returns to scale or imperfect competition (due to limitations in the availability of quarterly data). These studies attempt to strip out the factors that contaminate the usual TFP index and recover measures of the production function scale factor. The data requirements are extremely burdensome; detailed industry-level and worker-level data are needed. Moreover, additional behavioral assumptions are required in order to measure unobserved factors such as input utilization rates.

10 This may in part explain the perplexing fact that Statistics Canada's official measure of TFP (which the agency calls multifactor productivity, or MFP) has exhibited zero cumulative growth since the late 1970s in spite of the obvious fact that a substantial amount of technological change has occurred since then. The Statistics Canada MFP index for the business sector was 98.2 in 1978 and 98.3 in 2013 (from CANSIM Table 383-0021). Another part of the explanation may be measurement challenges.

11 This is equivalent to the condition that marginal revenue equals marginal cost.

technology, β_t is constant over time so that real wages are proportional to average labour productivity. This relationship (or something close to it) holds even in many models in which the TFP residual is hard to interpret. Theory therefore provides us with a reason to care about labour productivity (or partial productivity measures more generally) as well as TFP.

Interpreting Partial Productivity Measures

The final point is that certain partial productivity measures are not without their own problems in terms of theoretical interpretation. In the neoclassical growth model, for example, the capital-labour ratio grows at the same rate as labour productivity in the long run - which implies that capital productivity growth in the long run is zero. A naive analyst who observes rising labour productivity and constant capital productivity might conclude that there is some problem with the way the economy is using capital, but this would be incorrect; constant capital productivity would simply reflect the continuous accumulation of new capital at the optimal rate. Thus, care must be taken in interpreting capital productivity.

Simple models provide frameworks for organizing and interpreting data, but empirical evidence is often at odds with the models that have been referred to in this section. A first example: in Canada and across the OECD, the growth paths of average wages and labour productivity have diverged significantly in recent decades, with wages growing more slowly than labour productivity (Sharpe *et al.*, 2008; Uguccioni, 2016b; and Uguccioni and Sharpe, 2016). A second example: the basic neoclassical model implies that TFP growth drives capital deepening, but Oulton (2016b) finds no evidence of this in OECD data. In fact, he finds that higher TFP growth leads to *lower* subsequent capital accumulation.

Such theoretical puzzles may lead us to give more weight to practical considerations when deciding on the relative prominence of different productivity measures.

Practical Considerations

In practice, the choice of productivity measure should reflect the objectives of the analyst. For some purposes, a partial productivity measure may be more informative than TFP. This is especially true in the realm of environmental policy and sustainability. Energy productivity (i.e. output per unit of energy input used) may be more useful than TFP for measuring progress toward environmental policy goals, for example.[12] For policymakers interested in agricultural policy or land management issues, a measure of land productivity (i.e. output per unit of land input used) may be more useful than TFP. Given the tight connection between labour productivity and living standards, an environmentally-adjusted measure of labour productivity may be more useful than environmentally-adjusted TFP as a tool for assessing the effect of environmental damages on living standards. The general point is that partial measures allow us to zero in on the efficiency of the use of specific resources that are of special interest in a particular context.

In cases in which a partial productivity measure is preferable to TFP, an important side-benefit is that partial measures are (individually) easier to construct than TFP.[13] Careful TFP measurement requires a large amount of data - data on output and on the quantities, prices and

12 The reader is referred to the unabridged version of this article (Murray and Sharpe, 2016) for data on both partial (including energy productivity) and total factor productivity measures in natural resource industries in Canada.

quality compositions of all inputs. Diewert (2000) identifies at least nine types of input that must be measured: labour; intermediate inputs; reproducible capital; inventories; land; natural resources; working capital, money, and other financial instruments; knowledge capital; and infrastructure. The measurement of some of these elements is itself sensitive to modelling assumptions; analysts who possess the same raw data but who make different - and arguably equally defensible - methodological choices can end up with markedly different TFP estimates. In addition, the fact that the composite input measure is a unit-free growth index implies that TFP can be measured only in growth rates; we have no meaningful measure of the absolute level of TFP. By contrast, a partial productivity measure carries less burdensome data requirements, is less sensitive to controversial assumptions, and can be measured in both levels and growth rates.

The remainder of this section reviews some of the measurement challenges that arise in measuring TFP growth. Each of these challenges would also impinge on the measurement of a particular partial productivity measure; for example, difficulties in measuring capital services pose a problem for the measurement of capital productivity. But challenges associated with one input do not spill over to the measurement of partial productivity for other inputs. For TFP, by contrast, all the challenges matter.

Unmeasured and Unpriced Inputs

The fact that TFP measurement requires data on the volumes and cost shares of all inputs immediately raises two distinct but related challenges. The first is the problem of unmeasured inputs. The second is the problem of unpriced (or non-marketed) inputs.[14]

A firm's production process may depend on inputs that statistical offices do not measure. Intangible capital has been an important example of this, although official statistical offices are improving along this dimension.[15]

For another example, consider the role of bees (and the ecosystem that supports them) in the agriculture sector. Official statistical offices do not produce measures of the pollination services of bees or other services provided by the natural environment that are used as inputs in agricultural production. The exclusion of these services

13 Of course, to estimate the entire set of partial productivity measures would require most of the same data that are needed for TFP measurement. As noted above, however, researchers and policymakers often require only one partial productivity measure in order to do their work.

14 Conventional inputs, such as labour and machinery and equipment, are both measured and priced. Public infrastructure (roads, bridges, etc.) is an example of an input that is measured but usually not priced; we have measures of infrastructure, but for the most part firms do not pay a market price for the services of infrastructure. (There are sometimes fees, such as tolls or congestion taxes for the use of roads.) The services of the natural environment (e.g. the pollination services of wild bees or the water supplied by rain) constitute an example of unmeasured, unpriced inputs. We can think of no examples of inputs that are priced but unmeasured; the national accounts can in principle capture all inputs that are bought and sold on markets.

15 Intangible capital is also called knowledge-based capital or intellectual property products. According to the 2008 System of National Accounts (SNA) definition, it includes five types of asset: research and development; mineral exploration and evaluation; computer software and databases; entertainment, literary and artistic originals; and other intellectual property products (Ahmad and Schreyer, 2016). Corrado *et al.* (2005) identify a number of additional types of intangible capital, including branding and advertising, financial innovation, and innovations in organizational structure. Statistical offices differ in their treatment of the components of intangible capital. Software has long been counted in nonresidential investment, but the U.S. Bureau of Economic Analysis only began treating R&D as a form of capital investment in 2013, in response to the 2008 SNA revisions; until then, it had been treated as an intermediate input expenditure (Bureau of Economic Analysis, 2013). At Statistics Canada, research on the measurement of intangible capital and on its inclusion in the growth accounting framework is ongoing (Baldwin *et al.*, 2009; 2012).

from measured inputs means that TFP growth measures will be distorted; the part of output attributable to those unmeasured services will be attributed (incorrectly) either to other inputs or to 'technology.' The size of the distortion depends on the output elasticity of the excluded input (which determines the weight it should receive in TFP calculations) and on the extent to which the growth rate of the excluded input differs from that of the composite index of included ones.

How do unmeasured inputs affect partial productivity measures? Clearly a partial productivity measure cannot be computed for an input that is not measured. However, the absence of data on one input does not distort the measurement of the partial productivity of any other input.

The problem of unpriced inputs arises when an input has no market price. Consider the example of infrastructure such as roads and bridges. Such assets are measured as part of the stock of reproducible capital if privately owned, but much of the stock of infrastructure is publicly owned. The transportation services provided by public roads are a valuable input for firms, but firms do not pay a market price for those services. (They may sometimes pay fees, such as tolls or licensing fees.) Such prices are required in order to compute the cost-share weight on infrastructure in the composite input growth index for TFP measurement, so the fact that there is no market for infrastructure services poses a challenge. It is possible to develop econometric estimates of unobserved 'shadow prices,' but such estimates are sensitive to the methodological assumptions underlying them.

Sensitivity to Methodological Assumptions

The sensitivity of estimates to controversial methodological assumptions is a problem that extends to the measurement of other capital assets. We consider two examples. The first is the measurement of intangible capital, and the second is the measurement of physical capital services.

Consider the example of knowledge capital, a component of intangible capital. Two prices are required in order to include knowledge capital in a TFP measure: the price of R&D investment and the user cost of knowledge capital. The former is used to deflate nominal R&D expenditures into an index of real R&D investment, while the latter is used to construct the cost share weight on knowledge capital in a composite input index. TFP measurements will be sensitive to the methodological choices made by the analyst, and different choices may be defensible.

Corrado *et al*. (2005) deflated intangible capital investment by the non-farm business sector GDP deflator, while Bureau of Economic Analysis (2007) used the output deflators of R&D-intensive industries. Alternatively, prices could be estimated based on the costs of the inputs (mainly labour and materials) that were used to produce the intangible assets. In their experimental estimates of intangible capital in Canada, Baldwin *et al*. (2012) use asset-specific deflators for some components of intangible capital and follow the approach of Corrado *et al*. (2005) otherwise. User cost estimates depend on these investment prices as well as estimates of depreciation rates, relevant tax rates, and the opportunity cost of capital.

Controversial measurement assumptions also affect the measurement of capital services. Diewert and Yu (2012) estimated that TFP in the Canadian business sector grew by 1.03 per cent per year over the 1961-2011 period. Statistics Canada's official estimates showed that TFP growth over that period was 0.28 per cent per year. Gu (2012) attributed this difference to the fact that Diewert and Yu's estimate of the growth rate of capital services – at 3.0 per cent per year – was far lower than the official Statistics Canada estimate of 4.8 per cent per year. Faster measured growth of capital input, everything else being equal, implies slower measured growth of TFP. Gu traced the discrepancy in the capital services growth estimates to three main methodological differences:

- Statistics Canada estimates capital services at the industry level and then aggregates them to a business-sector estimate. Diewert and Yu compute capital services directly at the business sector level.
- In estimating the user cost of capital, Statistics Canada assumes that competitive forces equalize the nominal rate of return across assets and that the user cost includes asset-specific capital gains. Diewert and Yu assume that the real rate of return is equalized across assets and that the user cost does not include asset-specific capital gains.
- Statistics Canada uses more detailed data on capital assets than do Diewert and Yu.

A detailed discussion of these methodological differences is beyond the scope of this article.[16] The point is that there is no expert consensus that either set of assumptions is 'better' or 'worse' than the other, yet the choice matters enormously for the measurement results. Schreyer (2012) notes that the part of the TFP growth discrepancy attributable to the first bullet in the list (i.e. the choice of a top-down versus a bottom-up approach) is interpretable as an industry reallocation effect; whether one wishes to include that effect in a TFP measure depends on one's purposes. He also points out that "although user costs of capital are officially recognized in the System of National Accounts, there is no single recommendation on the details of implementation." Thus, TFP estimates can vary substantially based on the methodological preferences of the analyst constructing them.

A partial productivity measure, by contrast, depends only on a measure of output and a measure of one input. While capital productivity is affected by the challenges associated with measuring capital services, the partial productivity of other inputs is unaffected. In particular, labour productivity - the most common partial productivity measure - does not require the measurement of capital services. Labour input is easy to measure compared to capital services. This is especially true if we do not care about separating the effect of labour quality growth from other sources of labour productivity growth. In that case, we need only count aggregate hours worked as a measure of labour input.

Transparency

TFP carries burdensome data requirements, relies on complex methodological judgments about which no expert consensus exists, and has a subtle interpretation that differs from common notions of 'technical progress.' An implication of these observations is that TFP measures lack transparency and are difficult for non-experts to understand. Partial productivity measures are easier for the public to understand and relate to. Anyone can grasp the sense in which a firm has grown more productive if it produces more output per hour worked, for example. It is more difficult to explain why they should care whether output growth exceeds a cost-share weighted average of the growth rates of input volume indexes.

Challenges Affecting Both TFP and Partial Productivity Measures

Finally, it is worth pointing out two measurement challenges that affect both TFP and partial productivity measures. The first is the challenge of measuring output quality changes. The second is the issue of the comprehensiveness of the

16 Gu (2012) contains such a discussion.

output measure, especially with respect to externalities like pollution.

Output quality is said to have improved if the same physical volume of output delivers more satisfaction to consumers than it had in the past, everything else being equal.[17] Many technological changes take the form of output quality improvements. Arguably, these improvements (or at least the costless portion of them) should be included in productivity measures, but they will not be if the output measure is not adjusted to account for quality change. If the quality of a firm's output doubles but it still produces the same physical volume of output using the same physical quantities of inputs as before, productivity measures register no change even though consumers are better off. If the same welfare improvement had been achieved by doubling the physical volume of output produced with the given inputs, measured productivity would have doubled.

In order for productivity measures to capture quality change, real output must be measured in 'efficiency units' that include both physical volume and quality change. Discussions of the econometric methods that can be used to develop such estimates and the quantitative importance of unmeasured quality change for productivity measures are beyond the scope of this article.[18] In practice, statistical offices do not measure output in quality-adjusted terms except for certain goods and services (e.g. computers) for which quality change is believed to be of particular importance.[19]

The comprehensiveness of an output measure refers to its scope in terms of what is counted as output and what is not. A comprehensiveness issue of particular importance is the measurement of negative environmental externalities from production - greenhouse gases and other pollutants.[20] The level of a productivity measure may be overstated if the costs of pollution are not valued (negatively) as a part of output. The growth rate of a productivity measure may be understated (overstated) if the pollution component of output is declining (rising) over time.

The preceding discussion has stressed challenges associated with measuring and interpreting TFP. It has pointed out that partial productivity measures are often simpler to compute and easier for non-experts to interpret, and that they can provide targeted insights that a measure like TFP, based on an index of multiple inputs, misses. On the other hand, any given partial productivity measure necessarily provides an incomplete picture of overall productivity performance. Attempting to examine every partial productivity measure could lead to 'information overload,' and a single summary indicator such as TFP can be useful. Our point is not that one type of productivity measure is always and everywhere superior to the other. Both types of measure are useful in certain analytical contexts.

17 We focus on the production of consumer goods in this discussion. Aggregate output includes both consumption and capital goods. The latter are both outputs and inputs of production, so the effects of quality change in capital goods on productivity measures are subtle. An improvement in capital goods quality raises effective inputs but also raises output, and the effects on productivity are offsetting. Along the optimal growth path, the effects cancel exactly. See Hulten (2001) and the references therein.

18 Triplett (2006) provides a comprehensive overview of quality-adjustment methods.

19 Byrne *et al.* (2016) ask whether unmeasured quality change can explain the recent productivity slowdown in the U.S. and find that it cannot. They do note that unmeasured quality change may be substantial even if it does not explain a trend growth decline. Their paper includes an overview of past research on the issue. A related problem is how to account for the introduction of new goods that deliver the same services as an old good at a different rate of service flow per unit. See Nordhaus (1996).

20 The problem of comprehensiveness extends beyond environmental concerns. It is related to the long-standing critique of GDP per capita as a measure of welfare on the grounds that it excludes much (and perhaps most) of what matters for people's well-being.

Conclusion

The aim of this article is to make the case that an assessment of industry productivity trends is best carried out on the basis of a suite of productivity measures including both total factor productivity (TFP) and partial productivity measures. TFP is important because of its central role as the driver of long-run growth in the neoclassical growth model. In addition, it is useful within the neoclassical growth accounting framework because it is a source of the growth of partial productivity measures. However, TFP measurement brings a number of theoretical and practical challenges. These include:

- TFP is not a measure of technical progress, though it is often interpreted as such. At best, it measures the costless part of technical change. When various stringent assumptions do not hold, standard TFP measures capture a number of non-technological effects and these complicate its interpretation.
- The data requirements for TFP measurement are burdensome compared to those of partial productivity measurement. Unmeasured and un-marketed inputs present particular challenges.
- TFP measurement is sensitive to certain methodological choices about which there is no widespread consensus. Reasonable analysts can disagree about what methods are most appropriate, and the effect on TFP measures can be quantitatively large.
- The complexity of the methods, the subtlety of interpretation, and the fact that it can be measured in growth rates but not in levels make TFP difficult to explain to the general public compared to partial productivity measures.

Partial productivity measures are less affected by these challenges. A partial productivity measure requires less data and is less sensitive to theoretical and methodological assumptions. It can be estimated in either levels or growth rates, and it has an intuitive interpretation that non-experts can grasp with relative ease. Theory implies a direct link between partial productivity measures and factor payments; in particular, labour productivity is relevant for average wages and, hence, for living standards.

Neither TFP nor a partial productivity measure, by itself, provides a complete picture of productivity trends. TFP growth and partial productivity growth are related within the growth accounting framework, and a complete understanding of productivity growth is best achieved by examining TFP and partial productivity measures together. Moreover, particular partial productivity measures are preferable to TFP for some analytical purposes. For example, an environmental economist or policymaker might be more interested in trends in the energy intensity of production - which measures of energy productivity provide - than in trends in TFP.

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