# Editor's Overview

The 35th issue of the *International Productivity Monitor* contains eight articles featuring two individual articles and two symposia. The topics of the two articles are employment and productivity in U.S. manufacturing and the role of demand and digitization in solving the productivity puzzle. The topic of the first symposium of four articles is explaining slower productivity growth since 2000 in Canada. The topic of the second symposium of two articles is the global productivity slowdown.

The manufacturing sector experienced very rapid productivity growth in the United States up to the Great Recession of 2008-2009. Since 2010 however, the productivity performance of the sector has been dismal, with the absolute level of labour productivity falling. The counterpart of falling labour productivity has been strong employment growth, with U.S. manufacturing since 2010 enjoying the second longest period of rising employment growth in the post-war period.

In the first article of the issue, **Richard Schmalensee** from Massachusetts Institute of Technology provides a detailed industry analysis of recent developments in U.S. manufacturing related to productivity, output, and employment. After advancing at a 4.2 per cent average annual rate in 1980-2000 and 5.3 per cent in 2000-2010, output per hour in U.S. manufacturing fell at a 0.1 per cent annual rate in 2010-2017. The computer and semi-conductors industry (NAICS 334) is found to account for 38 per cent of the slowdown in manufacturing productivity growth, with the fall in the rate of decline of deflators for computers and semiconductor responsible for around 85 per cent of this contribution.

The puzzle of slower productivity growth in advanced economies in a period of rapid technological change has intrigued many researchers. In the second article **Jaana Remes**, **Jan Mischke** and **Mekala Krishnan** from the McKinsey Global Institute offer a comprehensive and cogent explanation of the slowdown in labour productivity growth in seven countries between 2000-2004 and 2010-2014. They identify three waves or drivers of productivity growth: the waning of effects of the first ICT revolution; financial crisis aftereffects, including weak demand and uncertainty; and digital disruption. They estimate that the first two waves reduced labour productivity growth by 1.9 percentage points, on average in the countries studied, between the two periods, from 2.4 per cent per year to 0.5 per cent. The impact of the digital revolution is uncertain, but the authors argue that it has the potential to boost labour productivity growth by at least 2 per cent per year over the next decade. Capturing this potential requires promoting both demand growth and digital diffusion in addition to the traditional supply-side approaches.

The first symposium in the issue containing four articles is on explaining slower productivity growth in Canada and is based on papers presented at two sessions of the annual meeting of the Canadian Economics Association held at McGill University in June 2018. The sessions were organized by the Centre for the Study of Living Standards and the Productivity Partnership.

Any analysis of the productivity slowdown must be based on a solid grasp of the stylized facts associated with slower productivity growth. The first paper in the symposium by **Andrew Sharpe** and **John Tsang** from the Centre for the Study of Living Standards provide these stylized factors. The article shows that it was multifactor productivity that accounted for the lions share of the post-2000 labour productivity showdown in Canada, that the slowdown was primarily a within-industry phenomenon and not due to resource re-allocation, and that the slowdown was largely in the goods sector, with manufacturing making by far the largest industry contribution to the slowdown, especially to the labour productivity slowdown. Since 2000, labour productivity growth has been around 0.9 per cent per year in both the 2000-2008 and 2008-2016 subperiods, but the sources of this growth have been different, with multifactor productivity much more important in the more recent period and capital intensity growth less important. This post-2008 pick-up in multifactor productivity growth may bode well for future labour productivity growth.

A major focus of the productivity debate in Canada has been comparisons with the United States. From the mid-1980s to 2010 productivity growth in Canada trailed that in the United States, but since 2010 this situation has been reversed. In the second article in the symposium **Wulong Gu** and **Michael Willox** from Statistics Canada provide a detailed industry analysis of labour productivity growth and the sources of labour productivity growth in Canada and the United States in the 1987-2010 and 2010-2014 periods and shed light on this reversal. Factors that contributed to this reversal of labour productivity growth were stronger demand and output growth in Canada after 2010 and the greater waning of the productivity gains from ICT production and use south of the 49th parallel. For example, one third of the much faster business sector MFP growth in the United States in 1987-2010 relative to Canada was due to the computers and electronics products industry. By 2010-2014, the contribution to MFP growth from this industry was the same in both countries. The authors conclude that the search for the determinants of productivity growth should focus on the factors contributing to demand growth such as access to international markets and financial stability.

It is widely recognized that the ICT revolution boosted productivity growth in the second half of the 1990s in Canada and the United States. But is the post-2000 slowdown in productivity growth in Canada explained by a weaker contribution to productivity from ICT? This is the issue addressed in the third article of the symposium by **Jeff Mollins** and **Pierre St-Amant** from the Bank of Canada. The authors investigate a number of models with different channels by which ICT affects productivity, including production effects, the use effect, and the impact of the relative price of ICT goods. They find that 0.1-0.2 percentage points (20-40 per cent) of the labour productivity slowdown in Canada since the early 2000s can be explained by a weaker ICT contribution, but point out that the timing of the two developments do not coincide. While productivity growth slowed in the first half of the 2000s, the ICT contribution only fell around the time of the Great Recession. The authors note that future work on this topic needs to address both potential price mismeasurement and the growing role of ICT services, especially cloud computing, which because of data limitations, they were unable to do.

Likely the most widely given explanation for slower productivity growth is that the pace of fundamental technological change has fallen off. But how does one in fact quantify technological change? Multifactor productivity growth is affected by many factors so cannot be used as a proxy in this regard. Direct measures of the pace of technological change may be more promising. In the fourth article in the symposium **Michelle Alexopoulos** and **Jon Cohen** from the University of Toronto provide such direct measures of innovation for Canada, namely books held in Canadian libraries. They find that a fall-off in the commercialization of new technologies in this country after 2000, as evidenced by book-based indicators of technological change, did indeed contribute to slower productivity growth. The large fall-off in titles in mechanical/manufacturing and electrical technologies is consistent with the greater slowdown in productivity growth in the goods sector. The authors conclude on an optimistic note, arguing that data suggest that Canada may be on the threshold of major technological breakthrough in the areas of artificial intelligence and robotics and that this may lead to a pick-up in productivity growth.

The second symposium in the issue contains two articles on the productivity slowdown in a global context. The articles are based on presentations made at the Third Annual OECD Global Forum on Productivity held at the Bank of Canada in Ottawa, Canada in June 2018.

A key issue for economists is whether the slower output and productivity growth observed in advanced countries since 2000 represents the new normal or whether this is a transitory state that will be replaced by stronger growth. In the first article in this symposium **John Fernald** from INSEAD argues the former. He points out that the demographic developments that have led to slower population growth are unlikely to be reversed. In addition, labour quality improvements are likely to be weaker and a drag on future labour productivity growth. He notes that neither mismeasurement issues nor regulation appear to explain slower productivity growth. In terms of total factor productivity, he sees 0.5 per cent per year as the new trend, not enough to revive the current modest labour productivity growth. This situation reflects a return to normal after the exceptional 1995-2005 period when IT drove productivity gains.

An industry perspective on the productivity slowdown can provide insight into its nature and causes. In the second article in the symposium **Kevin Fox** from the University of New South Wales-Sydney presents industry data to shed light on the productivity slowdown in Australia. He finds that for the 15 industries in his sample, virtually all (14 of 15) experienced slower multifactor productivity growth in the 2003/04-2016/17 period than in the 1989/90-2003/04 period, even though the productivity experiences of the industries were very diverse. He suggests that this pattern may mean a common factor, such as a slower pace of technological change or a rise in inefficiency, is behind the slowdown. He concludes by identifying a number of directions or areas for future research to shed light on the productivity slowdown, namely the treatment of new and disappearing goods, the valuation of new free goods and services, better time-use data, and exploitation of firm-level data.

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# Puzzles and Surprises in Employment and Productivity in U.S. Manufacturing After the Great Recession

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Abstract

Though U.S. manufacturing output recovered more slowly from the Great Recession than historical experience would have predicted, manufacturing employment, which peaked in 1979, *grew* between 2010 and 2017. This was the second-longest period of manufacturing employment growth in the entire post-war period. Linking these developments was an historically unprecedented, protracted absolute decline in labour productivity. This article provides an overview of these puzzling aggregate developments and of the diverse industry-level changes they summarize. The roles of foreign competition, mis-measurement of real output, and the computer industry are explored, and the value of looking within multi-industry aggregates like manufacturing is illustrated.

Using data from before the Great Recession, Houseman *et al.* (2011) provided a familiar description of U.S. manufacturing: steep declines in employment after 1979, robust growth in real value-added, and strong growth in labour productivity. They argued that growth in output and labour productivity after 1980 was attributable to a disproportionate extent to one three-digit industry, NAICS 334 (computer and electronic products).[2]

Between 2000 and 2010, manufacturing employment fell by almost a third, more rapidly than in any 10-year post-war period.[3] Just over half this fall occurred between 2000 and 2007, before the Great Recession. A number of influential studies, including Autor *et al.* (2013) and Pierce and Schott (2012),

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1 Richard Schmalensee is Emeritus Professor of Economics at the Massachusetts Institute of Technology. I am indebted to David Autor, Ernst Berndt, Austan Goolsbee, Paul Joskow, Susan Houseman, Dan Sichel, Andrew Sharpe, Hal Varian, and several anonymous referees for helpful comments on earlier drafts and to Kevin Barefoot, Randy Becker, Wayne Gray, Justin Harper, Gabriel Medeiros, Nilay Patel, and Jay Stewart for help with data. Of course, I alone am responsible for any shortcomings. Email: rschmal@mit.edu.

2 This argument is elaborated in Houseman *et al.* (2015) and Houseman (2018).

3 Until 1993-2003, no ten-year post-war period had experienced a fall of more than 10 per cent.

have concluded that increased Chinese competition after 2000 played an important role in the 2000-2007 fall in employment.

After U.S. manufacturing's emergence from the traumatic 2000-2010 decade,[4] all three elements of the Houseman *et al.* (2011) description were inverted: growth in real value-added was weak, employment grew, and labour productivity (measured as real value-added per employee) declined absolutely.[5] These inversions represent puzzling departures from pre-2000 patterns.

In 2010, observers might have predicted that manufacturing output would grow more slowly than that of the rest of the private economy for several years, despite manufacturing's greater decline in the Great Recession, because of increased foreign competition. On the other hand, if told that manufacturing output would grow more slowly between 2010 and 2017 than between 1979 and 2000, when 98 thousand manufacturing jobs were lost every year on average, it is hard to believe that anyone would have predicted the ensuing seven years of job *gains*, averaging 131 thousand jobs per year. And nobody who read popular accounts of the impact of computers, automation, and robotics on manufacturing would have predicted the dramatic collapse in labour productivity growth that occurred after 2010. NAICS 334 continued to play a disproportionate role after 2010, but it had a disproportionate impact on *declines* in the growth rates of output and productivity.

While a number of earlier studies have presented one or more elements of these shifts, as I note in what follows, this article provides a systematic overview of these dramatic, linked changes and sheds new light on the industry-level developments that underlie them. The roles of foreign competition, mis-measurement of real output, and NAICS 334 are explored.

This article highlights the value of recognizing that data on manufacturing as a whole are aggregates of the experiences of the constituent industries, and these experiences differed widely in the periods covered here. While NAICS 334 had a disproportionate impact on overall manufacturing productivity after 2010, for instance, its employment declined, and it was only one of many industries experiencing a slowdown in productivity growth. The analysis here seems to rule out some simple explanations of the changes in U.S. manufacturing after 2010, but a full solution of the associated aggregate and industry-specific puzzles discussed awaits further research.

This article contains three main sections. Section 1 focuses on manufacturing production, measured as real value-added. Before 1990, manufacturing pro-

4 Because of an interest in employment, I treat 2011, when manufacturing employment began to increase, as the start of the post-Great-Recession period rather than 2010, when real GDP began to recover.

5 This productivity measure excludes the labour input of the self-employed and is thus biased upward. The share of self-employed in total employed workers in manufacturing was 2.6 per cent in 2010 and declined to 2.3 per cent in 2017. Thus the bias in the measured level of productivity was very small and declining over this period, so that the measured rate of growth of productivity has a tiny downward bias.

duction grew only slightly more slowly than production in the rest of the private economy.[6] After 2010, that gap increased substantially. The analysis here suggests that increased foreign competition played a notable but not dominant role in slowing growth in manufacturing relative to the rest of the private economy, which is less vulnerable to foreign competition. Classifying three-digit industries by the ratio of real value-added in 2016 to 2000 reveals that those that did least well at recovering from after 2010 on that measure had on average the sharpest output declines in 2000-2010 and the greatest impact from foreign competition.[7]

Section 2 deals with employment and labour productivity in manufacturing. The pre-2010 history of robust productivity growth in manufacturing coupled with declining employment would have led most observers to predict that the unusually slow growth in manufacturing output after 2010 would have led to unusually rapid declines in employment. Instead, manufacturing employment rose from 2010 to 2016 in aggregate and in 12 of the 18 constituent three-digit industries. At the same time, productivity growth fell in 15 of those industries, and labour productivity fell absolutely in five industries and in manufacturing as a whole. The decline in manufacturing's productivity growth accounted for over half of the overall decline in productivity growth in the private economy between 1990-2000 and 2010-2016, even though manufacturing generally accounted for less than 20 per cent of private economy GDP in those periods.

Many have argued that the real output of innovative industries has been under-stated in official statistics (Feldstein, 2017). However, the analysis here does not support the notion that increasing under-statement of output was the main cause of the collapse of manufacturing productivity growth. In general, industries that did better over the 2000-2016 period in terms of value-added also performed better in terms of labour productivity.

Because NAICS 334 experienced the most dramatic productivity growth decline and because it has been at the center of many discussions of adjustment for quality changes, Section 3 examines productivity growth in that industry in more detail. Between 1990 and 2000, the decline in the NAICS 334 deflator accounted for 40 per cent of aggregate manufacturing productivity growth. Between 1990-2000 and 2010-2016 the fall in the rate of decline of the deflator accounted for 38 per cent of the drop in aggregate manufacturing productivity growth. Within NAICS 334, about 85 per cent of the fall in the rate of decline of the deflator between 1995-1997 and 2009-2011 was accounted for by falls

6 Throughout this article, data on value-added in the private economy are from the BEA series "Private Industries," and the corresponding employment data are from the BLS series "Total Private Employment."

7 Table 1 lists the 18 three-digit manufacturing industries and gives their NAICS codes.

in the rates of deflation of two of the 30 constituent six-digit industries: computers and, especially, semiconductors. While the changes in the official statistics for semiconductors may be the result of increasing mis-measurement, impacts on real GDP and, thus, aggregate productivity are likely to be small.

This analysis of NAICS 334 illustrates the fact that just as manufacturing is an aggregate of diverse industries, three-digit industries are also collections of markets that may differ substantially. It is always tempting simply to treat changes in economic aggregates as if they mirror similar changes in all their constituent parts, but it is often worthwhile to look behind the aggregation curtain.

## Manufacturing Production

Between 1947 and 1990, the average annual growth rate of real value-added in manufacturing was only 0.30 percentage points below that in the rest of the private economy.[8] Table 1 provides information on real value-added growth after 1990.

The first three columns in Table 1 show average annual growth rates of real value-added for 1990-2000, 2000-2010, and 2010-2016 for each of the 18 three-digit NAICS manufacturing industries, as well as for the private economy excluding manufacturing and for aggregates of interest within manufacturing. During 1990-2000, growth in manufacturing was more rapid than in the rest of the private sector (4.29 per cent versus 3.62 per cent per year), due to an important extent to the extremely rapid growth in NAICS 334 (22.12 per cent).

Because manufacturing output has historically been more cyclically variable than that of the rest of the private sector, and because manufacturing is more vulnerable to foreign competition, which apparently intensified after 2000, it is not surprising that growth slowed more in manufacturing than in the rest of the private sector during 2000-2010 relative to 1990-2000 (3.03 versus 2.00 percentage points). Because of manufacturing's historic cyclical variability, one might have expected growth to rebound more strongly in manufacturing in the post-2010 recovery than in the rest of the private sector, but, as Table 1 shows, the growth rate of manufacturing output in fact fell further.

Experiences within manufacturing were diverse in all three periods. Four three-digit NAICS industries had production declines during the generally prosperous 1990-2000 decade, while six had production increases during the difficult 2000-2010 decade. In the 2010-2016 recovery, six of the 18 industries had average growth rates of more than 2 per cent, while eight had declines in production. NAICS 334 is a clear outlier in the first two periods, but, because its

8 All rates of change reported in this article were calculated from changes in natural logarithms and, unless otherwise noted, all data were downloaded from the Bureau of Labour Statistics (BLS) and Bureau of Economic Analysis (BEA) websites. The Appendix describes the construction of the 1990-2016 three-digit NAICS manufacturing industry dataset employed in this article, as well as the calculation of real value-added for the private economy outside manufacturing and for a number of other aggregates that appear in various tables.

**Table 1: Real Value-added and Change in Nominal Net Import Penetration at the Three-digit NAICS Level in U.S. Manufacturing (average annual per cent change)**

| | | Real Value-added | | | ΔNIP Impacts | |
|---|---|---|---|---|---|---|
| | Sector/Sub-Sector/Industry | 1990-2000 | 2000-2010 | 2010-2016 | 2000-2010 | 2010-2016 |
| opvt | Other (Non-Manufacturing) Private Economy | 3.62 | 1.62 | 2.39 | -0.01 | 0.15 |
| mfg | All Manufacturing | 4.29 | 1.26 | 0.90 | -0.17 | -0.46 |
| mlc | All Manufacturing less 334 | 1.70 | -0.02 | 0.52 | 0.02 | -0.43 |
| dur | Durable goods | 6.05 | 1.91 | 2.14 | -0.42 | -0.50 |
| dlc | Durable goods less 334 | 1.64 | -0.52 | 1.96 | 0.00 | -0.54 |
| 321 | Wood products | -2.53 | -1.61 | 2.19 | 0.21 | -0.52 |
| 327 | Nonmetallic mineral products | 1.98 | -3.17 | 1.99 | -0.01 | -0.29 |
| 331 | Primary metals | 2.06 | -2.00 | 7.58 | 0.21 | 0.07 |
| 332 | Fabricated metal products | 2.65 | -2.26 | 0.97 | -0.28 | -0.37 |
| 333 | Machinery | 0.24 | -0.19 | -0.28 | 0.56 | -2.19 |
| **334** | **Computer and electronic products** | **22.12** | **10.25** | **2.77** | **-2.64** | **-1.21** |
| 335 | Electrical equip., appliances, & components | 0.77 | -0.44 | -0.03 | -1.78 | -1.73 |
| 336 | Transportation Equipment | 1.76 | 0.84 | 3.94 | 0.32 | -0.26 |
| 337 | Furniture and related products | 2.97 | -5.58 | 2.41 | -1.82 | -0.52 |
| 339 | Miscellaneous manufacturing | 3.43 | 2.74 | -1.26 | 0.16 | -0.11 |
| ndr | Nondurable goods | 1.75 | 0.45 | -0.66 | -0.02 | -0.25 |
| 311FT | Food and beverage and tobacco products | 0.83 | 1.06 | -1.68 | -0.08 | -0.25 |
| 313TT | Textile mills and textile product mills | 1.37 | -6.46 | 0.01 | -2.13 | -0.81 |
| 315AL | Apparel and leather and allied products | -1.87 | -5.97 | -2.48 | -10.35 | 11.11 |
| 322 | Paper products | -0.09 | -3.06 | -0.82 | 0.29 | -0.12 |
| 323 | Printing and related supports activities | -0.39 | -0.25 | -0.38 | -0.03 | 0.04 |
| 324 | Petroleum and coal products | 5.38 | 2.61 | 2.41 | 0.73 | 0.93 |
| 325 | Chemical products | 2.37 | 2.27 | -1.47 | -0.22 | -0.57 |
| 326 | Plastics and rubber products | 4.70 | -1.84 | -0.26 | -0.60 | -0.36 |

Source: BLS and BEA data, author's calculations.

growth slowed dramatically after 2010, it was closer to the pack during this most recent period.

Because increased foreign competition has been discussed as a contributor to the slowdown in manufacturing growth, the last two columns in Table 1 show a measure of the impact of foreign competition on growth in 2000-2010 and 2010-2016 based on net import penetration (NIP): net imports (i.e., imports minus exports) as a percentage of domestic sales. It was computed from BEA input-output tables, for which data are only available beginning in 1997, and all quantities are in current dollars. This measure of the impact of foreign competition takes into account both competition from imports into the United States and competition for U.S. exports in foreign markets.

The NIP growth impact measure in Table 1 was calculated as follows. For some industry, let $Q$ be nominal gross domestic output, $M$ be nominal net imports, $S$ be nominal domestic sales in an early year, with $NIP = \frac{M}{S}$, and let $Q'$, $M'$, $S'$, and $NIP'$ be the same quantities in a later year. Since $Q = S - M = S(1 - NIP)$, the percentage growth in total output between the two years can decomposed as follows:

**Table 2: Growth Rates of Real Value-added and Change in Net Import Penetration for Three-digit U.S. Manufacturing Industries Impacts by Recovery Ratio Cluster (average annual rate of change)**

| | Real Value-added | | | ΔNIP Impacts | |
|---|---|---|---|---|---|
| Recovery Ratio Cluster* | 2010-2016 | 2000-2010 | 1990-2000 | 2010-2016 | 2000-2010 |
| (1) R = 3.29 | 2.77 | 10.25 | 22.12 | -1.21 | -2.64 |
| (2) 1.15 ≤ R ≥ 1.50 | 2.24 | 1.29 | 3.00 | 0.01 | 0.24 |
| (3) 0.95 ≤ R ≥ 1.01 | -0.04 | -0.28 | -0.22 | -0.93 | -0.22 |
| (4) 0.47 ≤ R ≥ 0.84 | 0.26 | -4.05 | 1.67 | 1.24 | -2.13 |

Source: Data from Table 1. The recovery ratio, R, is the ratio of an industry's real value-added in 2016 to its real value-added in 2000.
*The industries in each cluster are as follows, ordered by declining recovery ratio: (1) 334, (2) 324, 336, 331, 339, 325, (3) 311FT, 321, 333, 335, 323, (4) 332, 327, 326, 322, 337, 313TT, 315AL.

$$\ln(\frac{Q'}{Q}) = \ln(\frac{(1-NIP')}{(1-NIP)}) + \ln(\frac{S'}{S}) \quad (1)$$

The first term on the right of (1), converted to an average annual growth rate, is shown in the last two columns of Table 1 for the periods indicated. This is only a very rough estimate, however, because in the BEA data, growth rates of total nominal output and of real value-added are not highly correlated across industries. Moreover, it should be clear that this measure is endogenous, reflecting developments in both domestic and foreign markets; use of the term "impact" in what follows is not intended to imply causation.

For manufacturing as a whole, with and without NAICS 334, for durable goods, for non-durable goods, and for half the 18 three-digit industries, the estimated per-annum negative effect of increased foreign competition was greater in 2010-2016 than in 2000-2010. In contrast, for the private economy excluding manufacturing, changes in foreign competition had only a tiny negative impact on growth in 2000-2010 and had a positive impact after 2010. Holding the growth of domestic sales constant, equation (1) implies that growth in manufacturing in 2010-2016 would have been 0.46 percentage points per year higher but for the increase in NIP, while growth in the rest of the private economy would have been 0.15 percentage points lower but for the corresponding fall in NIP. The sum of these effects, 0.61 percentage points, is 41 per cent of the difference between the 2010-2016 growth rates in manufacturing and in the rest of the private economy. This rough estimate suggests that changes in the pattern of foreign competition may have played a significant – but far from dominant – role in the weakness of post-2010 growth in manufacturing output relative to that in the rest of the private economy.

It is instructive to cluster industries based on the extent to which their production had recovered from the 2000-2010 decade by 2016. As Table 2 indicates, there are four distinct clusters in the data:

1. NAICS 334, for which real-value-added more than tripled over the 2000-2016 period, despite a 42 per cent fall in employment;
2. five industries that experienced increases of real value-added between

15 per cent and 50 per cent;
3. six industries that had roughly returned to their 2000 output levels; and
4. seven industries for which 2016 real value-added was at least 15 per cent below the 2000 level.

Industries in clusters (1) and (2) on average experienced positive growth in all of the periods shown; industries in cluster three averaged close to zero growth in all periods; while industries in cluster (4) were hit much the hardest during 2000-2010. Apart from NAICS 334, industries in cluster (4) also seem to have suffered most from increased foreign competition during 2000-2010. The small number of three-digit industries, of course, precludes claiming statistical significance, let alone causal relationships, for these patterns.

## Employment and Productivity

From 1979 to 2000, real manufacturing value-added grew at an average annual rate of 3.26 per cent, and employment declined from its 1979 peak at an average annual rate of 1.17 per cent. Because real manufacturing value-added grew considerably more slowly from 2010 to 2017, the historical record of robust productivity growth would have led one to predict more rapid declines in employment in that period, perhaps after a brief cyclical rebound. Instead, the 2010-2017 period was much the longest and most substantial period of manufacturing job growth since the 1979 employment peak.[9] In fact, in the entire post-war period, only the 1961-1969 period of manufacturing job growth was longer. Between 2010 and 2017 manufacturing employment grew by 7.6 per cent, and about 915,800 jobs were added.[10]

As Chart 1 suggests, this expansion represented a departure from the post-1979 relationship between employment growth in manufacturing and in the rest of the private economy. From 1979 to 2000, the rate of growth of employment in the private economy apart from manufacturing averaged 3.16 percentage points above the rate of growth in manufacturing. Between 2010 and 2017, that difference fell to 1.04 percentage points.[11]

As Chart 2 shows, both manufacturing and the rest of the private economy saw drops in labour productivity growth around the mid-2000s, attributed by

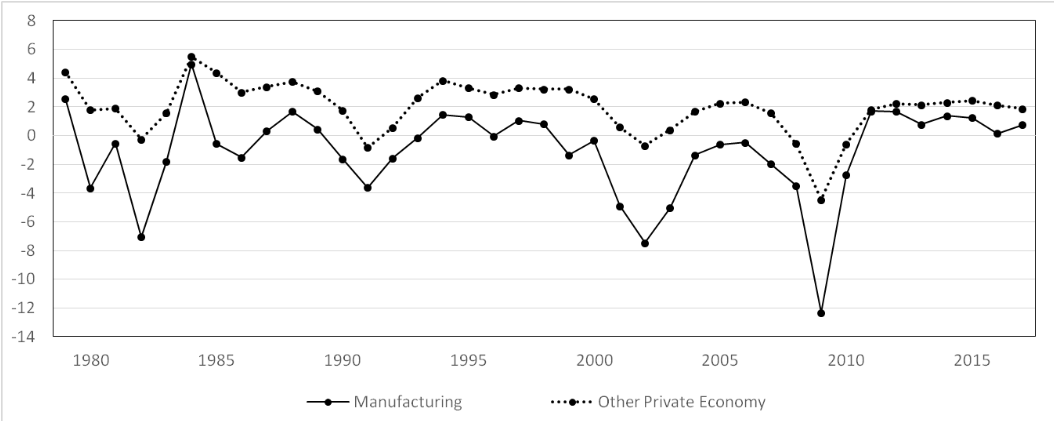
9 Fort *et al.* (2018), Levinson (2017) and Lawrence (2017) are among the few who have taken note of the historically exceptional manufacturing job growth after 2010. Lawrence (2017) is the only study I have seen that notes the apparent link to the collapse in manufacturing productivity growth at the same time, though he considers only aggregate manufacturing data.

10 In the next-longest post-1979 expansion, 1986-89, employment grew by only 2.5 per cent.

11 The p-value for a two-tailed t-test of the null hypothesis that the mean difference was the same in both periods was $9.9 \times 10^{-6}$. Between 1947 and 2000, this difference averaged 2.21 percentage points, and the p-level of the corresponding t-test was .0075.

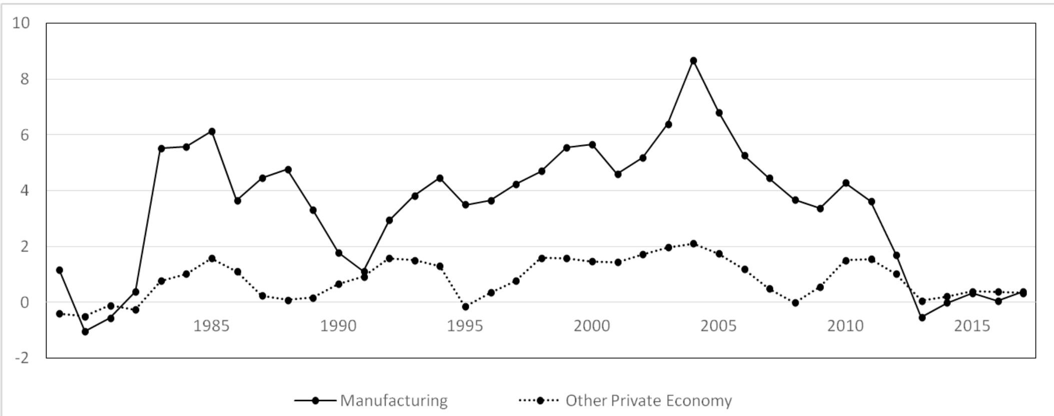
12 Dey *et al.* (2012) and others find that manufacturing employment growth prior to 2000 was substantially understated, and thus labour productivity was substantially over-stated, by increased outsourcing.

**Chart 1: Employment Growth Rates in U.S. Manufacturing and Other Private Economy Industries, 1980-2016 (per cent change)**




Source: BLS.

**Chart 2: 3-Year Moving Average Labour Productivity Growth in U.S. Manufacturing and Other Private Economy, 1980-2016 (per cent change)**




Source: BEA and BLS data, author's calculations.

many authors (e.g., Fernald (2015) and Gordon (2018)) to the end of a short IT-fueled productivity boom.[12] As Chart 2 also shows, the drop in productivity growth was much sharper in manufacturing than in the rest of the private economy. The absolute fall in manufacturing labour productivity from 2010 to 2017 is without precedent in the postwar period.

For several reasons, the sharp fall in manufacturing productivity growth after 2010 is the most puzzling post-Great-Recession change in U.S. manufacturing. First, plant closures between 2000 and 2010 were significant (Fort *et al.* 2018), and one might have expected the surviving plants to have been the most productive and the most able to increase productivity. Second, overall manufacturing capacity utilization remained low through 2017 (Pierce and Wisniewski, 2018), so capacity constraints are unlikely to have reduced productivity. (Excess capacity may have discouraged productivity-enhancing investment, though.) Third, this productivity growth collapse occurred during a period

**Table 3: Average Contributions of Manufacturing to U.S. Private Economy Labour Productivity Growth**

| Period | Avg. Productivity Growth (%) Private Economy | Manufacturing | Other Private | Avg. Annual Contribution of Manufacturing Absolute percentage points | Per cent of Private Economy | Avg. Mfg Share (%) of Private Economy Nominal Value-added |
|---|---|---|---|---|---|---|
| 1947-1980 | 1.72 | 2.64 | 1.26 | 0.75 | 43.8 | 29.0 |
| 1980-1990 | 1.37 | 3.85 | 0.66 | 0.86 | 62.4 | 22.1 |
| 1990-2000 | 1.75 | 4.54 | 1.15 | 0.85 | 48.6 | 19.1 |
| 1980-2000 | 1.56 | 4.20 | 0.91 | 0.85 | 54.7 | 20.6 |
| 2000-2010 | 1.86 | 5.30 | 1.37 | 0.71 | 37.9 | 15.2 |
| 2010-2017 | 0.18 | -0.05 | 0.26 | 0.03 | 16.8 | 14.0 |

Source: BEA and BLS data, author's calculations.

of concern about robots substituting for humans (Acemoglu and Restrepo, 2017), which would have increased the measured productivity of those workers who remained employed. Finally, if anything, growth in the number of manufacturing employees understates the growth of quality-adjusted labour input. Average weekly hours of manufacturing employees grew slightly during 2010-2017; the ratio of self-employed workers to employees in manufacturing was tiny (footnote 5); and, at least through 2016, the average education level of manufacturing workers increased (Levinson, 2017).

From 1980 to 2000, as manufacturing employment was declining, labour productivity in U.S. manufacturing grew at an average annual rate of 4.20 per cent (Table 3) and declined in only one of those 20 years. Then from 2010 through 2017, manufacturing productivity fell at an average annual rate of 0.05 per cent and fell in three of those seven years. From 1980 to 2000, annual productivity growth in manufacturing averaged 3.29 percentage points above that in the rest of the private economy, and it exceeded growth in the rest of the private economy in all but one of those 20 years.[13]Then from 2010 to 2017, productivity growth in manufacturing averaged 0.31 percentage points below that in the rest of the private sector,[14] and it was below that in the rest of the private sector in four of those seven years.[15]

13 The difference is less dramatic in the earlier post-war years. Productivity in the rest of the private economy grew more rapidly than in manufacturing in 12 of the 33 years between 1947 and 1980, and manufacturing productivity grew more rapidly by only 1.37 percentage points per annum on average over that period. Houseman (2018) has argued that the acceleration of manufacturing productivity in the 1980-2000 period was due in large part to a surge of measured productivity in NAICS 334. In any case, the p-level for a two-tailed t-test of the null hypothesis that the mean difference between the growth rate of productivity in manufacturing and that in the rest of the private economy was equal in 1947-2000 and 2010-2017 was .0015.

14 The p-level for a two-tailed t-test of the null hypothesis that the mean difference between the two growth rates was the same in both periods was $6.5 \times 10^{-5}$. Syverson (2016) has shown that labour productivity growth fell more in manufacturing between 1995-2004 and 2005-2015 than in the nonfarm private economy generally and that the fall in manufacturing productivity growth between these periods had a disproportionate impact on the broader economy. Lawrence (2017) compared aggregate manufacturing labour productivity growth in 2010-2016 and in prior years, and Baily and Montalbano (2016) showed that growth of total factor productivity (TFP) in manufacturing in 2004-2014 was lower than in prior years.

15 The decomposition used to construct Table 3 is presented in the Appendix.

Table 3 shows that changes in manufacturing labour productivity were disproportionately important for the private economy as a whole. The first three columns show average rates of growth of labour productivity in the entire private economy, manufacturing, and the private economy excluding manufacturing. The fourth column shows that the average absolute contribution of manufacturing to private economy labour productivity growth did not vary dramatically in the sub-periods before 2010. The fifth and sixth columns show that manufacturing's per cent contribution to private economy productivity growth was substantially above its share of private economy (nominal) value-added in those sub-periods.[16]The third line of Table 3 shows that labour productivity in the entire private economy grew at an average annual rate of 1.75 per cent during 1990-2000, and almost half of that growth (0.486 = 0.85/1.75) reflected productivity growth in manufacturing, even though manufacturing accounted for only 19.1 per cent of nominal private-economy value-added on average.

This pattern changed dramatically after 2010. Comparing lines 3 and 6 in Table 3 shows that the decline in manufacturing's average contribution to private-economy productivity growth (0.82=0.85-0.03) accounted for 52 per cent of the total decline in the average growth rate of private-economy productivity (1.57=1.75-0.18) from 1990-2000 to 2010-2016 even though manufacturing generally accounted for less than 20 per cent of private-economy GDP during both those periods.[17] The decline in the growth rate of productivity in manufacturing was not the whole private-economy story, but the importance of manufacturing's role in that story greatly exceeded its share of real value-added.

Table 4 shows annual rates of change of employment and productivity for three-digit industries and aggregates of interest for the periods considered in Table 1. All industries suffered employment declines during 2000-2010, and the seven industries with rates of decline above 5.2 per cent lost at least 40 per cent of their jobs over that period. During the 2010-2016 expansion in aggregate manufacturing employment, six of the 18 industries, including NAICS 334, experienced employment declines. Durable goods industries accounted for about 60 per cent of manufacturing employment in 2010 and about 80 per cent of 2010-2016 employment growth, consistent with their suffering greater cyclical losses in the preceding decade. Two industries, NAICS 332 and 336, accounted for about two-

16 Baily and Montalbano (2016) show that this is also true for total factor productivity over the 1987-2014 period

17 Syverson (2016) compared labour productivity growth before and after 2004 and obtained quantitatively similar results. It may seem odd that Table 3 shows that manufacturing made a (tiny) positive contribution to overall private economy productivity growth in 2010-2017 even though manufacturing productivity declined. This reflects the higher absolute level of productivity in manufacturing than in the rest of the private economy, coupled with employment growth in manufacturing. (I am indebted to an anonymous referee for demonstrating this.)

**Table 4: Productivity (Real Value-added per Employee) and Employment for U.S. Three-digit NAICS Manufacturing Industries**

| | | Average Annual Growth Rate | | | | |
|---|---|---|---|---|---|---|
| | | Productivity | | | Employment | |
| | Sector/Sub-Sector/Industry | 1990-2000 | 2000-2010 | 2010-2016 | 2000-2010 | 2010-2016 |
| mfg | *All Manufacturing** | 4.53 | 5.30 | -0.33 | -4.04 | 1.14 |
| mlc | *All Manufacturing less 334** | 1.93 | 3.90 | -0.81 | -3.92 | 1.33 |
| dur | *Durable goods** | 5.92 | 6.23 | 0.67 | -4.32 | 1.48 |
| dlc | Durable goods less 334 | 1.39 | 3.65 | 0.11 | -4.17 | 1.85 |
| 321 | Wood products | -3.78 | 4.27 | -0.09 | -5.88 | 2.28 |
| 327 | Nonmetallic mineral products | 1.50 | 0.85 | 0.43 | -4.02 | 1.56 |
| 331 | Primary metals | 3.07 | 3.41 | 6.87 | -5.41 | 0.71 |
| 332 | *Fabricated metal products** | 1.80 | 0.86 | -0.79 | -3.13 | 1.76 |
| 333 | Machinery | -0.09 | 3.62 | -1.62 | -3.80 | 1.35 |
| **334** | ***Computer and electronic products**** | **22.56** | **15.33** | **3.50** | **-5.09** | **-0.73** |
| 335 | Electrical equip., appliances, & components | 1.45 | 4.53 | -1.10 | -4.98 | 1.07 |
| 336 | Transportation Equipment | 2.14 | 5.17 | 0.64 | -4.34 | 3.30 |
| 337 | Furniture and related products | 1.74 | 0.87 | 0.96 | -6.45 | 1.45 |
| 339 | *Miscellaneous manufacturing** | 2.83 | 5.24 | -1.95 | -2.51 | 0.70 |
| ndr | Nondurable goods* | 2.60 | 4.03 | -1.26 | -3.58 | 0.60 |
| 311FT | Food and beverage and tobacco products | 0.81 | 1.89 | -3.29 | -0.82 | 1.61 |
| 313TT | Textile mills and textile product mills | 3.16 | 2.91 | 0.67 | -9.37 | -0.67 |
| 315AL | *Apparel and leather and allied products** | 4.22 | 4.74 | -0.27 | -10.72 | -2.21 |
| 322 | Paper products | 0.59 | 1.21 | 0.22 | -4.27 | -1.04 |
| 323 | Printing and related support activities | -0.37 | 4.78 | 1.09 | -5.03 | -1.47 |
| 324 | Petroleum and coal products | 7.54 | 3.39 | 2.75 | -0.79 | -0.34 |
| 325 | *Chemical products** | 2.92 | 4.47 | -1.98 | -2.21 | 0.51 |
| 326 | *Plastics and rubber products** | 3.28 | 2.36 | -2.12 | -4.20 | 1.86 |

Source: BLS and BEA data, author's calculations.
*Average productivity growth in 1990-2000 was significantly different from average productivity growth in 2010-2016 at the 10% level on a two-tailed t-test, allowing for unequal variances.

thirds of growth in durables employment, and NAICS 311 accounted for essentially all the increase in non-durables employment, even though, as Table 1 shows, its real value-added fell fairly rapidly.

Table 4 shows that in all but three of the 18 industries – NAICS 321, 331, and 323 – the rate of growth of labour productivity declined between 1990-2000 and 2010-2016. All three of those industries had job losses of about 40 per cent during 2000-2010, and all three had more rapid output growth during 2010-2016 than during 1990-2000 – with two (NAICS 321 and 331) experiencing noticeably more rapid growth. Despite the small sample size, for six of the industries in Table 4 as well as several aggregates, all shown in italics, average productivity growth declines between 1990-2000 and 2010-2016 were significant at the 10 per cent level using a two-tailed t-test.[18] In five of the 18 industries, as

18 For 12 of the 18 industries, productivity growth increased between 1990-2000 and 2000-2010. The increase was only significant at 10 per cent on a two-tailed test for two industries, however.

in manufacturing as a whole, real value-added per employee declined absolutely between 2010 and 2016.

Even if the extreme decline in productivity growth in NAICS 334 was in part the result of increased mis-measurement of real value-added in that innovative industry, it is clear from Table 4 that the aggregate manufacturing productivity growth decline reflected factors that affected most other industries. Even excluding NAICS 334, average labour productivity growth fell by almost 3 percentage points between 1990-2000 and 2010-2016.

Arguing against the importance of increased mis-measurement as a source of declines in aggregate productivity growth, Syverson (2016) showed that labour productivity growth in manufacturing fell between 1996-2004 and 2004-2014 for 17 of the 20 OECD nations with available data.

To focus more sharply on leading industrialized nations and to focus on the post-2010 period, I looked at the G-7 nations for which manufacturing labour productivity data were available from the OECD from 1995 to 2015: the U.K., Germany, Italy, France, and Japan. All showed falls in average productivity growth between 1995-2000 and 2011-2015, though none were as dramatic as in the United States, and only the United States showed an absolute fall in productivity in the latter period.[19]

Thus, consistent with the arguments of Byrne *et al.* (2016) and Syverson (2017), the breadth of the productivity growth decline in United States manufacturing and experience in other leading industrialized nations is inconsistent with the notion that the overall productivity slowdown in the United States private economy mainly reflects increasing under-statement of real value-added in a few innovative manufacturing industries. Table 4 shows that this pattern is broadly consistent with several studies that find general declines in business dynamism, particularly among non-leading firms; see, e.g., Decker *et al.* (2017, 2018) and Andrews *et al.* (2016).

Even if increased mis-measurement of real value-added has not been the dominant cause of the collapse of manufacturing productivity growth, it could nonetheless have had some impact. Guvenen *et al.* (2017) argue that shifting profits off-shore led to a small over-statement of business sector productivity growth between 1994 and 2008 but had no effect from 2008 through 2014. This suggests that the productivity growth slowdown may be slightly over-stated in the official statistics. Houseman *et al.* (2011) argue that a shift to the use of lower-cost imported inputs similarly led to an over-statement of manufacturing productivity growth during 1997-2007. The estimated over-statement is again small relative to the productivity growth collapse in manufacturing after 2010, however, so that

19 Like the United States, Germany and the U.K. reported increases in manufacturing employment between 2010 and 2016, though the increases were smaller in percentage terms than in the United States Manufacturing employment fell in the other three nations considered.

**Table 5: Productivity (Real Value-added per Employee) and Employment in U.S. Three-digit NAICS Manufacturing Industries by Recovery Ratio Cluster**

| | Average Annual Percent Growth Rate | | | | |
|---|---|---|---|---|---|
| | Productivity | | | Employment | |
| Recovery Ratio Cluster* | 2010-2016 | 2000-2010 | 1990-2000 | 2010-2016 | 2000-2010 |
| (1) R = 3.29 | 3.50 | 15.33 | 22.56 | -0.73 | -5.09 |
| (2) 1.15 $\leq$ R $\geq$ 1.50 | 1.26 | 4.34 | 3.70 | 0.98 | -3.05 |
| (3) 0.95 $\leq$ R $\geq$ 1.01 | -1.00 | 3.82 | -0.39 | 0.97 | -4.10 |
| (4) 0.47 $\leq$ R $\geq$ 0.84 | -0.13 | 1.97 | 2.33 | 0.39 | -6.02 |

Source: Data from Tables 1 and 4. The recovery ratio, R, is the ratio of an industry's real value-added in 2016 to its real value-added in 2000.
*The industries in each cluster are as follows, ordered by declining recovery ratio: (1) 334, (2) 324, 336, 331, 339, 325, (3) 311FT, 321, 333, 335, 323, (4) 332, 327, 326, 322, 337, 313TT, 315AL.

even a reversal of this shift would seem unlikely to account for much of the aggregate productivity growth collapse. Moreover, the dollar rose by 12.7 per cent between 2010 and 2016, making imported inputs relatively more attractive, so a reversal of this trend is not particularly plausible.[20]

While neither of these measurement problems seems likely to have had a major effect on manufacturing as a whole, changes in the official measures for NAICS 334 have been dramatic, and that industry has been the focus of many discussions of mis-measurement. We accordingly turn to a closer examination of productivity in that industry in the next section.

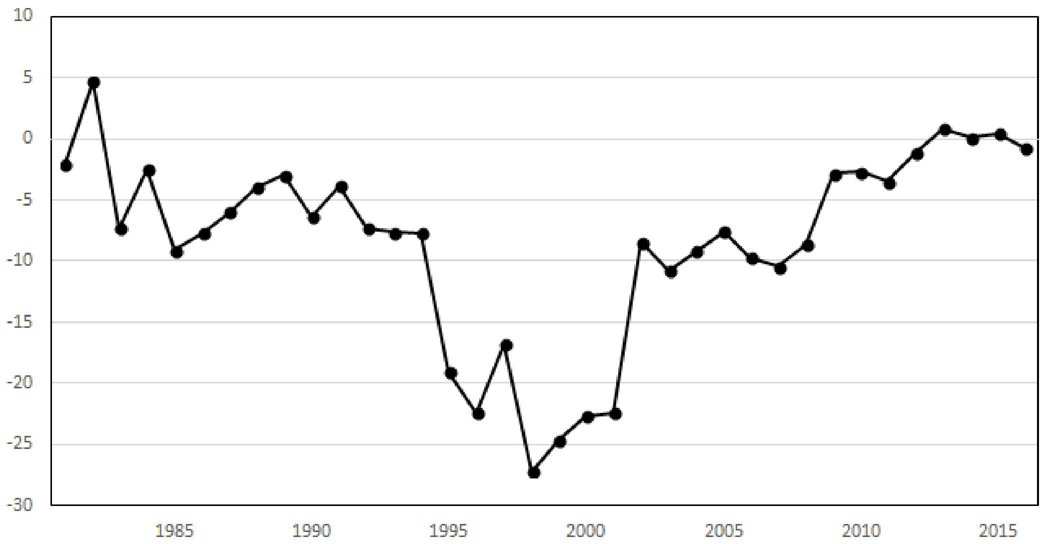
Table 5 follows the same format as Table 2 and computes average rates of growth of productivity and employment for clusters of industries defined by the ratios of their real value-added in 2016 to that in 2000. Because NAICS 334 is such an extreme outlier, it is most instructive to compare clusters (2), (3), and (4). Even though these clusters were defined by cumulative changes in real value-added, not productivity ot employment, industries that did well in those terms also suffered the smallest employment losses in 2000-2010 and the strongest employment gains in 2010-2016. Similarly, industries in cluster (2) had the strongest labour productivity growth on average in all three periods. The directions of causality, if any, among these variables is, of course, unknown. But it is clear that, as Houseman (2018) has stressed, robust labour productivity growth does not automatically lead to declines in employment.

## Productivity Growth in NAICS 334

Baily and Bosworth (2014) and Houseman *et al.* (2015) have stressed the importance of declines in the deflator for the computer and electronic products industry (NAICS 334) for measured

20 The 12.7 per cent figure was computed from annual averages of monthly figures of the Federal Reserve's Price-Adjusted Board Dollar index. For most of the 18 three-digit industries, the ratio of value-added to sales declined slowly over this period, consistent with a continuation of the Houseman *et al.* (2011) trend, not a reversal. The striking exception was NAICS 334, for which this ratio rose substantially. Analysis using the NBER-CES manufacturing database (available at http://www.nber.org/nberces/) indicated that this was entirely due to shifts in the relative importance of the constituent six-digit industries with different average value-added/sales ratios.

**Chart 3: Rates of Change of the Deflator for Computer and Electronic Products (NAICS 334), 1980-2016, per cent**




Source: BEA.

**Table 6: Average Contributions of NAICS 334 Deflation to U.S. Manufacturing Labour Productivity Growth**

| Period | Average Manufacturing Productivity Growth (%) | Avg. Contribution of 334 Deflation Absolute Percentage Points | Per cent of Total Manufacturing | Avg. 334 Share (%) of Manufacturing Nominal VA |
|---|---|---|---|---|
| 1947 - 1980 | 2.64 | -0.08 | -3.08 | 6.04 |
| 1980 - 1990 | 3.85 | 0.47 | 12.31 | 10.61 |
| 1990 - 2000 | 4.53 | 1.95 | 43.04 | 12.44 |
| 2000 - 2010 | 5.30 | 1.16 | 21.97 | 12.53 |
| 2010 - 2016 | -0.33 | 0.09 | -27.57 | 12.89 |

Source: BEA and BLS data, author's calculations.

manufacturing productivity growth in in the two decades before 2010. Chart 3 shows that the decline of the deflator for NAICS 334 accelerated sharply in the mid-1990s and then decelerated sharply after 2000.

Over the 1990-2000 period, measured labour productivity in NAICS 334 grew 22.6 per cent per annum on average, and 68 per cent of this growth (15.4 percentage points) was accounted for by the decline in the industry-specific deflator.[21] From 2010 to 2016, in contrast, that deflator declined only 0.68 per cent per year on average, suggesting a dramatic fall in the decline in the rate of improvement of computer and electronic products. The dramatic fall in the rate of deflation for NAICS 334 accounted for 77 per cent of the decline in that industry's average annual productivity growth between 1990-2000 and 2010-2016.

Table 6, which uses the same format as Table 3, shows that changes in the NAICS 334 deflator had an important impact on total manufacturing pro-

21 The change in the log of labour productivity growth equals the change in the log of nominal labour productivity growth minus the change in the log of the deflator.

ductivity.[22] Between 1947 and 1980, NAICS 334 was generally unimportant, its deflator increased, and that increase had essentially no impact on aggregate manufacturing productivity. This began to change around 1980 as this industry became more important, and its pace of innovation accelerated. Comparing the first and third lines of Table 6 reveals that between 1947-1980 and 1990-2000 increases in the rate of decline of the NAICS 334 deflator (and increases in its relative weight in Appendix equation (A3)) accounted for 2.03 (=1.95+.08) percentage points of the increase in the average manufacturing productivity growth rate, more than the actual 1.89 (=4.53-2.64) percentage point increase. The contribution of all other manufacturing industries in aggregate was, therefore, negative.

Between 1990 and 2000, the decline in the NAICS 334 deflator accounted for over 40 per cent of estimated aggregate manufacturing productivity growth, and even during the catastrophic 2000-2010 decade it accounted for over 20 per cent. But the pattern changed sharply after 2010. Comparing the third and fifth lines in Table 6 shows that the fall in the rate of decline of the deflator for NAICS 334 between 1990-2000 and 2010-2016 (1.84=1.95-.09 percentage points) accounted for just over 38 per cent of the drop in aggregate manufacturing productivity growth (4.86=4.53+0.33 percentage points) between those periods, even though NAICS 334 accounted for less than 13 per cent of nominal manufacturing value-added on average during these periods. Changes in the rate of decline of the NAICS 334 deflator account for a substantial and disproportionate share of the collapse in aggregate manufacturing productivity growth.

It is important to be clear that the "accounted for" statements in the preceding two paragraphs are in fact only about accounting, not about causation. Suppose that the real price declines of goods produced by some industry have been understated in the official statistics. Correcting that understatement would, of course, increase the measured real output of the corresponding industry. But the effect on broader measures of real output would depend on who bought the industry's production.[23] At one extreme, it might all be exported, and the increase in the industry's measured output would translate directly into an increase in measured real GDP. At the other extreme, the industry's output might all be sold to another domestic industry. In that case, correcting the understatement of deflation would simply increase that other industry's measured purchases of intermediate goods and decrease its measured value-added accordingly, with no impact on real GDP.

To look more closely at the sources of changes in the NAICS 334 deflator and their potential consequences for broader aggregates, I employed the NBER-CES

22 See the Appendix for the decomposition used to create Table 6.

23 See Byrne *et al.* (2017) for a discussion and quantitative analysis.

**Table 7: Decomposition of the Fall in the Rate of Deflation of NAICS 334, 1995-1997 to 2009-2011**

| NAICS Code | Description | Share of NAICS 334 Value Added Mean | Share of NAICS 334 Value Added Change | Annual Percentage Change in Deflator Mean | Annual Percentage Change in Deflator Change | % Contribution to Fall in Rate of 334 Deflation Total | % Contribution to Fall in Rate of 334 Deflation Deflator | % Contribution to Fall in Rate of 334 Deflation Share |
|---|---|---|---|---|---|---|---|---|
| 334111 | Electronic Computers | 7.91 | -5.61 | -20.64 | 15.49 | 19.84 | 13.72 | 6.12 |
| Other 3341 | Computers & peripheral equipment, other | 5.50 | -2.21 | -11.21 | 10.30 | 7.59 | 5.30 | 2.29 |
| 3342 | Communications equipment | 14.36 | -6.66 | -1.71 | 1.11 | 2.61 | 1.50 | 1.10 |
| 3343 | Audio & video equipment | 0.85 | -0.30 | -1.65 | -0.44 | 0.00 | -0.04 | 0.04 |
| 334413 | Semiconductors & related devices | 26.09 | 2.16 | -21.52 | 29.28 | 65.49 | 70.86 | -5.39 |
| Other 3344 | Semiconductors & other electronic components, other | 10.94 | -2.31 | -1.23 | 2.98 | 3.43 | 3.08 | 0.35 |
| 3345 | Navigational, measuring, electromedical, & control instruments | 32.58 | 16.11 | 0.86 | -0.08 | 0.95 | -0.25 | 1.20 |
| 3346 | Manufacturing & reproducing magnetic & optical media | 1.77 | -1.18 | -2.10 | -0.65 | 0.12 | -0.12 | 0.24 |

Source: NBER-CES manufacturing database, author's calculations.

manufacturing database, which has data on nominal value-added and shipments deflators for 30 six-digit manufacturing industries in NAICS 334 from 1958 through 2011.[24] Chart 3 shows that this period covers most of the post-2000 fall in the rate of decline of the NAICS 334 deflator.[25]

I compared the periods 1995-1997, the first three years of double-digit rates of decline of both official and approximate NAICS 334 deflators, and 2009-2011, the latest three-year period in the NBER-CES database, during which NAICS 334 deflation was less than 4 per cent per annum in each year. For each six-digit industry or broader aggregate considered, the first four columns in Table 7 show the average percentage share of nominal value-added in those two periods, the change in that average share between those two periods, the average percentage change of the corresponding approximate deflator in those two periods, and the percentage point change in that average rate of change. Positive numbers in the fourth column thus correspond to falls in the rate of decrease of the corresponding deflator. For comparison, the average rate of decline of the approx-

24 The database can be accessed at http://www.nber.org/nberces/

25 The methods used to construct an approximate deflator for NAICS 334 from the NBER data and to use it to produce Table 7 are presented in the Appendix.

imate deflator was 13.3 per cent over 1995-97 and 2.9 per cent during 2008-2011, so the change, corresponding to the fourth column in the Table was 10.4 percentage points.

Table 7 shows that computers (NAICS 334111) and semiconductors (NAICS 334413) had much the largest average rates of declines of their deflators, as well as the largest falls in those decline rates between the earlier and later periods. Computer manufacturing experienced a substantial drop in its share of NAICS 334 value-added, corresponding to a 60 per cent drop in average nominal value-added, as computer manufacturing moved rapidly overseas.

The fifth column of Table 7 shows that computers and semiconductors accounted for 85.3 per cent of the drop in the approximate NAICS 334 rate of deflation between 1995-1997 and 2009-2011, even though they accounted for only 34 per cent of nominal value-added on average in those two periods. The last two columns in Table 7 report the percentages of the total difference in the average rate of deflation for NAICS 334 between the two periods accounted for by changes in rates of deflation and changes in shares, respectively. This table shows that change in its components' rates of deflation accounted for 94 per cent of the decline in the aggregate rate of deflation for NAICS 334; changes in the relative importance of the components had very little impact. A substantial drop in the share of computers was almost completely offset by a small increase in the share of semiconductors. Table 7 makes clear that the single most important contributor to the fall in the rate of decline of the deflator for NAICS 334 was the dramatic fall in the rate of decline of the deflator for semiconductors.

On its face, this dramatic fall implies a collapse in the rate of innovation in semiconductors. Estimating rates of quality improvement in innovative industries is, of course, difficult.[26] The business press seems devoid of complaints about a collapse of semiconductor innovation over this period, however, so one should be cautious about accepting that such a dramatic collapse actually occurred. In addition, Byrne and Corrado (2017) and others have argued that the rates of improvement of a wide range of high-tech goods have been understated for some time. For mis-measurement to have made a noticeable contribution to the dramatic slowdown in the rate of deflation of NAICS 334 shown in Table 6, however, mis-measurment would have had to have increased substantially. As it happens, Byrne *et al.* (2018) have argued persuasively that the rate of decline of the deflator for semiconductors *has* been more substantially under-stated in the official statistics since around 2004. Correcting such an understatement would in-

26 For a general discussion of methods used in the United States to adjust for quality change, see Groshen *et al.* (2017). It is worth noting that the BLS did not begin to employ hedonic methods for server microprocessors until mid-2018, and the initial model did not include energy efficiency, though that appears to be an important attribute for server farms (U.S. Bureau of Labour Statistics, 2018).

crease measured real output and labour productivity in NAICS 334413. But, as Byrne *et al.* (2018) stress, semiconductors are an intermediate good for which net exports are small (Platzer and Sargent, 2016), so correcting an understatement in the rate of decline of their deflator would likely have little impact on measured GDP.[27]

## Summary Remarks

The aggregate changes in U.S. manufacturing since the Great Recession have been both dramatic and puzzling, and they have had disproportionately large impacts on the private economy as a whole. This article looked behind those surprising aggregate shifts to examine underlying developments at the three-digit industry level. In important respects the diversity among industry experiences simply pushed puzzles down to the industry level and made clear the need for more research at that level, but the analysis here did reveal a number of interesting patterns.

First, increased foreign competition may have been a significant reason for the slow growth of manufacturing output after 2010 relative to growth in the rest of the private economy, but it does not seem likely to have been the only reason. Second, growth in employment and declines in labour productivity growth occurred in most industries. The pattern of declines in labour productivity growth argues strongly against the notion that the aggregate decline primarily reflects increasing mis-measurement of real output in a few innovative industries, but the analysis here does not supply an alternative explanation.

Third, even though the accounting identity connecting changes in output, employment, and labour productivity suggests that robust productivity growth reduces employment, Table 5 shows that industries that recovered well from the Great Recession in output terms also had average employment growth and above-average productivity growth. As Houseman (2018) has stressed, that accounting identity cannot be treated as a causal relation.

Finally, on essentially all dimensions and in all periods, NAICS 334 is an extreme outlier, and changes in estimates of quality changes in computers and semiconductors have had a substantial impact on aggregate productivity statistics. If, as estimated above, computers and semiconductors accounted for around 85 per cent of the slowdown in the decline of the NAICS 334 deflator, and that slowdown accounted for around 38 per cent of the overall drop in manufacturing productivity growth, then as a rough approximation (taking note of the fact that these percentages were computed for somewhat different periods), falls in the rates of decline of the deflators for computers and semiconductors accounted for around 32 per cent of the overall decline in manufac-

27 Since a change in the deflator for semiconductors will affect both imports and exports, net exports is the relevant measure for the impact on real GDP.

turing productivity growth between the 1990s and the post-2010 period. But there have also been substantial post-Great-Recession changes in other manufacturing industries. Estimates of quality change in NAICS 334 matter greatly for estimates of aggregate manufacturing productivity growth, but they are not all that matters.

## References


Acemoglu, Daron and Pascual Restrepo (2017) "Robots and Jobs: Evidence from US Labor Markets," Working Paper, MIT Department of Economics, March.

Andrews, Dan, Chiara Criscuolo, and Peter N. Gal (2016) "The Best Versus the Rest: The Global Productivity Slowdown, Divergence Across Firms and the Role of Public Policy," OECD Productivity Working Paper No. 05, November.

Autor, David H., David Dorn, and Gordon H. Hanson (2013) "The China Syndrome: Local Labor Market Effects of Import Competition in the United States," *American Economic Review*, Vol. 103 , No. 6. pp. 2121-2168.

Baily, Martin N., and Barry P. Bosworth (2014) "U.S. Manufacturing: Understanding Its Past and Its Potential Future," *Journal of Economic Perspectives*, Vol. 28, No. 1 pp. 3-26.

Baily, Martin N. and Nicholas Montalbano (2016) "Why is U.S. Productivity Growth So Slow?" Brookings Institution, Hutchins Center Working Paper 22, September.

Byrne, David M., and Carol Corrado (2017) "ICT Services and Their Prices: What do They Tell us About Productivity and Technology?" *International Productivity Monitor*, No. 33, Fall, pp. 150-181.

Byrne, David M., John G. Fernald, and Marshall B. Reinsdorf (2016) "Does the United States Have a Productivity Slowdown or a Measurement Problem?" *Brookings Papers on Economic Activity*, pp. 109-157.

Byrne, David M., Stephen D. Oliner, and Daniel E. Sichel (2018) "How Fast Are Semiconductor Prices Falling?" *Review of Income and Wealth*, Vol. 64, Issue 3. pp. 679-702.

Byrne, David M., Stephen D. Oliner, and Daniel E. Sichel (2017) "Prices of High-Tech Products, Mismeasurement, and the Pace of Innovation.," *Business Economics*, Vol. 52, No. 2. pp. 103-113.

Dey, Mathew, Susan N. Houseman, and Anne E. Polikva (2012) "Manufacturers Outsourcing to Staffing Services," *Industrial and Labor Relations Review*, Vol. 65, No. 3, pp. 533-569.

Decker, Ryan A., John C. Haltiwanger, Ron S. Jarmin, and Javier Miranda (2017) "Declining Dynamism, Allocative Efficiency, and the Productivity Slowdown," *American Economic Review Papers and Proceedings*, Vol. 107, No. 5, pp.322-326.

Decker, Ryan A., John C. Haltiwanger, Ron S. Jarmin, and Javier Miranda (2018) "Changing Business Dynamism and Productivity: Shocks vs. Responsiveness," National Bureau of Economic Research, Working Paper 24236, January.

Diewert, Erwin (1978) "Superlative Index Numbers and Consistency in Aggregation," *Econometrica*, Vol. 46, No. 4, pp. 883-900.

Dumagan, Jesus C. (2002) "Comparing the Superlative Törnqvist and Fisher Ideal Indexes," *Economics Letters*, Vol. 76, No. 4, pp.251-258.

Feldstein, Martin (2017) "Underestimating the Real Growth of GDP, Personal Income, and Productivity," *Journal of Economic Perspectives*, Vol. 31, No. 2, pp. 145-164.

Fernald, J. G. (2015) "Productivity and Potential Output Before, During, and After the Great Recession," *NBER Macroeconomics Annual*, Vol. 29, No. 1, pp. 1-51.

Fort, Teresa C., Justin R. Pierce, and Peter K. Schott (2018) "New Perspectives on the Decline of U.S. Manufacturing Employment," *Journal of Economic Perspectives*, Vol. 32, No. 2, pp. 47-72.

Gordon, R. J. (2018) "Why Has Economic Growth Slowed When Innovation Appears to be Accelerating?" Cambridge, MA: National Bureau of Economic Research, Working Paper 24554, April.

Groshen, Erica L., Brian C. Moyer, Ana M. Aizcorbe, Ralph Bradley, and David M. Friedman (2017) "How Government Statistics Adjust for Potential Biases from Quality Change and New Goods in an Age of Digital Technologies: A View from the Trenches," *Journal of Economic Perspectives*, Vol. 31, No. 2, pp. 187-201.

Guvenen, Faith, Raymond J. Mataloni, Jr., Dylan G. Rassier, and Kim J. Ruhl (2017) "Offshore Profit Shifting and Domestic Productivity Measurement," Cambridge, MA: National Bureau of Economic Research, Working Paper 23324, April.

Houseman, Susan H (2018) "Understanding the Decline of U.S. Manufacturing Employment," Upjohn Institute Working Paper 18-287, Kalamazoo.

Houseman, Susan N., Christopher Kurz, Paul Lengermann, and Benjamin Mandel (2011) "Offshoring Bias in U.S. Manufacturing," *Journal of Economic Perspectives*, Vol. 25, No. 2, pp. 111-132.

Houseman, Susan N., Timothy J. Bartik, and Timothy Sturgeon (2015) "Measuring Manufacturing: How the Computer and Semiconductor Industries Affect the Numbers and Perceptions," in Susan N. Houseman and Michael Mandel (eds.) *Measuring Globalization: Better Trade Statistics for Better Policy Volume 1. Biases to Price, Output, and Productivity Statistics from Trade* (Kalamazoo: W.E Upjohn Institute), pp. 151-194.

Lawrence, Robert Z. (2017) "Recent Manufacturing Employment Growth: The Exception that Proves the Rule," National Bureau of Economic Research, Working Paper 24151, December.

Levinson, Marc (2017) "Job Creation in the Manufacturing Revival," Congressional Research Service Report, May 5.

Pierce, Justin R. and Peter K. Schott (2012) "The Surprisingly Swift Decline of US Manufacturing Employment," *American Economic Review*, Vol. 106, No.7, pp. 1632-1662.

Pierce, Justin R. and Emily Wisniewski (2018) "Some Characteristics of the Decline in Manufacturing Capacity Utilization," Washington: Federal Reserve Board of Governors, FEDS Notes, March 1.

Platzer, Michaela D. and John F. Sargent Jr. (2016) "U.S. Semiconductor Manufacturing: Industry Trends, Global Competition, Federal Policy," Washington, DC: Congressional Research Service, R44544, June.

Syverson, Chad (2016) "The Slowdown in Manufacturing Productivity Growth," *Brookings Briefs*, August.

Syverson, Chad (2017) "Challenges to Mismeasurement Explanations for the US Productivity Slowdown," *Journal of Economic Perspectives*, Vol. 31, No. 2, pp. 165-186.

U.S. Bureau of Labor Statistics (2018) "PPI Introduces Hedonic Price Estimation for Server Microprocessors," August 9. Available at https://www.bls.gov/ppi/server-microprocessors-hedonics.htm

Whelan, Karl (2002) "A Guide to U.S. Chain Aggregated NIPA Data," *Review of Income and Wealth*, Vol. 48, No. 2, pp. 217-233.

## Appendix

### The Törnqvist Approximation and Dataset Construction

To compute value-added in the private economy excluding manufacturing, I used the (chained) Törnqvist approximation to the (chained) Fisher Ideal quantity index used by BEA.[28] If $q_{i,t}$ is real value-added for industry $i$ in year $t$, and $Q_t$ is the real value-added of an aggregate of a set of industries in year t, the approximation is as follows:

$$\ln\left(\frac{Q_t}{Q_{t-1}}\right) \approx \sum_i w_{i,t} \ln\left(\frac{q_{i,t}}{q_{i,t-1}}\right), \quad \text{(A1)}$$

where $w_{i,t}$ is the average of industry $i$s share of the nominal value-added of the aggregate in years $t$ and $t-1$. I also used this approximation to combine the real BEA value-added numbers for industries 336MV (motor vehicles, bodies and trailers, and parts) and 3364OT (other transportation equipment). And, because NAICS 334 (computer and electronic products) is an outlier on several dimensions discussed below, I also used it to produce series for real value-added for manufacturing excluding NAICS 334 and for durable goods excluding NAICS 334.

I added BLS employment numbers for industries 313 (textile mills) and 314 (textile product mills) to match BEA value-added data for industry 313FT.

BEA reports real value-added for industry 311FT, which is the sum of 311 (food manufacturing) and 312 (beverage and tobacco product manufacturing), and for BEA industry 315AL, which is the sum of 315 (apparel manufacturing) and 316 (leather and allied product manufacturing). On the other hand, BLS reports average annual employment for 311 and 315 and, as CEU industry 32329, for the sum of average employment in 312 and 316. From 2002 through 2015, it reports May employment figures for 312 and 316 separately, and for those years I simply re-scaled the May numbers so that their total equaled the corresponding 32329 annual average number. The ratio of 316 to 312 employment declined smoothly from 0.238 in 2002 to 0.134 in 2015. I regressed this ratio against a time-trend ($R^2$=0.93) and used the fitted values, which rose to 0.330 in 1990, to allocate 32329 employment between 312 and 316 for the years 1990-2001. I then added the 312 estimates to the BLS numbers for 311 to produce an employment series for 311FT, and I added the 316 estimates to the BLS numbers for 315 to produce a series for 315AL.

I also used a natural extension of the Törnqvist approximation to decompose total private economy labour productivity growth into that due to manufacturing and that due to the rest of the private economy:

28 See Diewert (1978), Whelan (2002), and Dumagan (2002). Houseman *et al.* (2015) use this same approximation.

$$\ln\left(\frac{Q_t}{L_t}\right) - \ln\left(\frac{Q_{t-1}}{L_{t-1}}\right) \approx \sum_i \left[w_{i,t} \ln\left(\frac{q_{i,t}}{q_{i,t-1}}\right) - \eta_{i,t} \ln\left(\frac{l_{i,t}}{l_{i,t-1}}\right)\right], \tag{A2}$$

where $q_{i,t}$ is real value-added in industry $i$ in period $t$, $l_{i,t}$ is employment in industry $i$ in period $t$, and $\eta_{i,t}$ is the average of industry $i$'s share of employment in the aggregate in years $t$ and $t-1$. Then the $i^{\text{th}}$ bracketed term is the absolute contribution of component $i$ to measured aggregate productivity change. Manufacturing's contribution depends on both its rate of productivity improvement and on its shares of nominal value-added and employment.

To examine the importance of the NAICS 334 deflator for aggregate manufacturing productivity changes, I decomposed the term for NAICS 334 on the right of equation (A2) into the (weighted) deflator and weighted nominal productivity:

$$[w_t \ln\left(\frac{q_t}{q_{t-1}}\right) - w_t \ln\left(\frac{q_t^n}{q_{t-1}^n}\right)] + [w_t \ln\left(\frac{q_t^n}{q_{t-1}^n}\right) - \eta_t \ln\left(\frac{l_t}{l_{t-1}}\right)] \equiv [w_t \ln\left(\frac{d_t}{d_{t-1}}\right)] + [w_t \ln\left(\frac{q_t^n}{q_{t-1}^n}\right) \eta_t \ln\left(\frac{l_t}{l_{t-1}}\right)]. \tag{A3}$$

The notation is as above, with $q_n$ denoting nominal value-added.

## Analyzing the NAICS 334 Deflator

I used the (chained) Törnqvist approximation presented above to obtain deflators for four of the six 4-digit industries in NAICS 334, for two important six-digit industries, and for the remainders of the two corresponding four-digit industries, as shown in Table 7. As is common practice (see, e.g., Fort *et al.* 2018), and for lack of an alternative, I treated the shipments deflator as if it applied to value-added, and I used nominal value-added weights in the Törnqvist approximation. The Törnqvist approximation to the rate of change of the deflator for some aggregate k within NAICS 334 is given by

$$D_{k,t} \equiv \sum_{i \in k} w_{i,t} \ln\left(\frac{p_{i,t}}{p_{i,t-1}}\right), \tag{A4}$$

where $w_{i,t}$ is the average of industry $i$s share of aggregate $k$s nominal value-added in periods $t$ and $t-1$, and $p_{i,t}$ is the shipments deflator for industry $i$ in period $t$.

Similarly, I used the (chained) Törnqvist approximation to obtain an approximation to the rate of change of the aggregate deflator for NAICS 334, $P_t$:

$$\ln\left(\frac{P_t}{P_{t-1}}\right) \equiv \sum_k C_{k,t} \equiv \sum_k \sum_{i \in k} \Omega_{i,t} \ln\left(\frac{p_{i,t}}{p_{i,t-1}}\right), \tag{A5}$$

where the second equality defines the $C_{k,t}$, $p_{i,t}$ is as above, and $\Omega_{i,t}$ is the average of industry $i$s share of value-added in NAICS 334 in periods $t$ and $t-1$. Percentage changes in the approximate and official deflators were highly correlated over 1995-2011 ($\rho = 0.81$) and nearly equal in 2009-2011, but the approximate series had lower percentage declines on average.

The contribution of each aggregate in

Table 7 to the change in the average rate of decrease in the approximate NAICS 334 deflator is the change in the within-period averages of their contributions to that deflator, the $C_{k,t}$ in equation (A5). These differences, expressed as percentages of the change in the average rate of decrease of the NAICS 334 deflator, are shown in the fifth column of Table 7.

Define the *average effective weight* of each aggregate in NAICS 334 in each comparison period, T, as

$$\theta_{k,T} \equiv \frac{\sum_{t \in T} C_{k,T}}{\sum_{t \in T} D_{k,t}} = \frac{\sum_{t \in T} \sigma_{k,t} \sum_{i \in k} w_{i,t} \ln\left(\frac{p_{i,t}}{p_{i,t-1}}\right)}{\sum_{t \in T} \sum_{i \in k} w_{i,t} \ln\left(\frac{p_{i,t}}{p_{i,t-1}}\right)}, \tag{A6}$$

where $\sigma_{k,t}$ is the share of aggregate $k$ in manufacturing value-added in period $t$.

If for some aggregate the early-period and late-period values of this average effective weight are $\theta$ and $\theta'$, respectively, and the early and late average rates of change of the corresponding deflator are $\gamma$ and $\gamma'$, we can decompose this aggregate's contribution to the change in the average rate of increase of the overall NAICS 334 deflator as follows:

$$\theta'\gamma' - \theta\gamma \equiv .5(\theta' + \theta)(\gamma' - \gamma) + .5(\gamma + \gamma')(\theta' - \theta) \tag{A7}$$

# Solving the Productivity Puzzle: The Role of Demand and the Promise of Digitization

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Abstract

What is behind exceptionally weak productivity growth across many developed economies? We analyze seven countries (United States, Germany, France, UK, Italy, Spain, and Sweden) across six sectors (automotive, technology, retail, electric power, tourism, and finance) and examine supply and demand factors in the period from 2010 to 2014 compared to 2000 to 2004. For each sector, we combine economic analyses with McKinseys industry expertise to shed light on the microeconomic causes behind industry productivity performance. We find three waves collided to drive productivity growth across sectors: the waning of the impact of the 1990s information technology revolution; financial crisis aftereffects, including weak demand and uncertainty; and digital disruption which offers substantial opportunities to boost productivity growth but comes with lags and transition costs. We calculate that the first two waves dragged down productivity growth by 1.9 percentage points across countries since the mid-2000s, from 2.4 per cent to 0.5 per cent. As financial crisis aftereffects recede and more companies incorporate digital solutions, we expect productivity growth to recover, with productivity growth potential of at least 2 per cent per year across countries over the next decade.

A decade into recovery from the Great Recession, labour productivity growth rates remain near historic lows across many advanced economies. Productivity growth is crucial to increase wages and living standards and helps raise the purchasing power of consumers to grow demand for goods and services. Therefore, slowing labour productivity growth heightens concerns at a time when aging economies depend on productivity gains to drive economic growth (Manyika *et*

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2 Note that in this article, we often refer to labour productivity as simply "productivity"; we specify other types of productivity, such as total factor productivity, when referring to them.

*al.*, 2015).[2] Yet in an era of digitization, with technologies ranging from online marketplaces to machine learning, the disconnect between disappearing productivity growth and rapid technological change could not be more pronounced.

In this article, we shed light on the recent slowdown in labour productivity growth in the United States and Western Europe and outline prospects for future growth.[3] We find that three waves collided to produce a productivity-weak but job-rich recovery: the waning of a the impact of the first IT revolution that began in the 1990s, financial crisis aftereffects, and digitization. The first two waves have dragged down productivity growth by 1.9 percentage points on average across countries since the mid-2000s, from 2.4 per cent to 0.5 per cent. In particular, financial crisis aftereffects include weak demand, uncertainty, excess capacity, contraction and expansion of hours, and, in some sectors, a boom-bust cycle. The third wave, digitization, is fundamentally different from the first two because it contains the potential to reignite productivity growth but the benefits have not yet materialized at scale. This is due to adoption barriers and lag effects as well as transition costs. As financial crisis aftereffects recede and more companies incorporate digital solutions, we expect productivity growth to recover; the good news is that we are seeing an uptick today in productivity and GDP growth across many countries.

We calculate that the productivity-growth potential could be at least 2 per cent per year across countries over the next decade. However, capturing the productivity potential of advanced economies may require a focus on promoting both demand and digital diffusion in addition to more traditional supply-side approaches. Furthermore, continued research will be needed to better understand and measure productivity growth in a digital age.

This article contains five main sections. The first section outlines the methodology used to assess productivity trends and drivers. Section two provides an overview of the micro-patterns of slower productivity growth in seven advanced economies. The third section analyzes productivity developments from the angle of three waves or drivers of productivity: the waning of the ICT revolution and restructuring and offshoring; financial crisis aftereffects, including weak demand and heightened uncertainty; and the missing benefits of digitalization. The fourth section takes a sector view on the productivity slowdown in the seven advanced economies. The fifth and final section discusses how best to capture the productivity potential, largely by promoting both demand and digital diffusion.

3 This article draws from Remes *et al.* (2018).

## The McKinsey Global Institute Productivity Methodology

We analyze the productivity growth slowdown across a sample of seven countries: France, Germany, Italy, Spain, Sweden, the United Kingdom, and the United States. These countries were chosen to cover a large and diverse portion of GDP in advanced economies, representing about 65 per cent.[4]

In addition to country aggregate analysis, we analyzed six sectors across our sample of economies to identify what patterns are similar across sectors and what features are sector-specific, in order to understand what drives aggregate productivity trends. We chose these sectors – automotive manufacturing, finance, retail, technology, tourism, and utilities – because they represent a large and diverse share of the economies in our sample countries and played a significant role in explaining the recent slowdown.

In our analysis across countries and sectors, we assess the evidence for today's leading explanations for the productivity growth slowdown.[5] We find evidence of a non-measurement-related productivity growth slowdown and therefore focus our work in this report on explaining the productivity slowdown as measured.[6]

We take an integrated analytical approach across supply and demand to assess the linkages and "leakages" around the virtuous cycle of economic growth (from production of goods and services, leading to incomes for households and profits for companies, in turn resulting in continued demand for goods and services). This allows us to diagnose why productivity growth has slowed, particularly as many of the leading explanations today take a supply-focused view rather than an integrated one.

In our analysis, we often compare the turn of the century (2000-04) – a five-year period before the start of the recent productivity growth slowdown in the United States that encompasses the late boom of 2000, recession of 2001, and recovery period – with the post-recession years (2010-14), a somewhat stable period a decade later (though encompassing the double dip recession in Europe). Looking closely at the recent slowdown allows us to identify short-term factors behind the productivity-growth slowdown that are likely to be resolved, as well as long-term trends that are likely to remain in place, helping us

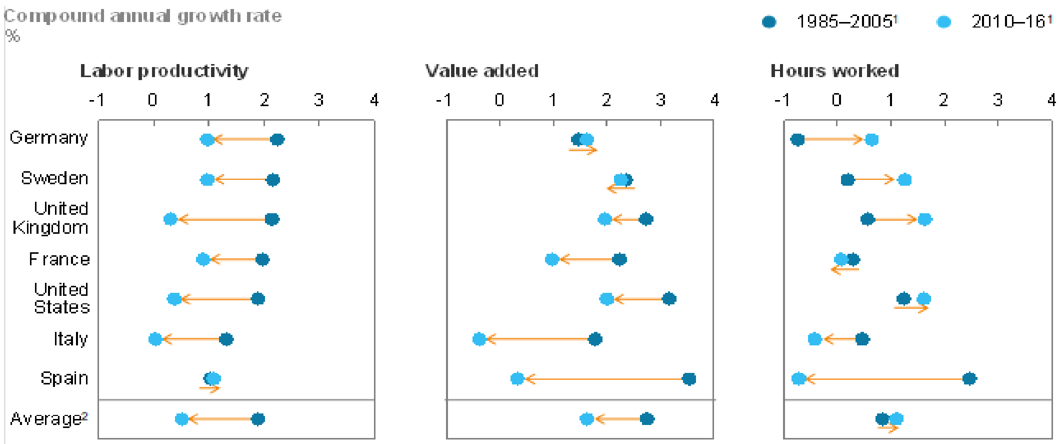
4 We do not include any analysis of emerging markets, which have a different productivity growth dynamic compared to mature markets.

5 These include: mismeasurement; financial crisis-related factors such as weak investment postcrisis and the rise of zombie firms; and structural shifts such as the rate of technological diffusion, the increasing concentration of businesses, and declining business dynamism together with a growing divergence of productivity among firms, a mix shift toward less productive sectors, a maturation of global supply chains, and secular stagnation. For more detail about each explanation, see Chapter 1 of Remes *et al.* (2018).

6 For more details, see Chapter 1, Box 3 of Remes *et al.* (2018).

7 While we are aware that choosing specific years involves some degree of arbitrariness, after assessing the pros and cons of multiple periods, we determined that concentrating on the period following the crisis allowed us to isolate different factors at the sector level across many different countries more easily. We also conduct

**Chart 1: Trend in Labour Productivity, Value-added and Hours Worked in Advanced Economies, 1985-2005 and 2010-2016**




1 Looking at these periods allows us to identify short-term factors behind the productivity-growth slowdown that are likely to be resolved, and long-term trends that are likely to remain in place.
2 Weighted average across France, Germany, Italy, Spain, Sweden, United Kingdom, and United States, based on 2016 GDP (2016 $ million).
NOTE: Order of countries based on fastest to slowest productivity growth in the 1985–2005 period.

SOURCE: The Conference Board (May 2017 release); McKinsey Global Institute analysis

to determine the potential for productivity growth in the future.[7]

While our methodology allows us to provide a much better understanding of the productivity growth slowdown and the implications for the future, questions for further research surely remain such as how to better measure the digital economy and understand the economic impact of digital transitions.

## Micro-Patterns of the Productivity Growth Slowdown: An Overview

Any explanation of the productivity puzzle should take into account the micro-patterns of the slowdown and not just the headline aggregate productivity numbers. We find three major micro patterns. First, the recovery from the financial crisis has been "job-rich" and "productivity-poor" with low "numerator" (value added) growth accompanied by robust "denominator" (hours worked) growth.[8] Chart 1 on this page shows that in many countries the exceptionally low productivity growth in the post-recession 2010-2016 period reflects slower value-added growth combined with robust growth in hours worked. The broad-based pattern of job-rich but productivity-weak recovery across most countries raises the question of why companies are increasing employment without corresponding increases in productivity growth. It also highlights the

robustness tests to assess how much these years impact our results. See the technical appendix of Remes *et al.* (2018) for a detailed discussion of our methodology.

8 That is not to say economies experienced a jobs boom but that solid job growth continued over a long time through and beyond the period from 2010 to 2014. While some considered this recovery "jobless" early on (see, for example, Kolesnikova and Liu, 2011), because it took so long for unemployment to recover, we find that hiring has been exceptionally steady over a long period. The time periods in this exhibit were chosen to allow us to compare a long-term trend (1985 to 2005, ending prior to the crisis, to eliminate the impact of the crisis) with the most recent trends in the recovery (the period of the particularly low productivity growth).

importance of examining demand-side drivers for slow value-added growth and low productivity growth.

Second, looking across more than two dozen sectors, we find few "jumping" sectors today, and the ones that are accelerating are too small to have an impact on aggregate productivity growth.[9] For example, only 4 per cent of sectors in the United States were classified as jumping in 2014, compared with an average of 18 per cent over the last two decades, and they contributed only 4 per cent to value added.[10] The distinct lack of jumping sectors we have found across countries is consistent with an environment in which digitization and its benefits to productivity are happening unevenly.

Third, since the Great Recession, capital intensity, or capital per hour worked, in many developed countries has grown at the slowest rate in postwar history. Capital intensity indicates access to machinery, tools, and equipment and is measured as capital services per hour. An important way productivity grows is when workers have better tools such as machines for production, computers and mobile phones for analysis and communication, and new software to better design, produce, and ship products. But capital deepening has not been occurring at past rates. Chart 2 shows that from a growth accounting decomposition of labour productivity shows that slowing growth of capital per hour worked contributes about half or more of the productivity growth decline in many countries.[11]

While labour productivity growth has been declining across the United States and Western Europe since the boom in the 1960s, it decelerated further after the financial crisis to historic lows (Chart 3). We focus here on the slowdown since the early 2000s and identify three major patterns of the productivity growth slowdown across our sample of countries: low "numerator" (value added) growth accompanied by robust "denominator" (hours worked) growth, creating a job-rich but productivity-weak recovery across most countries; too few and too small "jumping" sectors; and the critical importance of declining capital intensity growth across countries. These patterns indicate that the productivity-

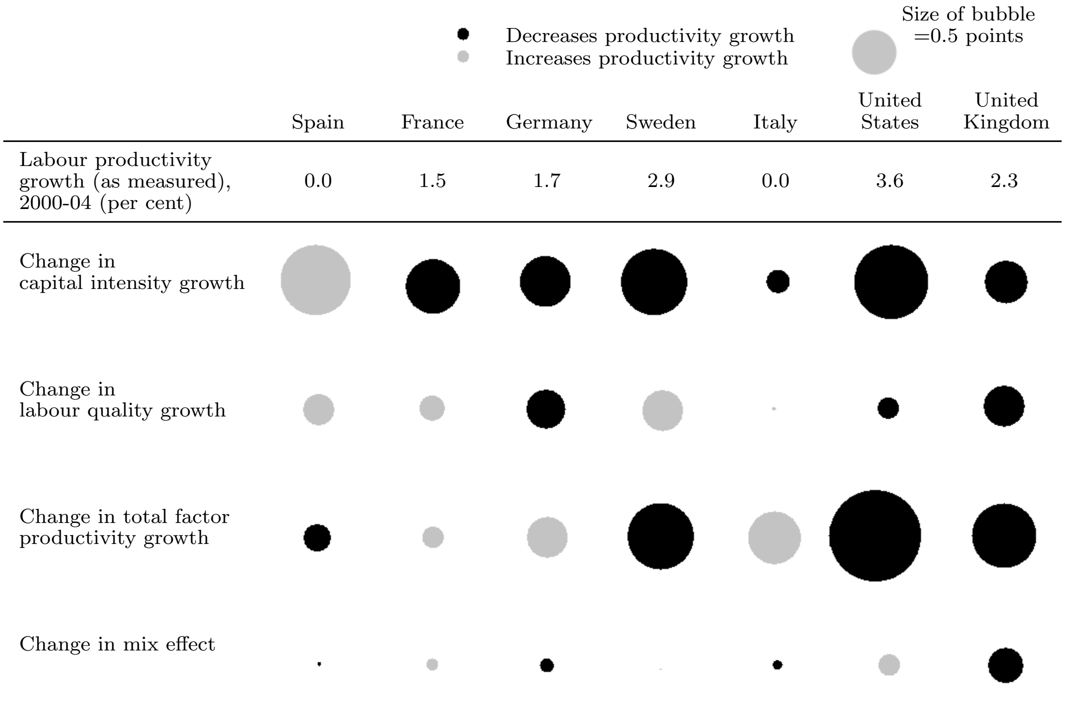
9 A sector is classified as "jumping" in year Y if its compound annual growth rate of productivity for years Y-3 through Y is at least three percentage points higher than it was for 1995 to 2014 as a whole (a "long-term" average).

10 Similar trends are also seen in Europe. Less than 5 per cent of sectors in France, Germany, Sweden, and the United Kingdom are classified as jumping today. See Chapter 2 of Remes *et al.* (2018) for more details.

11 We acknowledge that this analysis represents a decomposition and is not a causal analysis and is sensitive to the underlying growth accounting formulation. The choice of time periods reflects both the specific trends we want to highlight and constraints from data availability. Comparing the productivity growth in the 2000 to 2004 period with the recent slowdown (2010 to 2014 period) allows us to identify short-term factors behind the productivity-growth slowdown that are likely to be resolved, helping to determine the potential for productivity growth in the future. We were also constrained by a longer-term comparison due to data availability issues across countries in EU KLEMS. For further details, see the technical appendix of Remes *et al.* (2018). Other researchers have also found large contributions from capital intensity growth and total factor productivity growth in the United States, for example Murray (2017).

**Chart 2: A Growth Accounting Perspectives on the Labour Productivity Slowdown in Seven Advanced Economies – Contribution to the Change in Labour Productivity Growth, 2000-04 Versus 2010-14 (percentage points per year)**

| | Spain | France | Germany | Sweden | Italy | United States | United Kingdom |
|---|---|---|---|---|---|---|---|
| Labour productivity growth (as measured), 2000-04 (per cent) | 0.0 | 1.5 | 1.7 | 2.9 | 0.0 | 3.6 | 2.3 |




| | Spain | France | Germany | Sweden | Italy | United States | United Kingdom |
|---|---|---|---|---|---|---|---|
| Labour productivity growth (as measured), 2010-14 (per cent) | 1.4 | 1.0 | 0.9 | 0.9 | 0.6 | -0.2 | -0.2 |

1 See technical appendix in Remes *et al.* (2018) for details on methodology.
2 EU KLEMS data on total factor productivity (TFP) was significantly different compared with other data sources such as The Conference Board and Penn World Tables. Hence, we take the average TFP of the three databases and calculate labour quality as a residual.
3 In Italy, the period analyzed is 2010-13 instead of 2010-14 due to data limitations.
4 US data are for the private business sector only. Europe data are for total economy.
NOTE: Order of countries based on fastest to slowest productivity growth in 2010-14.

SOURCE: EU KLEMS (2016 release); BLS Multifactor Productivity database (2016 release); McKinsey Global Institute analysis.

growth slowdown is broad-based across countries and sectors, point to a set of common, overarching factors at work, and reveal the importance of demand-side as well as supply-side factors.

While we find many similar patterns of the productivity-growth slowdown across our sample of countries, there are also notable differences. Sweden and the United States experienced a strong productivity boom in the mid-1990s and early-2000s followed by the largest productivity-growth decline, and much of that decline predated the financial crisis. France and Germany started from more moderate levels and experienced less of a productivity-growth decline, with most of the decline occurring after the crisis. Productivity growth was close to zero in Italy and Spain for some time well before the crisis, so severe labour shedding after the crisis actually accelerated productivity growth, as seen in Chart 2.

While many key economic variables such as GDP growth and investment as

**Chart 3: Long-term Trends in Labour Productivity Growth in the United States and Europe**


[1] Simple unweighted average of France, Germany, Italy, Spain, Sweden and the United Kingdom.
Note: Productivity defined as GDP per hour worked. Calculating using Hodrick Prescott filter. Drawn from similar analysis in Baily and Montalbano (2016).
Source: Bergeaud *et al.* (2016).

a share of GDP, as well as productivity growth, have started to pick up recently in the United States and Europe, productivity growth remains low relative to historical rates, with many countries in our sample seeing around 1 per cent per year productivity growth or less.

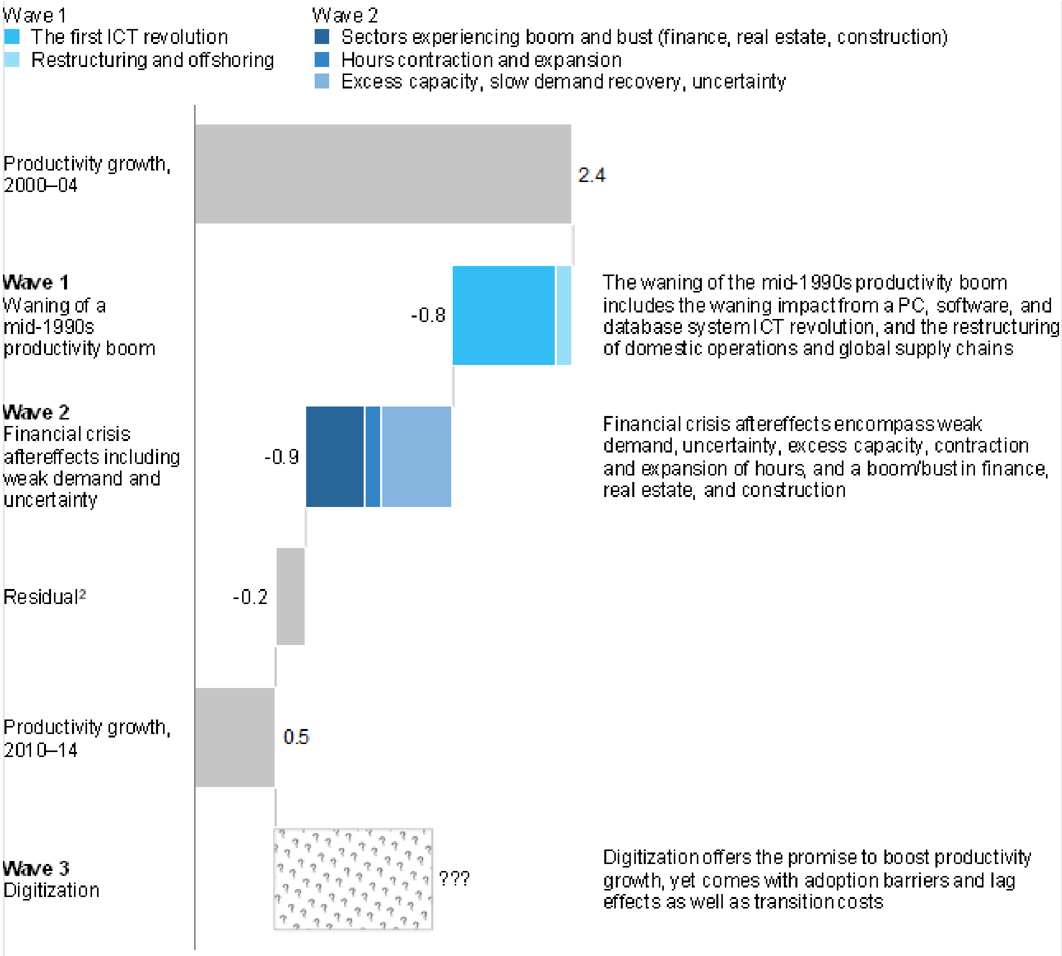
## Productivity Developments: A Detailed Analysis of the Three Waves

This section of the article provides a detailed discussion of productivity developments in seven advanced economies using the MGI methodology outlined earlier, which has identified three productivity wavers or drivers. Chart 4 shows that the first two waves have dragged down productivity growth by 1.9 percentage points on average across countries since the mid-2000s:

The waning of a boom that began in the 1990s with the first information and communications technology (ICT) revolution, and a subsequent phase of restructuring and offshoring, which reduced productivity growth by about one percentage point. Financial crisis aftereffects, including weak demand and uncertainty, reduced it by another percentage point. A third wave, digitization, contains the promise of significant productivity-boosting opportunities but the benefits have not yet materialized at scale. This is due to adoption barriers and lag effects as well as transition costs; the net effect on productivity in the short term is unclear. We do not attempt to quantify the impact of digitization. Today we find that companies are allocating substantial time and resources to changes and innovations that do not yet have a direct and immediate impact on output and productivity growth.

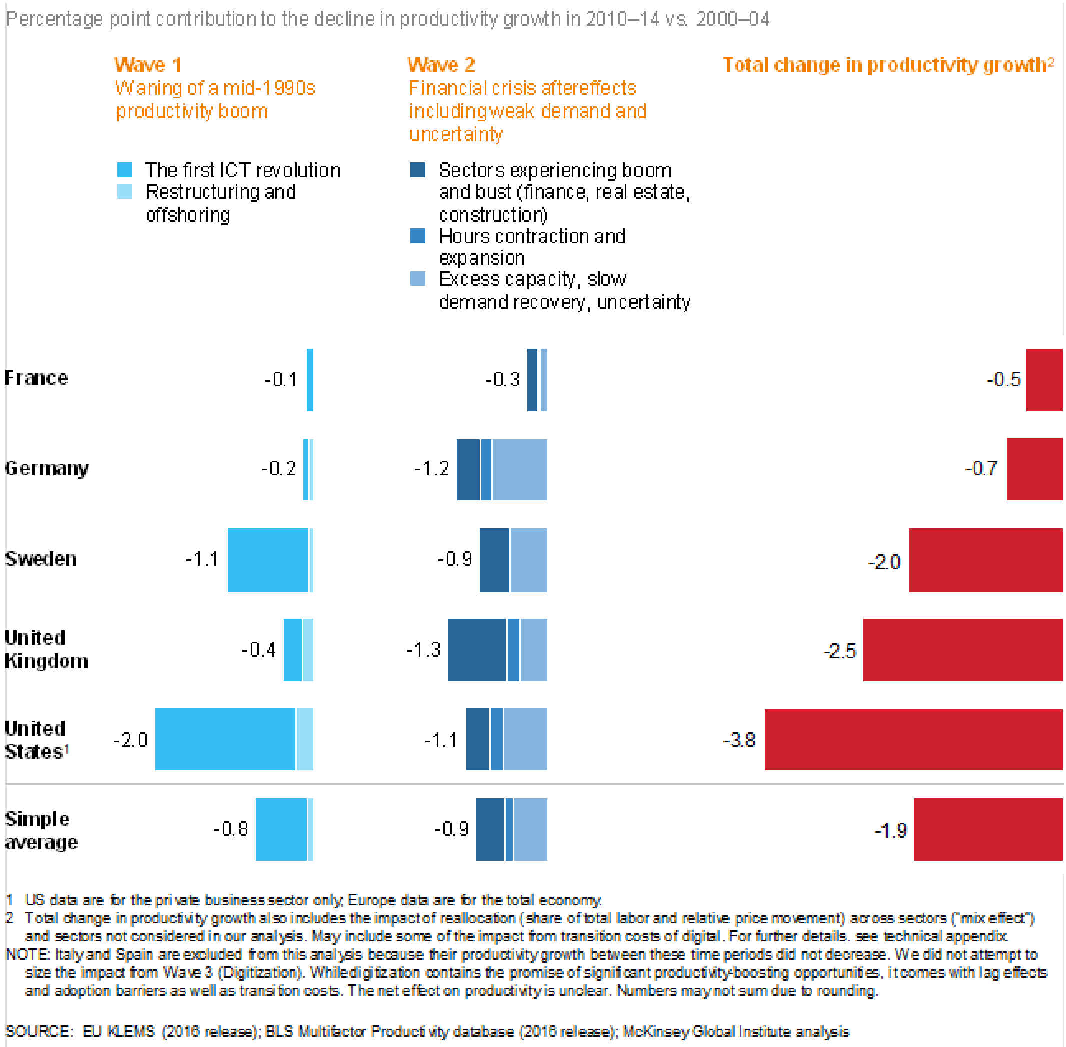
The importance of these waves was not equal across countries (Chart 5).

Chart 4: **The Impact of the Three Waves on Productivity Growth in Seven Advanced Economies (contribution to the decline in productivity growth in 2010-14 vs. 2000-04[1])**




1 US data are for the private business sector only. Europe data are for the total economy.
2 Includes impact of reallocation (share of total labour and relative price movement) across sectors ("mixed effect") and sectors not considered in our analysis. May include some of the impact from tarnsition costs of digital. For further details, see technical appendix.
NOTE: Italy and Spain are excluded from this analysis because their productivity growth between these time periods did not decrease. We did not attempt to size the impact of Wave 3 (Digitalization). While digitalization contains the promise of significant productivity-boosting opportunities, it comes with lag effects and adoption barriers as well as transition costs. The net effect on productivity is unclear. Numbers may not sum due to rounding.
Source: EU KLEMS (2016 release); BLS Multifactor Productivity database (2016 release); McKinsey Global Institute analysis.

**Chart 5: Productivity by Country (percentage point contribution to the decline in productivity growth in 2010-14 vs. 2000-04)**




The first wave mattered more in Sweden and the United States, where the productivity boom had been more pronounced, while financial crisis aftereffects were felt more broadly across countries.[12]

## The First Wave: Waning of the ICT Revolution and Restructuring and Offshoring

An initial ICT-enabled productivity boom, starting in the second half of the 1990s, was particularly strong in Sweden and the United States. The productivity boom in the ICT sector itself reflected a wave of rapid innovation in semiconductor design and manufacturing processes that raised productivity in the sector significantly and translated into higher-quality and higher-value prod-

12 For an overview of the methodology used to conduct this sizing, see technical appendix of Remes *et al.* (2018). This analysis ends at 2014 due to lack of data availability across countries after that date. Note that this analysis is based on sector-level data. Firm-level trends can also play a role in influencing productivity growth.

ucts of downstream computer equipment producers. It also benefited sectors like retail, as large-format retailers like Walmart used technology to transform supply chains and the rest of the industry followed (McKinsey Global Institute, 2002).

The global industry restructuring following the 2001 tech downturn helped sustain productivity gains across manufacturing as production shifted to Asia and nearshore assembly locations in Mexico and Eastern Europe, and manufacturing production employment declined in the United States and Western Europe. In addition, rapid declines in ICT equipment prices encouraged an investment boom in other sectors such as professional and business services, as well as strong growth in the ICT services and software sector and boosted productivity growth as these industries integrated new technology into their business processes and systems.

By the mid-2000s, the productivity-growth benefits from that first wave of ICT innovation had matured. The retail and wholesale supply chain revolution had largely run its course. Productivity growth in the tech sector itself declined by roughly 14 per centage points in the United States from 2000-04 to 2010-14. The composition of the tech industry had shifted toward skilled, labour-intensive, less scalable software services. And tech manufacturing became more fragmented and innovation more complex as the proliferation of electronic devices and applications broadened the demands on performance beyond just processor speed.[13]

For example, the shift in demand toward smartphones requires managing sometimes dozens of sensors from fingerprint recognition and GPS to multiple cameras, all requiring efficient power consumption to save battery time. Virtual world gaming, artificial intelligence, and autonomous driving have dramatically expanded the performance demands on Graphics Processor Units (GPUs). The breadth and depth of innovation is vast, making it harder both to accurately measure improvements and to achieve past pace of improvements given the scale in many specialized chips is lower and cost declines slower.[14]

At the same time, the productivity gains from globalization and offshoring as well as efficiency gains from restructuring post-2001 were plateauing. While we found this trend had a smaller impact on productivity growth across countries than the waning of the ICT-enabled boom, it did affect certain sectors. In the auto sector in the United States, the productivity improvements from restructuring and job declines after the 2001 downturn and of regional footprint optimization across NAFTA tapered off by the

13 Some researchers also question whether Moore's law still holds or takes more effort. See, for example, Flamm (2017); Bloom *et al.* (2017); and McKinsey & Company (2013).

14 Other research has also pointed to the importance of the waning of this first ICT-enabled boom. See, for example, Fernald and Wang (2015). Others have questioned whether mismeasurement could explain the productivity-growth decline, given the exceptionally thorny challenges of measuring output of rapidly changing tech industries. For a good overview, see Byrne, Oliner and Sichel (2017).

mid-2000s. In Germany, regional offshoring to Eastern European countries continues today.

## The Second Wave: Financial Crisis Aftereffects Including Weak Demand and Heightened Uncertainty

Demand for goods and services across countries and industries dropped sharply during the financial crisis as employees lost jobs, income contracted, and the credit impulse reversed.[15] For example, in the United States, light-vehicle production fell by 47 per cent between 2007 and 2009,[16] while in retail demand growth slowed by roughly 1 percentage point compared with the pre-crisis period (data from BLS). This fall in demand for goods and services resulted in significant excess capacity and a pullback of investment. At the same time, in many countries, companies reacted to the demand shock by cutting hours worked, particularly in sectors like manufacturing, retail, finance, and construction. The contraction of hours was so dramatic in the United States that it briefly increased productivity growth in 2009 and 2010.

By the end of 2009, the crisis reached a turning point, with GDP levels bottoming out in the United States. However, the depth of the crisis, deleveraging by households and corporations, weak animal spirits, and structural demand drags such as rising inequality and the declining labour share of income resulted in a prolonged recovery that by some measures continues today.

A combination of factors in this slow recovery period created a dynamic of declining productivity growth: a slow increase in demand, excess capacity, and economic, political, and regulatory uncertainty, all in an environment of low wage growth. This cocktail contributed to the trend of weak growth in productive capital coupled with a rebound in hours worked growth. The decline in the growth rate of capital intensity, the lowest in the postwar period, reflects a substantial decline in equipment and structures investment during the crisis with a slow recovery while intangible investment, such as R&D and software, recovered more quickly after a brief and smaller dip in 2009.[17]

As hours worked had significantly contracted during the crisis and capacity was underutilized, companies met slowly rising demand by filling excess capacity and adding hours. For example, in the auto sector in the United States, growth in hours worked surged after 2010, but total hours still remained below pre-crisis levels in 2015 (based on data from the BLS).

Across the economy, once capacity utilization picked up, a reason for continued weak investment was the persis-

15 The credit impulse is measured as acceleration or deceleration in debt-to-GDP ratios and thus indicative of the role of borrowing in impacting demand. See, for example, Biggs and Mayer (2013).

16 Data from IHS Markit, 2017 for light-vehicle production.

17 Companies typically see R&D investment as longer term. In many industries with a rapid pace of technological change, competitive pressure kept investment a priority for companies.

tent slow recovery in demand. Normalizing capital-to-output ratios across countries indicates that the investment recovery kept pace with the recovery in demand, but since demand growth was weak, capital services growth also remained weak.[18]

Slow wage growth dampened the need to substitute capital for labour. Low wages in retail in the United States, for example, seem consistent with comparatively slow investment in technologies like automated checkouts and redeploying freed-up resources in low-productivity occupations like greeters.[19] In addition, stagnant wages had implications for limiting demand growth. In our sector analysis, we found weak demand dampened productivity growth through other channels than investment (Box 1).

The slow recovery, together with political and regulatory uncertainty in the aftermath of the crisis, may be continuing to restrain investment today.[20] There is debate around how far the recovery has progressed. For instance, while we have witnessed an extended period of job growth, employment rates are still well below pre-crisis levels in some countries, notably the United States, where the unemployment rate is around historic lows but labour force participation has not fully recovered.[21] Household investment remains subdued, and business investment as a share of GDP has only slowly recovered to rates seen before the crisis, and has still not fully recovered in parts of Europe. Real investment in structures and equipment remains below trend lines in many countries. Indeed, the latest economic data highlight the fact that capital intensity growth remains noticeably weak across countries.

Demand and uncertainty are key drivers of these trends. We have found from our global surveys of business that 47 per cent of companies that are increasing their investment budgets are doing so because of an increase in demand, yet 38 per cent of respondents say risk aversion is the key reason for not investing in all attractive opportunities (McKinsey Quarterly Survey, March 2017).

## The Third Wave: The Missing Benefit of Digitalization

The first wave of ICT investment starting in the mid-1990s was mostly

18 For other explanations of the slowdown, see IMF (2015), Adler *et al.* (2017), ECB (2016), Erber, Fritsche and Harms (2017), Anzoategui *et al.* (2016), Borio (2017), and van Ark and Jäger (2017).

19 See, for example, Vanderzeil, Currier and Shavel (2017). For a review of findings related to the role of minimum wages on employment, see Neumark (2014). Interestingly, even when retailers are investing in automation, they have tended to move existing workers to other jobs such as food service to keep store service levels up and improve customer engagement.

20 For a measure of uncertainty, see the Economic Policy Uncertainty Index (2018) and Baker, Bloom and Davis (2016). Research has also shown that long-run uncertainty, which is influenced by policy uncertainty, influences both investment and hiring, but the former is more affected than the latter. This is due to lower depreciation rates and higher adjustment costs of investment relative to hiring. See Barrero, Bloom and Wright (2017).

21 One reason why the aggregate participation rate is still below its pre-recession peak is the aging of the population (Yagan, 2017).

**Box 1: The Dampening Effect of Week Demand on Productivity During the Recovery**

> We identify two channels by which weak demand hurt productivity growth during the recovery in addition to holding back investment, namely economies of scale and the shape of demand, and subsector mix effect:
>
> In finance, productivity growth declined, particularly in Spain, the United Kingdom, and the United States, due to contractions in lending volumes that banks were unable to fully offset with staff cuts due to the need for fixed labour (for example, to support branch networks and IT infrastructure). The utilities sector, which has seen flattening demand growth due to energy efficiency policies, as well as a decline in economic activity during the crisis, was similarly not able to downsize labour due to the need to support electricity distribution and the grid infrastructure.
>
> Consumer preferences boosted productivity growth in both the auto and retail sectors from the mid-1990s to the mid-2000s through a shift to higher value-per-unit, more productive goods. Today that trend has slowed. The German and US auto sectors have experienced a trend of customers purchasing higher-value-added SUVs and premium vehicles. This boosted productivity growth by 0.4 to 0.5 percentage point in the auto sector in the early 2000s. That trend has slowed slightly in both countries, contributing only 0.3 percentage point to productivity growth in 2010-14. Similarly, in retail, we estimate that consumers shifting to higher-value goods, for example higher-value wines or premium yogurts, contributed 45 per cent to the 1995-2000 retail productivity-growth increase in the United States. This subsequently waned, dragging down productivity growth.

from using technology to deliver supply-chain, back-office, and later front-office efficiencies. Today we are experiencing a new way of digitization that comes with a more fundamental transformation of entire business models and end-to-end operations. We may be experiencing a renewal of the Solow Paradox of the 1980s, with the digital age around us but not yet visible in the productivity statistics.

There are several reasons that the impact of digital is not yet evident in the productivity numbers. These include lag effects from technological and business readiness to reaching adoption at scale; costs associated with the absorption of management's time and focus on digital transformation; and transition costs and revenue losses for incumbents that can negatively impact sector productivity during the transition. The net impact today of digitization is unclear.[22]

On the lag effects, we have found that digitization has not yet reached scale, with a majority of the economy still not digitized. MGI has calculated that Europe overall operates at only 12 per

22 See also Bughin and van Zeebroeck (2017) and Brynjolfsson, Rock and Syverson (2017).

23 Potential is defined by comparing each sector against a frontier sector defined as the US ICT sector. This analysis uses a set of 18 metrics of digitization spanning assets, usage, and labour. Our use of the term "digitization" and our measurement of it encompasses: the digitization of assets, including infrastructure, connected machines, data, and data platforms; the digitization of operations, including processes, payment and business models, and customer and supply-chain interactions; and the digitization of the workforce, including worker

cent of digital potential, and the United States at 18 per cent, with large sectors lagging in both.[23] While the ICT, media, financial services, and professional services sectors are rapidly digitizing, other sectors such as education, health care, and construction are not. We also see the lack of scale in our sector deep dives. In retail, for example, we found that the growing share of sales taking place online in the United States added roughly 0.5 percentage point to productivity growth in the sector per year in the 2010-2014 period, as those forms of retail are more productive than traditional forms yet those sales are about 10 per cent of retail volume.[24]

History shows that technological diffusion takes time and comes with barriers to adoption.[25] An MGI review of the historical rate of adoption of 25 technologies over the past half century shows that the time from commercial availability to 90 per cent adoption ranges from approximately eight to 28 years.[26] This was demonstrated by the first Solow Paradox of the mid-1970s and 1980s, for example, and the ICT boom in the 1990s. Productivity growth in the United States slowed in the former period, despite innovations at the time in the area of microelectronics and communications technology (David, 1989). Productivity gains were not automatic and did not occur in all industries that invested heavily in ICT. Instead, productivity gains required significant changes in business process, as well as managerial and technical innovation (McKinsey Global Institute, 2002).

The challenge of adoption in the current digital wave may be even harder because of the broad range of uses of digital that not only help improve current processes but fundamentally transform business models and operations. For example, in retail, the first ICT revolution was focused on getting the right goods to the right place at the right time. With digitization, the transition to online requires building a new channel with a new supply-chain structure to deliver goods directly to customers and determining what combination of stores and online presence is optimal. Digital also requires significant up-front investment and new skills in data analysis; our survey shows fear of technological obsolescence as well as gaps in digital technical and organizational capabilities as barriers. The current wave of digitization also requires customers

use of digital tools, digitally skilled workers, and new digital jobs and roles (McKinsey Global Institute, 2015).

24 Impact on retail productivity growth calculated based on the mix shift between online and offline retail, assuming today's level of relative productivity between the two segments. Based on data from Euromonitor International, Retailing data (2018 edition) and S&P Capital IQ.

25 See Jovanovic and Rousseau (2005). Take the advent of steam power, for example. Productivity growth was quite rapid, at 2 to 3 per cent, when steam power was introduced around 1870 but fell with the arrival of electrification in the 1890s, to 1 to 2 per cent in the United States. It was only in the period after 1915, which saw the diffusion of machines operated by stand-alone secondary motors and the widespread establishment of centralized power grids, that electricity finally pervaded businesses and households, and productivity growth began to rise. Then productivity growth rose to 3 per cent. See also David (1989).

26 See McKinsey Global Institute (2017). See also Comin and Hobijn (2010).

**Chart 6: A Diagnostic of the Productivity Growth Slowdown in Seven Advanced Economies**

Percentage points

Low or no effect · Moderate effect · Large effect

Decline in productivity growth

| | | United States | United Kingdom | Sweden | Germany | France | Italy | Spain |
|---|---|---|---|---|---|---|---|---|
| Decline in productivity growth[2] | | -3.8[1] | -2.5 | -2.0 | -0.7 | -0.5 | 0.6 | 1.4 |
| Low "numerator" (value added) growth[3] | | -1.2 | -0.8 | -0.1 | 0.1 | -1.3 | -2.2 | -3.2 |
| High "denominator" (hours worked) growth[3] | | 0.4 | 1.1 | 1.1 | 1.4 | -0.2 | -0.9 | -3.2 |
| Few jumping sectors[4] | | -46[1] | -30 | -28 | -7 | -14 | 0 | 10 |
| Broad-based productivity-growth decline across sectors[5] | | 88[1] | 87 | 83 | 67 | 70 | 34 | 50 |
| Contribution of factors in growth accounting decomposition[2] | Capital intensity | -1.5[1] | -0.5 | -1.2 | -0.7 | -0.9 | -0.2 | 1.4 |
| | Labor quality | -0.2[1] | -0.5 | 0.5 | -0.4 | 0.2 | 0.0 | 0.3 |
| | Total factor productivity | -2.3[1] | -1.2 | -1.2 | 0.5 | 0.2 | 0.8 | -0.2 |
| | Sector mix shift | 0.2[1] | -0.4 | 0.0 | -0.1 | 0.1 | 0.0 | 0.0 |
| Impact of waves on productivity growth[2] | Waning of a mid-1990s productivity boom | -2.0[1] | -0.4 | -1.1 | -0.2 | -0.1 | n/a | n/a |
| | Financial crisis aftereffects | -1.1[1] | -1.3 | -0.9 | -1.2 | -0.3 | n/a | n/a |
| Top sectors contributing to the decline in productivity growth | Arts, entertainment, and other services | | | | | ● | | |
| | Construction | | | ● | | | | |
| | Finance and insurance | | ● | | | | | |
| | Information/communication services | ● | ● | | | ● | | |
| | Manufacturing | ● | ● | ● | ● | ● | | |
| | Real estate | | | | ● | | | |
| | Retail and wholesale | ● | | ● | | | | |
| | Transportation and storage | | | | ● | | | |

1 US data are for the private business sector only; Europe data are for the total economy.
2 2010–14 vs. 2000–04.
3 2010–16 vs. long-term (1985–2005).
4 Share of jumping sectors, 2014 vs. 2004.
5 Share of sectors with lower productivity growth in 2010–14 vs. 2000–04.
NOTE: Numbers may not sum due to rounding.

SOURCE: McKinsey Global Institute analysis to embrace developments such as mobile banking, online shopping, autonomous driving, and resolving questions with a bot. Finally, some incumbents have reasons to actively delay adoption, whether for fear of cannibalization or, in some cases, the challenges of large-scale transformations.

While new digital entrants as well as fast-moving incumbents may increase profits and productivity, others can experience a transition that impedes productivity. As they lose revenue to disrupters and their growing digital arms cannibalize revenues further, some companies may end up with duplicate structures and processes, and underutilized capacity in their traditional operations. For example, in retail, when firms increase their online presence and stores or entire malls suffer declining footfall, that cannot readily be remedied.[27] In a recent survey we conducted, companies with digital transformations under way said that 17 per cent of their market share from core products or services was cannibalized by their own digital products or services (McKinsey & Company, 2017). Industry productivity benefits will then materialize mostly as incumbent businesses restructure or exit, and adoption costs are outweighed by benefits as digitization reaches scale.

Chart 6 provides estimates of the impact of the first two waves on the slowdown in productivity growth between 2000-2004 and 2010-2014 for seven advanced economies. It also provides estimates of the sources of the labour productivity slowdown from a traditional growth accounting perspective (capital intensity, labour quality, and total factor productivity) and identifies the section most important in contributing to the decline in productivity growth.

We find three broadly similar groups of countries: Sweden, the United Kingdom, and the United States, which have experienced the largest productivity-growth decline in our sample; France and Germany, which experienced a less dramatic drop in productivity growth but a continuing long-term decline; and Italy and Spain, with no decline. These variations are mainly associated with the strength of the boom prior to the financial crisis, the extent of the crisis itself, and differences in labour market flexibility.

## A Sector View on the Productivity Slowdown

Our sector analysis provides an alternative lens to examine the macro trend of declining productivity growth. We find the three waves played out in different ways and to different degrees across sectors (Chart 7). Few sectors illustrate how this perfect storm impacted productivity growth across countries as well as the retail sector. By the time the crisis hit in 2007, the retail sector was at the tail end of a productivity boom that began around 1995. Then weak demand

27 See also Bughin and van Zeebroeck (2017); Bughin, LaBerge and Mellbye (2017); and Bughin and van Zeebroeck (2017).

**Chart 7: The Impact of the Three Waves of Productivity Drivers for Six Sectors**

Contribution to overall productivity growth slowdown (%)[1]

**Productivity growth** Compound annual growth rate (%) — 2000–04, 2010–14

| | | 2000–04 | 2010–14 | | |
|---|---|---|---|---|---|
| **Automotive**[2] | 4 | 3.9 | 2.0 | Wave 1 | ▪ Benefits of US restructuring post-2001 and NAFTA-wide footprint optimization waned |
| | | | | Wave 2 | ▪ Excess capacity and low profits as demand dropped, slowing investment in equipment and structures (not R&D); slow demand recovery was met with hours expansion<br>▪ About 0.2 percentage point productivity drag from slower shift to higher-value vehicles |
| | | | | Wave 3 | ▪ Investment in digital currently under way (autonomous vehicles, connectivity, electric vehicles, industry 4.0) but still subscale; highly or fully autonomous cars not yet commercially available but could represent up to 15% of sales by 2030 |
| **Finance**[2,3] | 18 | 1.8 | 0.9 | Wave 1 | ▪ n/a |
| | | | | Wave 2 | ▪ Slow growth in lending/deposit volumes due to deleveraging, weak credit demand, stricter regulation, together with difficulty streamlining fixed labor<br>▪ Regulatory changes, settlements dampened value-added growth and occupied management attention |
| | | | | Wave 3 | ▪ Digitization, fintech are reshaping front and back end of banks, yet transformation takes time<br>▪ Potential to boost productivity from online and automation (e.g., up to 60% of total costs of retail and commercial banking could benefit from automation and shift to online banking)<br>▪ Strong customer willingness to move to digital products (e.g., only about 13% of North American customers obtain an account online but 56% are willing to do so) |
| **Retail**[2,4] | 17 | 2.9 | 1.9 | Wave 1 | ▪ Benefits from ICT-enabled supply-chain efficiencies and business process transformations reached saturation |
| | | | | Wave 2 | ▪ Weak demand reduced sales growth (by ~3 percentage points on average) without easy options to scale down labor<br>▪ Shift to higher value-per-unit goods waned, dragged down productivity growth<br>▪ Low wages limited automation (e.g., checkouts) and allowed redeployment into low-value tasks (meeter-greeter) |
| | | | | Wave 3 | ▪ Online is twice as productive as offline yet makes up only ~10% of total retail<br>▪ Shift to online involves transition costs (e.g., revenue loss for incumbents' stores) |
| **Technology**[2] | 18 | 6.5 | 1.7 | Wave 1 | ▪ Mobile and graphics use broadened performance requirements and added complexity without Moore's law improvement dynamics<br>▪ Benefits from restructuring and manufacturing offshoring after 2001 waned |
| | | | | Wave 2 | ▪ n/a |
| | | | | Wave 3 | ▪ Rapid innovations and performance improvements across broad range of industries, devices, applications (e.g., virtual reality, autonomous/electric vehicles, crypto-currencies)<br>▪ Continued growth of software and services (e.g., cloud services) with robust productivity growth, including driven by AI and machine learning (a growing measurement challenge across broadening performance dimensions) |
| **Tourism** | n/a | 0.7 | 0.7 | | The exception, with slow but sustained productivity growth from industry restructuring and consolidation (airlines and hotels), early introduction of digital (e.g., online transactions), and new business models (Airbnb, TripAdvisor); helped by robust yet at times volatile demand |
| **Utilities**[2] | 15 | 4.4 | -1.4 | Wave 1 | ▪ Efficiency gains from increasing competition after liberalization in the 1990s/2000s in electricity generation and retail subsectors waned along with incentives for the transmission and distribution subsector to drive efficiency, e.g., performance-based ratings schemes |
| | | | | Wave 2 | ▪ Energy efficiency efforts and the financial crisis eroded electricity demand (e.g., demand growth declined by ~3.5 percentage points in Europe between 2000–04 vs. 2010–14), while labor in transmission and distribution (60% of employment) could not be streamlined |
| | | | | Wave 3 | ▪ Smart meters and grids, digital productivity tools for employees, and automation of back-office processes could boost profitability by as much as 20 to 30%; however, investments are still subscale and come with a learning curve<br>▪ Solar and wind technologies have higher labor productivity but legacy plants cannot yet be decommissioned, resulting in transition costs and revenue losses |

1 Productivity-growth data in the bar charts are the simple average of all seven countries in our sample. However, the contribution to the overall productivity-growth slowdown is the simple average of only those countries in which the sector contributed to a slowdown (vs. an increase) in productivity growth. The contribution cannot be added up across sectors since the sample of countries varies by sector. For an overview of the sector codes used for each sector, please see sector infographics in Chapter 4.
2 US data are for the private business sector only; Europe data are for the total economy.
3 These data include both finance and insurance due to data availability issues across countries.
4 These data include both retail and wholesale trade due to data availability issues across countries.

SOURCE: BLS Multifactor Productivity database (2016 release); Eurostat (June 2017 release); EU KLEMS (2016 release); WTTC; McKinsey Global Institute analysis resulting from the financial crisis and recovery made matters worse in two ways: through an overall reduction in sales without a corresponding reduction in labour, and a switch to lower value-per-unit products and brands. As demand began to recover and wages across countries remained low, retailers hired more than they invested. In the middle of this slow recovery and challenging demand environment, the rise of Amazon and the wave of digital disruption occurring in the retail industry added about 0.5 percentage point per year to productivity growth from the shift to more productive online channels, accompanied by transition costs, duplicate structures, and drags on footfall in traditional stores.[28]

The tourism sector provides a counterexample. It shows how productivity growth has been slow but steady across many countries from the incorporation of new technology, new business models, increasing consolidation, new competitors, and growing demand.

As financial crisis aftereffects continue to dissipate, we expect productivity growth to recover from current lows across sectors and countries. Our sector deep dives reveal significant potential to boost productivity growth both from a continuation of more typical productivity opportunities such as operational efficiency gains and from new avenues enabled by digital technologies. Digital automation is just one channel in which digitization will impact productivity growth; digital flows and platforms can also accelerate globalization and global competition, and digital features can substantially increase customer value (McKinsey Global Institute, 2014). Over all, we estimate that the productivity-boosting opportunities could be at least 2 per cent on average per year over the next ten years, with 60 per cent coming from digital opportunities.[29] While low productivity growth of today may lead to concern about the future, research indicates that past productivity performance is a poor indicator of future productivity growth (Brynjolfsson, Rock and Syverson, 2017).

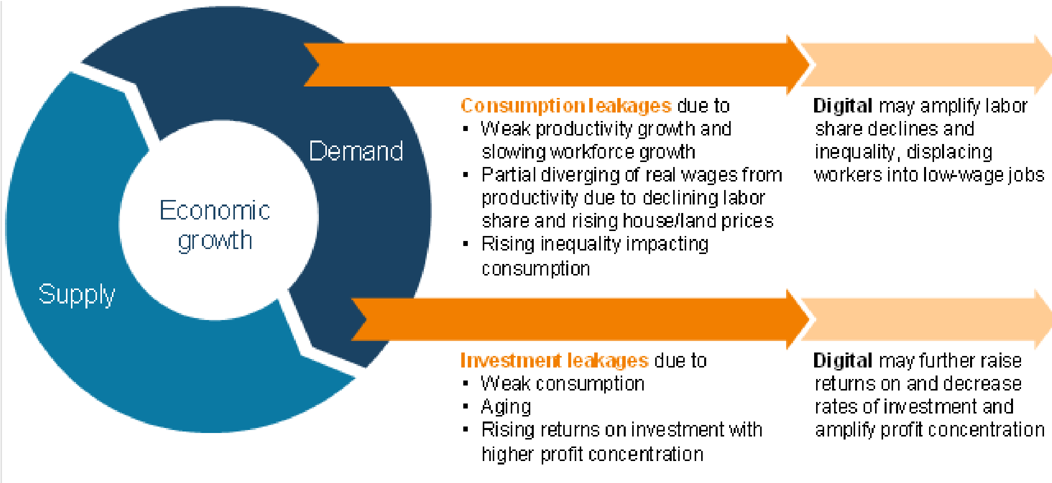
## Capturing the Productivity Potential: Promoting Both Demand and Digital Diffusion

There is no guarantee that the productivity-growth potential we identify will be realized without taking action. While we expect financial crisis-related drags to dissipate, long-term drags may continue, such as a rise in the share of low-productivity jobs and slack-

28 Impact calculated based on the mix shift between online and offline retail, assuming today's level of relative productivity between the two segments. Based on data from Euromonitor International, Retailing data (2018 edition) and S&P Capital IQ.

29 Our estimate for the productivity-growth potential builds on extensive past MGI research on sector opportunities for improving productivity through technologies that are already implemented today or have a clear path to deployment at scale by 2025. These include benefits from digitization (e.g., big data, Internet of Things, automation, AI) as well as non-digital opportunities such as mix shifts in products and channels, continued consolidation, etc. See McKinsey Global Institute (2015a); McKinsey Global Institute (2015b); McKinsey Global Institute (2016); and McKinsey Global Institute (2017). See the technical appendix of Remes *et al.* for more details.

**Chart 8: Long-term Demand Leakages and Links to Productivity Growth**




SOURCE: McKinsey Global Institute analysis

ening demand for goods and services due to changing demographics and rising income inequality; all of these factors may be further amplified by digitization. At the same time, the nature of digital technologies could fundamentally reshape industry structures and economics in a way that could create new obstacles to productivity growth.

## The Amplification of Demand Drags and the Potential Industry-Breaking Effects of Digital

While weak demand hurt productivity growth in the aftermath of the financial crisis, looking ahead, there is concern that some demand drags may be more structural than purely crisis-related. There are several "leakages" along the virtuous cycle of growth (Chart 8). Broad-based income growth has diverged from productivity growth, because the declining labour share of income and rising inequality are eroding median wage growth, and the rapidly rising costs of housing and education exert a dampening effect on consumer purchasing power.[30]

It appears increasingly difficult to make up for weak consumer spending via higher investment, as that very investment is influenced first and foremost by demand, and rising returns on investment discourage investment relative to earnings. Demographic trends may further diminish investment needs through an aging population that has less need for residential and infrastructure investment. These demand drags are occurring while interest rates are hovering near the zero lower bound. All of this may hold back the pace at which capital per worker increases, affect company incentives to innovate, and thus impact productivity growth, slowing down the virtuous cycle of growth.

Digitization may further amplify those leakages, for example as automa-

30 See Chapter 5 of Remes *et al.* (2018) for a more detailed discussion of the declining labour share of income.

tion may compress labour's share of income and increase income inequality by hollowing out middle-class jobs and may polarize the labour market into "superstars" vs. the rest. It may also raise returns on investment and thus reduce rates of investment. Cannibalization of incumbent revenues puts pressure on nominal demand. And the rate of technological labour displacement is set to rise. Unless displaced labour can find new highly productive and high-wage occupations, workers may end up in low-wage jobs that create a drag on productivity growth (Landesmann and Stehrer, 2004 and McKinsey Global Institute, 2017). Our ability to create new jobs and skill workers will impact prospects for income, demand, and productivity growth.

Digital technologies may also dampen their own productivity promise through other channels. Various digital technologies are characterized by large network effects, large fixed costs, and close to zero marginal costs. This leads to a winner-take-most dynamic in industries reliant on such technologies and may result in a rise in market power that can skew supply chains and lower incentives to raise productivity. For example, some digital platforms benefit from a growing user base, as social networks with more users allow for more connections, while larger pools of search data generate better and more targeted results. While the potential economic costs and approaches to regulation of network industries are well established, the nature of digital platforms is sufficiently different to warrant further policy consideration.

Independent of platform economies, rising corporate concentration throughout the economy may reduce competitive pressure and translate into weaker incentives to innovate and invest in raising productivity. While the empirical evidence suggests that the link between concentration and either competitive intensity or productivity growth may not be a strong one, this is another often-cited concern today (Furman and Orszag, 2015, and Gutirrez and Philippon, 2017). Importantly, in our sector deep dives, we have found no evidence that rising business concentration has hurt productivity growth so far. However, going forward, that may not be the case. There may be a tipping point where the initial benefits from industry consolidation, from factors such as economies of scale and reducing the need for staff, and from restructuring operations may give way to costs as competitive pressure declines with the rise of market power. Rising corporate concentration could also further increase income inequality and compress labour's share of income.

New digitally enabled business models can also have dramatically different cost structures that change the economics of industry supply significantly and raise questions about whether the majority of companies in the industry and the tail will follow the frontier as much as in the past. For example, in retail, productivity growth in the late 1990s and early 2000s was driven by Tier 2 and 3 retailers replicating the best practices of frontier firms like Walmart. Today, it is unclear if many of Amazon's practices can be replicated by most other retailers, given Amazon's large platform and low marginal cost of offering additional products on its platform. On the other hand, platforms like Amazon, TripAdvisor, and Airbnb offer the potential for new, small, and niche players to compete effectively with larger players, fundamentally changing the structure of the industry. It is unclear then what the net productivity impact of such changes in industry structure and economics will be, depending, for example, on the share of the market different players are able to gain and their relative productivity levels.

Finally, digitization may reduce price transparency and market efficiency as the customization of price, product, and terms proliferates through the use of consumer data, potentially reducing the incentives for companies to focus on efficiency gains as they extract more of the consumer surplus.

## Going Forward: The Need of a New Paradigm

Unlocking the productivity potential of advanced economies may require a focus on promoting both demand and digital diffusion, in addition to interventions that help remove traditional supply-side constraints such as red tape (Lewis, 2004; Taylor, 2016, Davis, 2017). To incentivize broad-based change, companies need competitive pressure to perform better, a business environment and institutions that enable change and creative destruction, and access to infrastructure and talent. Yet additional emphasis on digital diffusion and demand is warranted.

There are many opportunities today for policy makers to help boost productivity growth in advanced economies that focus on demand and digital diffusion. Demand may deserve attention to help boost productivity growth not only during the recovery from the financial crisis but also in terms of longer-term structural leakages and their impact on productivity. Suitable tools for this longer-term situation include: focusing on productive investment as a fiscal priority; growing the purchasing power of low-income consumers with the highest propensity to consume; unlocking private business and residential investment; and supporting worker training and transition programs to ensure that periods of transition do not disrupt incomes.

On digital, action is needed on the part of policy makers both to overcome adoption barriers of large incumbent business and to broaden the adoption of digital tools by all companies and citizens. Actions that can promote digital diffusion include: leading by example and digitizing the public sector; leveraging public procurement and investment in R&D; driving digital adoption by small and medium-sized enterprises (SMEs); investing in hard and soft digital infrastructure and clusters; doubling down on the education of digital specialists as well as consumers; ensuring global connectivity; and addressing privacy and cybersecurity issues. Furthermore, regulators and policy makers will need to understand the differences in the nature of digital platforms and networks from the network industries of the past, and develop the tools to identify non-competitive behavior that could harm consumers.

Other stakeholders have a role to play as well. How do companies, labour organizations, and even economists respond to the challenge of restarting productivity growth in a digital age? Companies will need to develop a productivity strategy that includes the digital transformation of their business model as well as their entire sector and value chain, and not just focus on operational efficiency. In addition, they may have to rethink their employee contract in order to develop a strategy, potentially together with labour organizations, where people and machines can work side by side and workers and companies can prosper together. Economists can play a key part by developing new and improved ways to measure productivity and by developing models that can assess the impact of technology on markets and prices.

## Conclusion

While productivity growth in advanced economies has been slowing for decades, the sharp downturn following the financial crisis has raised alarms. We find that the most recent slowdown is the product of two waves, the waning of a 1990s ICT productivity boom and financial crisis aftereffects, while a third wave, digitization, is under way. As financial crisis aftereffects continue to recede and digitization matures, productivity growth should recover from historic lows. How strong the recovery is, however, will depend on the ability of companies and policy makers to unlock the benefits of digitization and promote sustained demand growth. There is much at stake. A dual focus on demand and digitization could unleash a powerful new trend of rising productivity growth that drives prosperity across advanced economies for years to come.

## References


Adler, G., R. A Duval, D. Furceri, S.K. Celik, K. Koloskova, M. Poplawski-Ribeiro (2017) "Gone with the Headwinds: Global Productivity," IMF staff discussion note, No. 17/04.

Anzoategui, D., D. Comin, M. Gertler and J. Martinez (2016) "Endogenous Technology Adoption and R&D as Sources of Business Cycle Persistence," NBER Working Paper, No. 22005.

Baily, M.N. and N. Montalbano (2016) "Why is US Productivity Growth So Slow? Possible Explanations and Policy Responses," *The Brookings Institution*.

Baker, S.R., N. Bloom and S.J. Davis (2016) "Measuring Economic Policy Uncertainty," *Quarterly Journal of Economics*, Vol. 131, Issue 4.

Barrero, J.M., N. Bloom and I. Wright (2017) "Short and Long Run Uncertainty," NBER working paper, No. 23676.

Bergeaud, A., G. Cette and R. Lecat (2016) "Productivity Trends in Advanced Countries Between 1890 and 2012,"*Review of Income and Wealth*, Volume 62, No. 3, pp. 420-444.

Bigg, M. and T. Mayer (2013) "Bring Credit Back into the Monetary Policy Framework!" *Political Economy of Financial Markets Policy Brief*.

Bloom, N., C.I. Jones, J. Van Reenen, M. Webb (2017) "Are Ideas Getting Harder to Find?" NBER Working Paper, No. 23782.

Borio, C. (2017) "Secular Stagnation or Financial Cycle Drag?" National Association for Business Economics, 33rd Economic Policy Conference, March, Washington, DC.

Brynjolfsson, E., Daniel Rock, and Chad Syverson (2017) "Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics," NBER working paper number 24001, November.

Bughin, J. and N. van Zeebroeck (2017) "Getting Digital Bucks: How the Interplay of Disruption and Types of Strategic Responses Shapes Digital Investment Payoffs and Solves the Solow Paradox," working paper, December.

Bughin, J. and Nicolas van Zeebroeck (2017) "The Right Response to Digital Disruption," *MIT Sloan Management Review*, April.

Bughin, J., Laura LaBerge, and Anette Mellbye (2017) "The Case for Digital Reinvention," *McKinsey Quarterly*, February.

Byrne, D., S. Oliner, and D. Sichel (2017) "Prices of High-Tech Products, Mismeasurement, and Pace of Innovation," NBER Working Paper, No. 23369.

Comin, D. and B. Hobijn (2010) "An Exploration of Technology Diffusion, *American Economic Review*, Volume 100, No. 5, December.

David, P. (1989) "Computer and Dynamo: The Modern Productivity Paradox in a Not-Too Distant Mirror," *The Warwick Economics Research Paper Series*.

Davis, S.J. (2017) "Regulatory Complexity and Policy Uncertainty: Headwinds of Our Own Making," prepared for Hoover Institution conference on Restoring Prosperity, Stanford University, February.

ECB (2016) "Business Investment Developments in the Euro Area Since the Crisis," *European Central Bank: Occasional Paper Series*, No. 167.

Economic Policy Uncertainty (2018) "Economic Policy Uncertainty Index," accessed at: http://www.policyuncertainty.com/

Erber, G., U. Fritsche and P.C. Harms (2017) "The Global Productivity Slowdown: Diagnosis, Causes and Remedies," *Intereconomics*, Vol. 52, No. 1.

Fernald, J. and B. Wang (2015) "The Recent Rise and Fall of Rapid Productivity Growth," *FRBSF Economic Letter*, Federal Reserve Bank of San Francisco.

Flamm, K. (2017) "Has Moore's Law Been Repealed? An Economist's Perspective," *Computing in Science & Engineering*, IEEE, Vol. 19, Issue 2, pp. 29-40.

Furman, J. and Peter Orszag (2015) "A Firm-Level Perspective on the Role of Rents in the Rise in Inequality," presentation at Columbia University, October.

Gutirrez, G. and Thomas Philippon (2017) "Declining Competition and Investment in the US," NBER Working Papers 23583, March.

IMF (2015) "World Economic Outlook - Uneven Growth: Short- and Long-term Factors," International Monetary Fund.

Jovanovic, Boyan and Peter L. Rousseau (2005) General Purpose Technologies, in Philippe Aghion and Steven Durlauf (eds.) *Handbook of Economic Growth*, volume 1B (Amsterdam: Elsevier).

Kolesnikova, N.A. and Y. Liu (2011) "Jobless Recoveries: Causes and Consequences," Federal Reserve Bank of St. Louis.

Landesmann, M.A. and Robert Stehrer (2004) "Technology Diffusion, International Competition and Effective Demand," *Revue d'economie industrielle*, No. 105.

Lewis, W. (2004) *The Power of Productivity: Wealth, Poverty, and the Threat to Global Stability*, (Chicago: University of Chicago Press).

Manyika, J., J. Woetzel, R. Doobs, J. Remes, E. Labaye, and A. Jordan (2015) "Global Growth: Can Productivity Save the Day in an Aging World?" McKinsey Global Institute.

McKinsey & Company (2013) "Moore's Law: Repeal or Renewal?" McKinsey & Company.

McKinsey & Company (2017) "McKinsey Digital Global Survey 2017: How Digital Reinventors Are Pulling Away From the Pack," McKinsey & Company, October.

McKinsey Global Institute (2002) "How It Enables Productivity Growth: The US Experience Across Three Sectors in the 1990s," McKinsey Global Institute, November.

McKinsey Global Institute (2014) "Global Flows in a Digital Age: How Trade, Finance, People, and Data Connect to the World Economy," McKinsey Global Institute, April.

McKinsey Global Institute (2015a) "Digital America: A Tale of the Haves and Have-Mores," McKinsey Global Institute, December.

McKinsey Global Institute (2015b) "Global Growth: Can Productivity Save the Day in an Aging World?" McKinsey Global Institute," January.

McKinsey Global Institute (2016) "Digital Europe: Pushing the Frontier, Capturing the Benefits," McKinsey Global Institute, June.

McKinsey Global Institute (2017a) "A Future That Works: Automation, Employment, and Productivity, McKinsey Global Institute, January.

McKinsey Global Institute (2017b) "Jobs Lost, Jobs Gained: Workforce Transitions in a Time of Automation," McKinsey Global Institute, November.

Murray, A. (2017) "What Explains the Post-2004 U.S. Productivity Growth Slowdown?" CSLS Research Report No. 2017-05 (Ottawa: Centre for the Study of Living Standards). http://www.csls.ca/reports/csls2017-05.pdf.

Neumark, D. (2014) "Employment Effect of Minimum Wages," *IZA World of Labor*.

Remes, J., J. Manyika, J. Bughin, J. Woetzel, J. Mischke, and M. Krishnan (2018) "Solving the Productivity Puzzle: The Role of Demand and the Promise of Digitization," McKinsey Global Institute. https://www.mckinsey.com/~/media/McKinsey/Featured%20Insights/Meeting%20societys%20expectations/Solving%20the%20productivity%20puzzle/MGI-Solving-the-Productivity-Puzzle-Report/\-February-22-2018.ashx.

Taylor, J.B. (2016) Slow Economic Growth as a Phase in a Policy Performance Cycle, *Journal of Policy Modeling*, Vol. 38, Issue 4, JulyAugust.

van Ark, B. and K. Jager (2017) "Recent Trends in Europe's Output and Productivity Growth Performance at the Sectoral Level, 2002-2015," *International Productivity Monitor*, No. 33, Fall, pp. 8-23. http://www.csls.ca/ipm/33/vanArk_Jager.pdf

Vanderzeil, S., E. Currier and M. Shavel (2017) "Retail Automation: Stranded Workers? Opportunities and Risks for Labor and Automation," Investor Responsibility Research Center.

Yagan, D. (2017) "Employment Hysteresis From the Great Recession," NBER working paper, No. 23844.

# The Stylized Facts about Slower Productivity Growth in Canada

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Abstract

Productivity growth in the Canadian economy has been considerably slower in the post-2000 period than in the pre-2000 period, with important implications for the growth in the living standards of Canadians. Output per hour in the business sector in Canada advanced at a 0.9 per cent average annual rate from 2000 to 2016 compared to 1.6 per cent from 1981 to 2000. The objective of this article is to highlight the stylized facts of this important development. It first examines trends in both labour productivity and total factor productivity (TFP) at the aggregate level. It discusses growth accounting estimates of changes in the sources of labour productivity growth. Labour and total factor productivity estimates are provided for 15 industries, highlighting which industries experienced the largest slowdown in absolute terms and the industry contributions to the slowdown. Manufacturing is found to be the industry making the largest contribution to both the labour productivity and TFP slowdowns. Contributions of within-industry productivity growth and re-allocation effects to aggregate productivity growth are also examined.

Productivity growth in the Canadian economy has been considerably slower in the post-2000 period than in the pre-2000 period, with important implications for the growth in the living standards of Canadians. Output per hour in the business sector advanced at a 0.9 per cent average annual rate from 2000 to 2016 compared to 1.6 per cent from 1981 to 2000. In order to understand the reasons for this slower productivity growth, it is first essential to know the nature of this slowdown. Certain hypotheses to explain the slowdown may not be consistent with the stylized facts of the slowdown. The objective of this article is to highlight these stylized facts related to this important development from a number of perspectives, including the timing of the slowdown, the slowdown in inter-

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national perspective, the sources of the slowdown from a growth accounting perspective and in terms of within-sector and re-allocation effects, and the industry dimensions to the slowdown.

The article consists of four main parts. The first section examines trends in both labour productivity and total factor productivity (TFP) at the aggregate level, including how Canada fared internationally. This section also discusses growth accounting estimates of changes in the sources of labour productivity growth. The second section presents labour and total factor productivity estimates for 15 industries, highlighting which industries experienced the largest slowdown in absolute terms and the industry contributions to the slowdown. This section also discusses the contributions of within-industry productivity growth and re-allocation effects for aggregate productivity growth. The third discusses productivity performance within the post-2000 period, finding that while labour productivity growth was similar in the 2000-2008 and 2008-2016 sub-periods, the nature of this growth has quite different in terms of the sources of growth. The fourth and last section summarizes and concludes.[2]

The data for this article come from Statistics Canada. Indeed, we use annual sectoral data from Table 36-10-0208-01 at the national level from 1961 to 2016. Sectors or industries (the two terms are used as synonyms) are defined by the North American Industry Classification System (NAICS) at the S-level of industry aggregation. Table A1 in the Appendix lists the 15 industries and provided their NAICS codes.[3] Labour productivity in these tables is real value-added gross domestic product (GDP) per hour worked. Total factor productivity is real value-added GDP per unit of combined labour and capital inputs.

## Productivity Trends at the Aggregate Level

This section discusses labour productivity growth and total factor productivity growth at the aggregate level in Canada. We first examine labour productivity in the business sector from 1961 to 2016 by comparing compound annual growth rates in various sub-periods, and then look at total factor productivity in the business sector in the same manner.

### Labour Productivity in the Business Sector

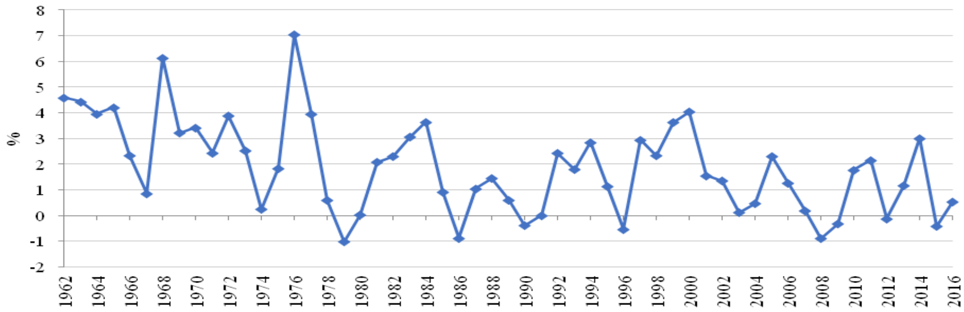
Panel A of Chart 1 shows the annual growth in business sector labour productivity in Canada from 1961 to 2016 while Panel B of Chart 1 provided a five-year moving average of the time series. Pro-

2 The paper presented at the 2018 CEA annual meeting included a discussion of productivity trends by province. This material is not included in this article for two reasons. First, to make the article shorter. Second, because of official productivity estimates for the provinces are only available from 1997, the three years pre-2000 productivity slowdown period is considered too short for a definitive comparison of productivity trends by province between the pre-2000 and post-2000 periods. For the provincial analysis, see Sharpe and Tsang (2018).

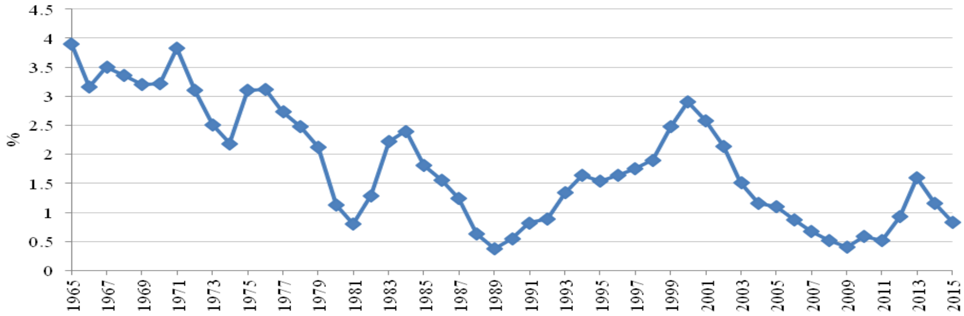
3 The tables and charts in the Appendix are found at www.csls.ca/ipm35/sharpe_tsang_appendix.pdf.

**Chart 1: Business Sector Labour Productivity Growth in Canada, 1961-2016**

**Panel A: Annual Rate of Change**




**Panel B: Five-year Moving Average of Labour Productivity Growth**




Source: Table 36-10-0208-01, Statistics Canada.

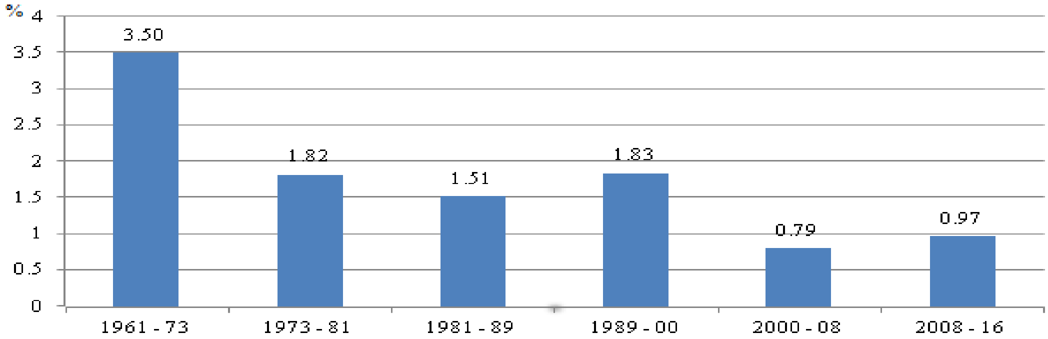
ductivity growth is very cyclical in the short term because of lags in the adjustment of labour input to fluctuations in output. Productivity can soar in years of strong growth such as 1976 and 1999 and turn negative in years of recession such as 2008 and 2009.

The five-year moving average series smoothes these annual variations and provides a better indication of trend productivity growth. One sees a sharp decline in trend in the 1970s, which was partially reversed in the early 1980s before again falling precipitously in the second fall of the 1980s, only to be reversed in the 1990s, peaking in 2000 before again falling in the 2000s.

Superimposed on these five-year moving averaged is the long-term two-step downward shift in labour productivity, which is shown in Chart 2 for six cyclically neutral periods, defined on a output peak to output peak basis.[4] In the first cyclically neutral period output per hour advanced at a 3.5 per cent average annual rate. The first productivity slowdown occurred after 1973 and lasted for three business cycles (1973-81, 1981-1989, and 1989-2000) when labour productivity averaged 1.6 per cent, The second productivity slowdown occurred after 2000 when labour productivity averaged 0.9 per cent in the two business cycles, although the cycle since 2008 is not yet complete. It is important to note that the magnitude of the first

4 See Chart A1 in the Appendix for a graphical presentation of labour productivity growth.

**Chart 2: Business Sector Labour Productivity Cyclically Neutral Periods, 1961-2016 (average annual rate of change)**




Source: Table 36-10-0208-01, Statistics Canada.

**Table 1: Business Sector Labour Productivity in Canada, 1961-2016 (average annual rate of change)**

| LP Peaks | Growth | Output Peaks | Growth | 10-year Periods | Growth | 5-year Periods | Growth |
|---|---|---|---|---|---|---|---|
| 1961 - 1978 | 3.26 | 1961 - 1973 | 3.50 | 1961 - 1970 | 3.68 | 1961 - 1965 | 4.30 |
| 1978 - 1985 | 1.56 | 1973 - 1981 | 1.82 | 1970 - 1980 | 2.13 | 1965 - 1970 | 3.19 |
| 1985 - 1989 | 0.56 | 1981 - 1989 | 1.51 | 1980 - 1990 | 1.38 | 1970 - 1975 | 2.18 |
| 1989 - 1995 | 1.30 | 1989 - 2000 | 1.83 | 1990 - 2000 | 2.06 | 1975 - 1980 | 2.08 |
| 1995 - 2007 | 1.63 | 2000 - 2008 | 0.79 | 2000 - 2010 | 0.78 | 1980 - 1985 | 2.40 |
| 2007 - 2011 | 0.67 | 2008 - 2016 | 0.97 | 2010 - 2016 | 1.05 | 1985 - 1990 | 0.37 |
| 2011 - 2014 | 1.34 | | | | | 1990 - 1995 | 1.64 |
| 2014 - 2016 | 0.06 | | | | | 1995 - 2000 | 2.47 |
| | | | | | | 2000 - 2005 | 1.16 |
| | | | | | | 2005 - 2010 | 0.40 |
| | | | | | | 2010 - 2016 | 1.05 |

Note: LP stands for labour productivity.
Source: Table 36-10-0208-01, Statistics Canada.

labour productivity growth slowdown after 1973 at 1.7 percentage points was approximately double that of the second slowdown after 2000 at 0.8 points.

Alternative dating of productivity trends confirms the two-step downward trend in labour productivity growth based on cyclicaly-neutral output peak to peak periods. Table 1 contains average annual growth rates between labour productivity peaks,[5] as well as 10-year periods and 5-year periods growth rates from 1961 to 2016. The early half of 1960s had the highest labour productivity growth (4.30 per cent from 1961 to 1965), followed by continuous declines until the end of 1980s. In 1990s, labour productivity growth picked up, especially during the second half of the decade. It declined again after 2000, picking up slightly in the 2010s.

## Total Factor Productivity in the Business Sector

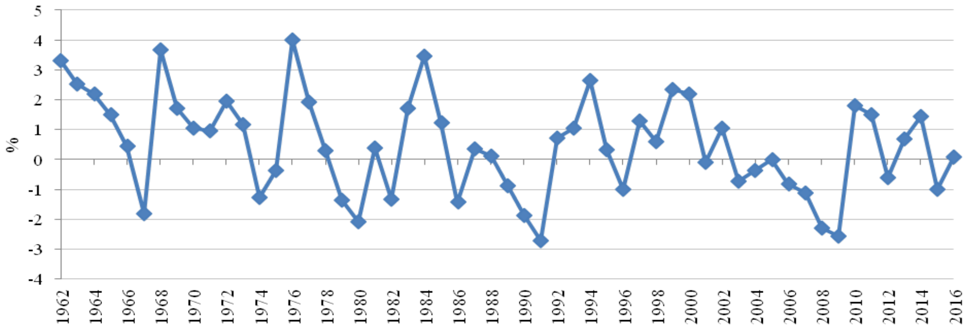
Panel A of Chart 3 shows the annual growth in total factor productivity or multifactor productivity[6] business sector in Canada from 1961 to 2016 while Panel

5 Productivity peaks are defined in an absolute sense as the year before productivity growth turns negative.

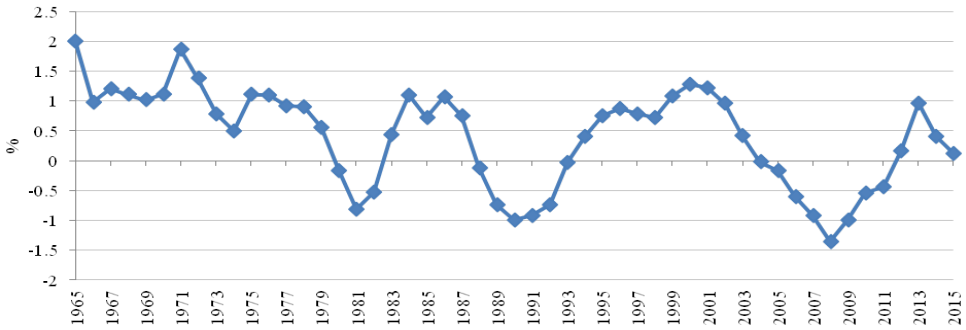
6 The two terms are used synonymously in this article.

**Chart 3: Business Sector Total Factor Productivity Growth in Canada, 1962-2016**

Panel A: Annual Rate of Change




Panel B: Five-Year Moving Average




Source: Table 36-10-0208-01, Statistics Canada.

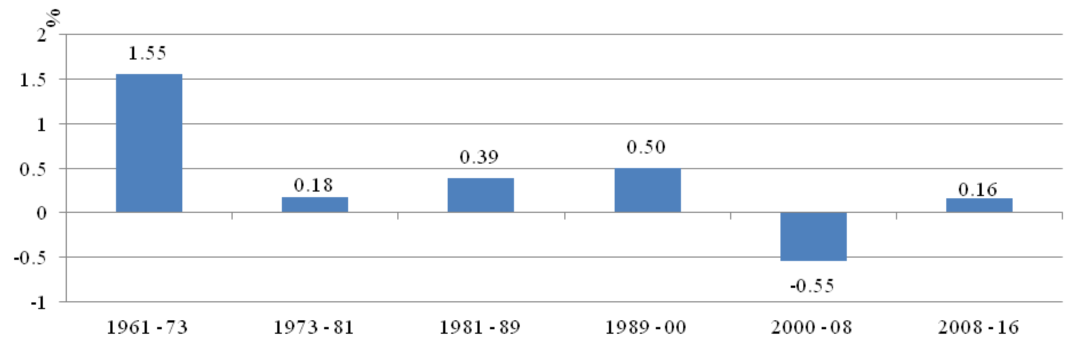
B provided a five-year moving average of the time series. Like labour productivity, TFP growth is also cyclical, rising in expansions and falling in recessions.

Again, the five-year moving average series smooths these annual variations and provides a better indication of trend productivity growth. The pattern is very similar to that of labour productivity, with a sharp decline in trend in the 1970s, which was partially reversed in the early 1980s before again falling precipitously in the second fall of the 1980s, only to be reversed in the 1990s, peaking in 2000 before again falling in the 2000s.

Superimposed on these five year moving averaged is the long-term two-step downward trend in TFP, which is shown in Chart 4 for six cyclically neutral periods, defined on a output peak to output peak basis.[7] In the first cyclically neutral period TFP advanced at a 1.6 per cent average annual rate. The first productivity slowdown occurred after 1973 and lasted for three business cycles (1973-81, 1981-1989, and 1989-2000) when TFP over the three cycles averaged 0.3 per cent per year. The second TFP slowdown occurred after 2000 when TPF growth averaged -0.2 per cent per year. It is again important to note that the magnitude of the first TFP growth slowdown after 1973 at 1.2 percentage points was approximately double that of the second slowdown after 2000 at 0.5 points.

7 See Chart A2 in the Appendix for graphical illustration of TFP growth between output peaks.

**Chart 4: Total Factor Productivity Growth in the Business Sector in Canada, 1961-2016 (average annual rate of change)**




Source: Table 36-10-0208-01, Statistics Canada.

**Table 2: Business Sector Total Factor Productivity in Canada (average annual growth rate, per cent), 1961-2016**

| TFP Peaks | Growth | Output Peaks | Growth | 10-year Periods | Growth | 5-year Periods | Growth |
|---|---|---|---|---|---|---|---|
| 1961 - 1966 | 1.99 | 1961 - 1973 | 1.55 | 1961 - 1970 | 1.61 | 1961 - 1965 | 2.39 |
| 1966 - 1973 | 1.24 | 1973 - 1981 | 0.18 | 1970 - 1980 | 0.51 | 1965 - 1970 | 1.00 |
| 1973 - 1978 | 0.90 | 1981 - 1989 | 0.39 | 1980 - 1990 | 0.16 | 1970 - 1975 | 0.49 |
| 1978 - 1985 | 0.27 | 1989 - 2000 | 0.50 | 1990 - 2000 | 0.73 | 1975 - 1980 | 0.53 |
| 1985 - 1995 | -0.18 | 2000 - 2008 | -0.55 | 2000 - 2010 | -0.52 | 1980 - 1985 | 1.08 |
| 1995 - 2000 | 1.08 | 2008 - 2016 | 0.16 | 2010 - 2016 | 0.35 | 1985 - 1990 | -0.74 |
| 2000 - 2011 | -0.34 | | | | | 1990 - 1995 | 0.39 |
| 2011 - 2016 | 0.12 | | | | | 1995 - 2000 | 1.08 |
| | | | | | | 2000 - 2005 | -0.03 |
| | | | | | | 2005 - 2010 | -1.01 |
| | | | | | | 2010 - 2016 | 0.35 |

Source: Table 36-10-0208-01, Statistics Canada.

Alternative dating of productivity trends confirms the two-step downward trend in TFP growth based on cyclicaly-neutral output peak to peak period. Table 2 contains average annual growth rates between TFP peaks, as well as 10-year periods and 5-year periods growth rates from 1961 to 2016. The early half of 1960s had the highest TFP growth followed by continuous declines until the end of 1980s. The second half of the 1990s saw strong TFP growth associated with the ICT boom. followed by negative TFP growth in the 2000s, with some pick-up after 2010.

## Canada's Aggregate Productivity Performance from an International Perspective

Slower productivity growth since 2000 is not unique to Canada. Indeed, Chart 5 shows that 30 out of 33 OECD countries experienced slower total economy GDP per hour growth in the 2000-2016 period relative to 1981-2000. The only exceptions were Ireland, Turkey and Iceland.

In terms of the of the magnitude of the slowdown Canada at 0.5 percentage points was the sixth smallest among the 30 countries that experienced a slowdown, and well below the OECD average of 1.7 percentage points. This reflects in part Canada's very weak relative productivity performance in the 1981-2000 period when Canada ranked 30th out of 33 OECD countries for GDP per hour growth (Chart A3 in the Appendix).

Indeed, in the 2000-2016 period Canada's ranked 24$^{\text{th}}$ out of 33 OECD countries in terms of labour productivity growth (Chart A3 in the Appendix), better than in the pre-2000 period.

Chart 6 above shows the implications of Canada's poor productivity performance in terms of our aggregate productivity level relative to that of the United States. With slower productivity growth than the United States since the early 1980s. Canada has experienced a significant widening of its business sector labour productivity gap from 95 per cent of the US level in the early 1980s (a 5 percentage point gap) to 72 per cent in 2010 (a 28 point gap). Since 2010 productivity growth has actually been slightly faster in Canada so the gap has closed somewhat and stood at 26 points in 2016.

## Growth Accounting Perspective on the Aggregate Productivity Slowdown

The standard methodology used by economists to analysis the sources of economic growth is growth accounting, which disaggregates labour productivity growth into contributions from capital intensity, labour quality or composition, and total factor productivity. Estimates produced by Statistics Canada are found in Panel A of Chart 7 for the 1981-2000 period, Panel B for the 2000-2016 period and Panel C for the change between period.

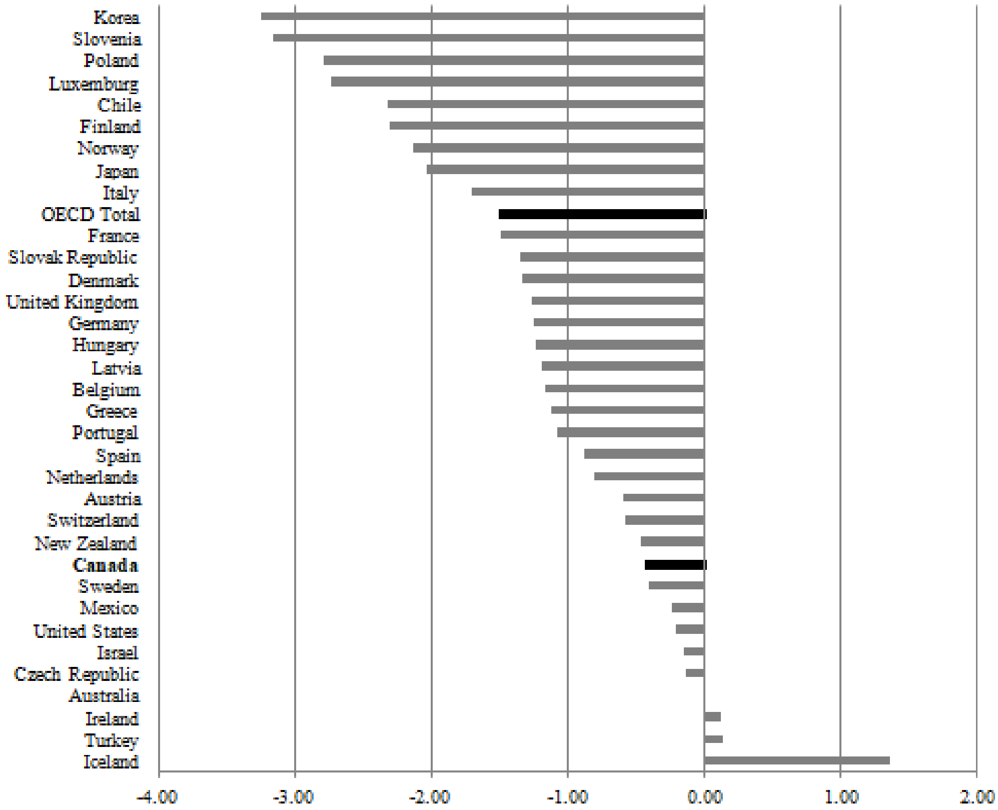
The major finding is that four fifths (0.65 points out of 0.82 points) of the labour productivity slowdown between the 1981-2000 and 2000-2016 periods was due to the fall in TFP growth, which fell from 0.45 per cent per year to -0.20 per cent. The remaining fifth came from a smaller contribution from labour composition (a fall from 0.39 percentage points to 0.23 points). No contribution to the labour productivity slowdown came from capital intensity which was 0.85 points in both periods.

Unfortunately, TFP is a black box or "measure of our ignorance" so this finding tells little about the causes of the productivity slowdown, only that it appears not to be associated with weaker capital intensity and only weakly linked to human capital growth. Factors affecting TFP include capacity utilization, economics of scale and scope, and measurement problems as well as the pace of underlying technical progress not embodied in new capital equipment.

## Impact of Sector Re-allocations on Aggregate Productivity Growth

Aggregate productivity is determined by productivity growth within sectors and the reallocation of inputs among industries with differences in both productivity levels and growth rates. The Centre for the Study of Living Standards has developed a methodology to decompose aggregate productivity growth into these two components, with the latter component in turn disaggregated into productivity level and growth rate effects (de Avillez, 2012). The calculations are

**Chart 5: Change in GDP per hour Growth in OECD Countries, between 1981-2000 and 2000-2016 (percentage points per year)**




Note: Austria: 1995-2000; Czech Republic: 1993-2000; Greece: 1983-2000; Hungary: 1991-2000; Mexico: 1991-2000; Poland: 1993-2000; Slovak Republic: 1995-2000; Chile: 1986-2000; Latvia: 1995-2000; Slovenia: 1995-2000. Source: OECD. http://stats.oecd.org/Index.aspx?DataSetCode=PDB_GR

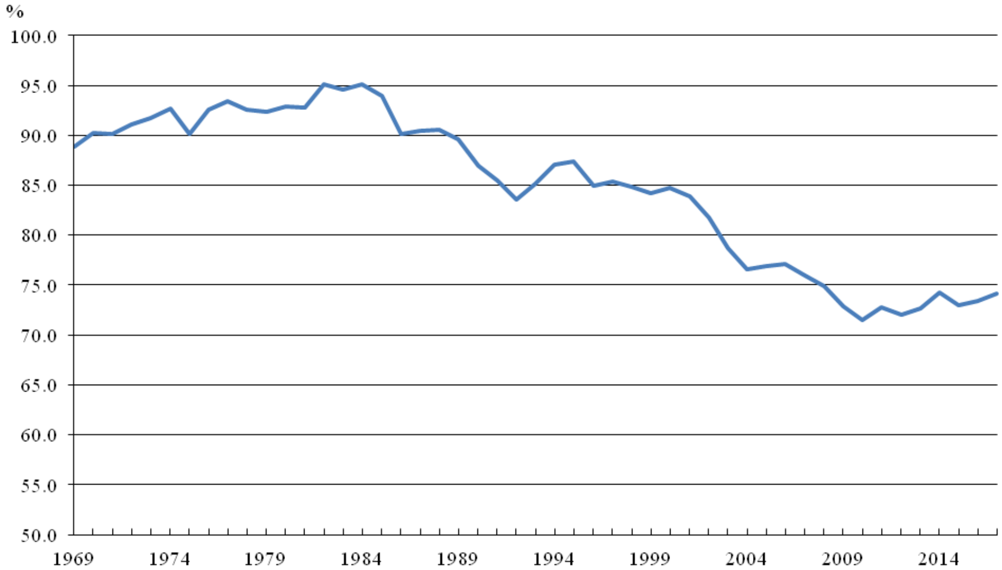
made on an industry basis to contribution by industry can also be obtained as well as the relative importance of within-sector productivity growth and reallocation effects, the sum of the level and growth effects.

Panel A of Chart 8 provides estimates of the decomposition of aggregate labour productivity into the within-sector effects and the reallocation effects for the 1981-2000 period, Panel B for the 2000-2016 period, and Panel C for the change between period. The bottom line is that reallocation effects appear to have made dampened the post-2000 fall in labour productivity growth.

In the 1981-2000 period re-allocation effects subtracted -0.25 points from business sector labour productivity growth as actual productivity growth 1.6 per cent was less than within-sector growth of 1.85 per cent.

In the 2000-2016 period re-allocation effects only reduced productivity growth by 0.08 points as the within-sector productivity growth at 0.98 per cent was only slightly higher than actual productivity growth (0.91 per cent). The difference in re-allocation effects between periods of 0.27 reduced the slowdown in productivity growth to 0.69 points from the within-sector effect slowdown of 0.87

**Chart 6: Relative Labour Productivity Levels (GDP per hour) in the Business Sector in Canada, 1969-2016 (Canada as % of the United States)**




Source: CSLS estimates.

points.

Panel A of Chart A5 in the Appendix provides estimates of the decomposition of TFP into the within-sector effects and the reallocation effects for the 1981-2000 period, Panel B for the 2000-2016 period, and Panel C for the change between period. The bottom line is that in contrast to labour productivity, reallocation effects appear to have increased the post-2000 decline in TFP growth.

In the 1981-2000 period re-allocation effects subtracted -0.03 points from business sector TFP growth as actual productivity growth 0.53 per cent was less than within-sector growth of 0.54 per cent.

In the 2000-2016 period re-allocation effects reduced productivity growth by 0.14 points as the within-sector productivity growth at -0.04 per cent was better than actual productivity growth of -0.17 per cent. The difference in re-allocation effects between periods of 0.11 increased the slowdown in productivity growth to 0.70 points from the with-in sector effect slowdown of 0.58 points.

## Productivity Growth at the Sectoral Level

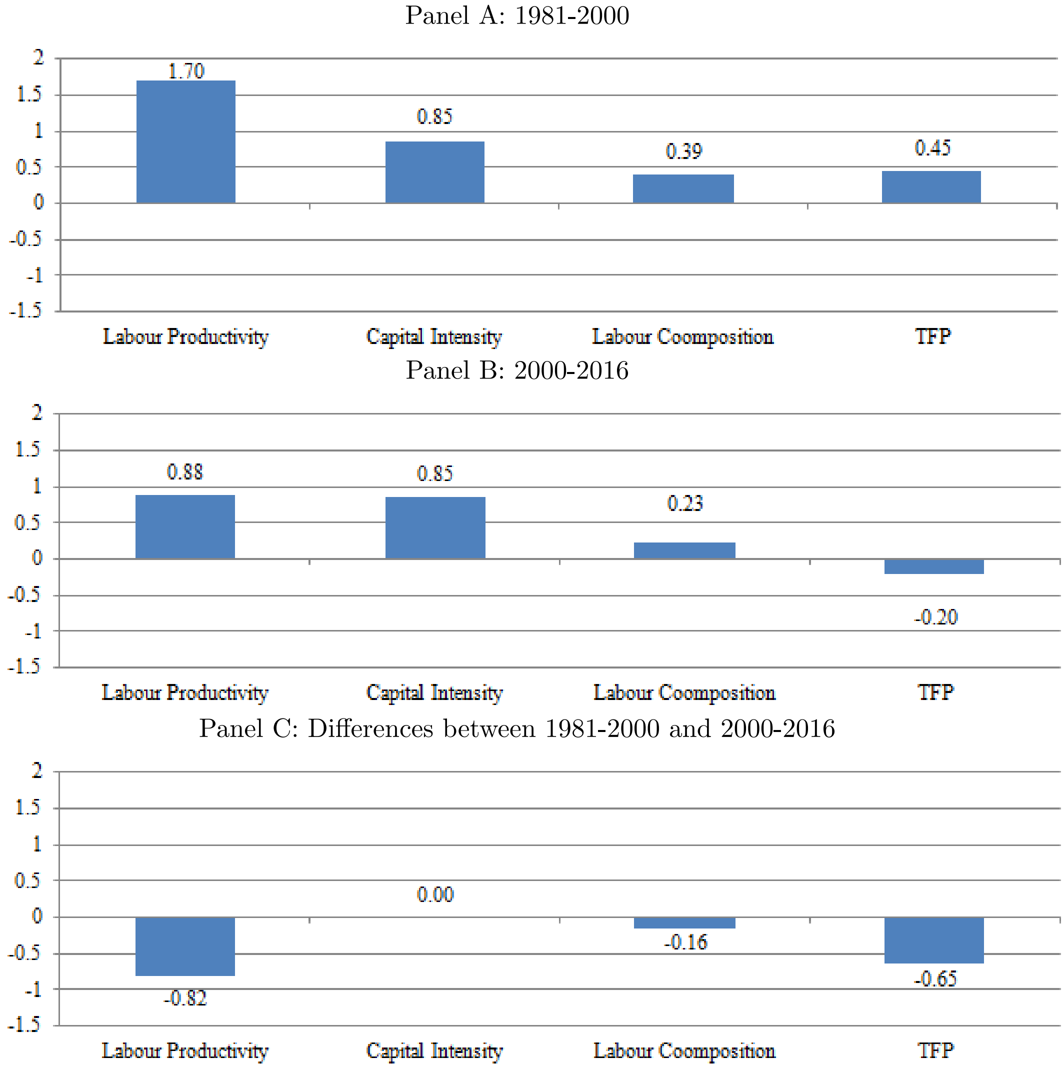
### Labour Productivity by Industry

#### Growth Rates

To understand the post-2000 productivity slowdown one must identify which sectors experienced slower productivity growth and the contributions of these sectors to the overall slowdown. Panel A of Chart 9 shows compound annual growth rates for output per hour for 15 two-digit NAICS industries for the 1981-2000 period, Panel B gives the figures for the 2000-2016 period, and Panel C the differences between periods.

Slower productivity growth has not been pervasive across all industries. In-

**Chart 7: Contributions of Capital Intensity, Labour Composition, and MFP to Labour Productivity Growth, Business Sector, Canada, 1981-2000 and 2000-2016 (percentage points per year)**



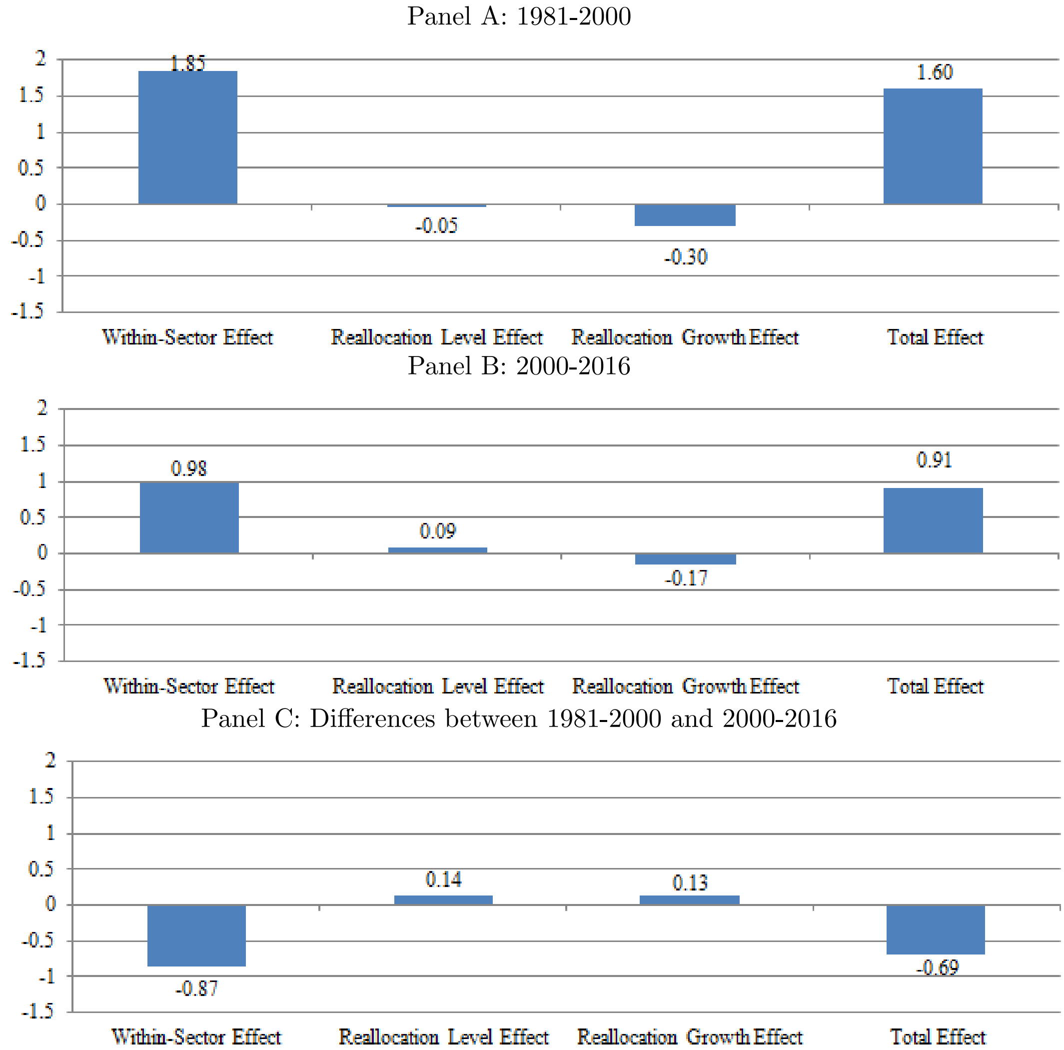

Source: Table 36-10-0208-01, Statistics Canada.

deed, only eight of 15 industries experienced slower labour productivity growth in 2000-2016 period relative to 1981-2000, and seven industries enjoying faster labour productivity growth.

The largest slowdown in labour productivity growth occurred in mining and oil and gas production (3.4 percentage points per year), followed by manufacturing (2.2 points). Productivity growth picked up after 2000 in a number of service industries, especially arts, entertainment, and recreation (2.5 points).

It is interesting to note that the number of sectors experiencing negative labour productivity growth was actually less after 2000 than before. In the 1981-2000 period four service industries saw an absolute decline in their productivity level: arts, entertainment and recreation; accommodation and food; administrative and support, waste management and remediation services (ASWMRS), and other private ser-

**Chart 8: CSLS Labour Productivity Decomposition, Business Sector, Compound Average Annual Growth Rates, Per Cent, Canada, 1981-2000 and 2000-2016**




Source: Table 36-10-0208-01, Statistics Canada.

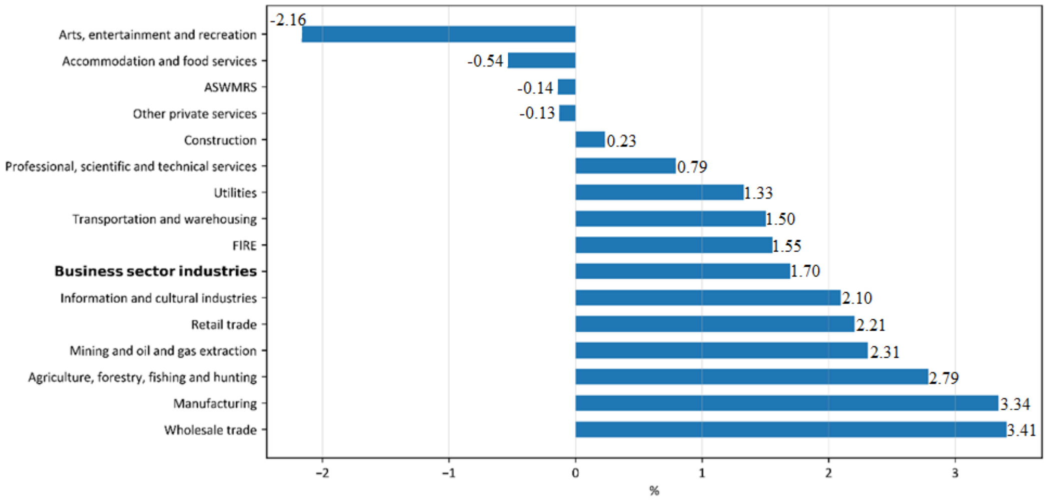
vices. In contrast to the 2000-2016 period only two industries, both in the good sector, experienced absolute declines: mining and oil and gas extraction and construction. The improved performance of a number of service sector industries is a positive development for overall productivity growth and suggests that the productivity slowdown was a phenomenon largely concentrated in the goods sector.

#### Contributions by Industry

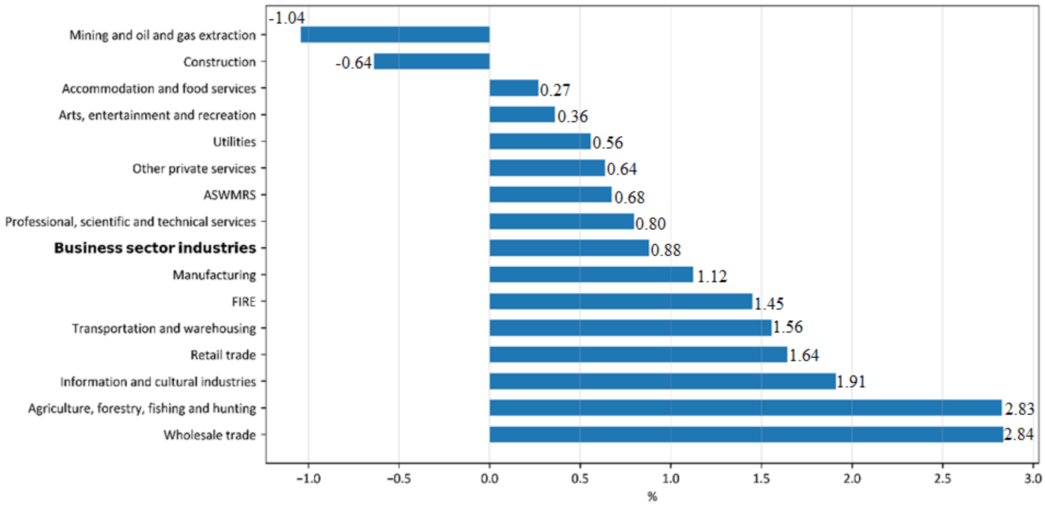
The contributions by industry to the productivity slowdown are determined by both the absolute size of an industry's productivity growth slowdown and the importance of the industry in total input and output, and reallocation effects. Panel A of Chart 10 shows the contributions to business sector labour productivity growth for the 15 industries in the 1981-2000 period, Panel B for the 2000-2008 period, and Panel C for the change between periods.

**Chart 9: Labour Productivity Growth in Canada by Industry, 1981-2000 and 2000-2016 (average annual rate of change)**

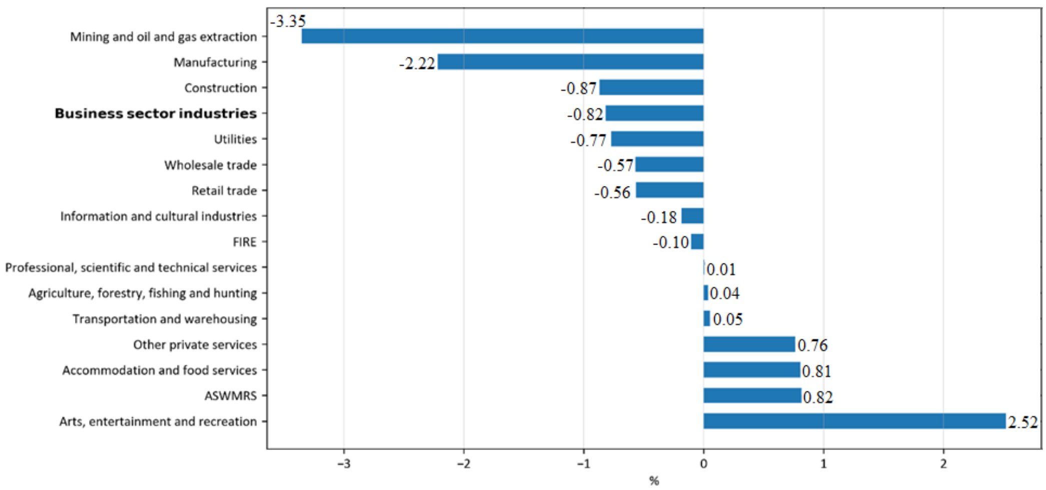
Panel A: 1981-2000




Panel B: 2000-2016




Panel C: Differences between 1981-2000 and 2000-2016 (percentage point change)

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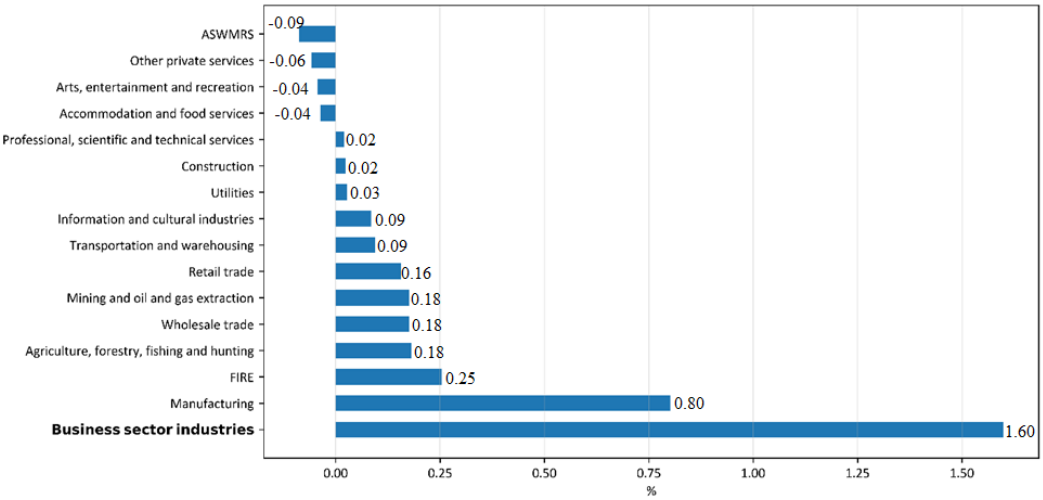
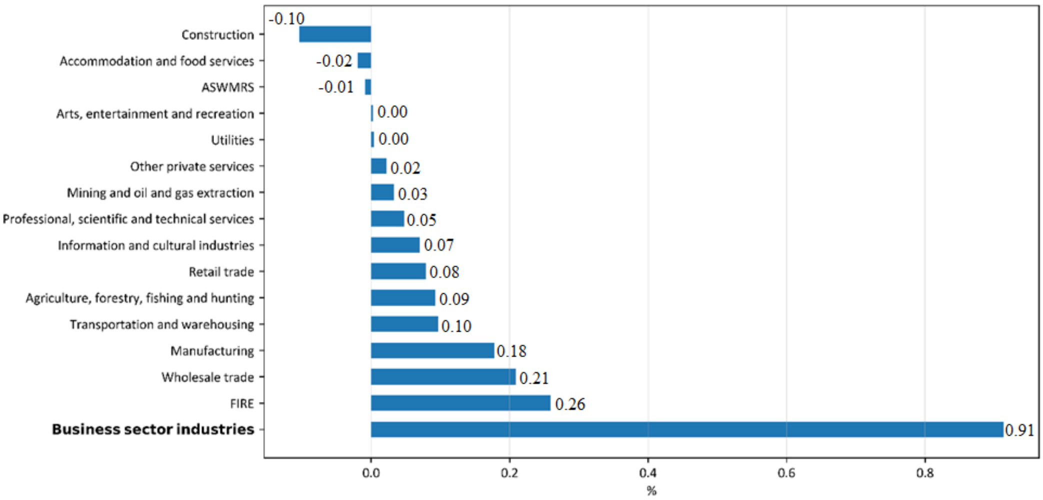
Note: FIRE stands for finance, insurance, real estate, rental and leasing. ASWMRS stands for administrative support, waste management and remediation services.
Source: Table 36-10-0208-01, Statistics Canada.

**Chart 10: Contribution to Labour Productivity Growth in Canada by Industry, 1981-2000 (percentage point contribution)**

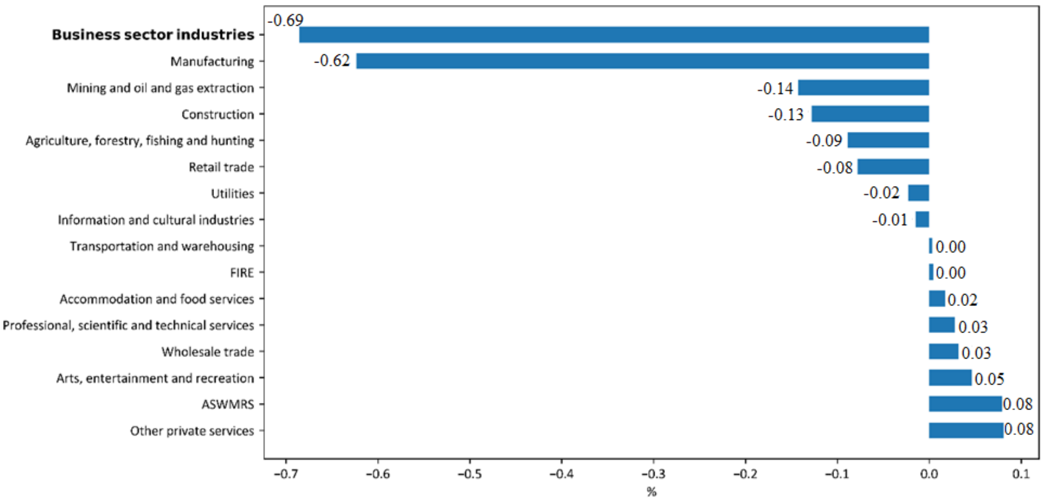
Panel A: 1981-2000




Panel B: 2000-2016




Panel C: Differences between 1981-2000 and 2000-2016 (Percentage Point Change)




Note: FIRE stands for finance, insurance, real estate, rental and leasing. ASWMRS stands for administrative support, waste management and remediation services.
Source: Table 36-10-0208-01, Statistics Canada.

The sector that made by far the largest contribution to business sector labour productivity growth in the 1981-2000 period was manufacturing at 0.8 points per year, one half of the overall productivity growth rate of 1.6 per cent. In the 2000-2016 period the largest industry contribution was made by FIRE at 0.26 points, followed by wholesale trade at 0.21 points. Manufacturing was third at 0.18 points.

Because of the drop in the contribution to labour productivity growth from manufacturing (0.62 points), this sector accounted for almost all (91 per cent) the labour productivity slowdown of 0.69 points. Additional contributions to the slowdown came from mining and oil and gas extraction, construction, agriculture, and retail trade offset by negative contribution (higher productivity growth after 2000) in ASWMRS and other service industries.

## Trends in TFP by Industry

### Growth Rates

Panel A of Chart 11 shows compound annual growth rates for TFP for 15 two-digit NAICS industries for the 1981-2000 period, Panel B gives the figures for the 2000-2016 period, and Panel C the differences between periods.

As was the case for labour productivity, slower TFP growth after 2000 has not been pervasive across all industries. Indeed, only eight of 15 industries experienced slower TFP growth in 2000-2016 period relative to 1981-2000, and seven industries enjoying faster labour productivity growth.

It is interesting to note that the profile of industries experiencing negative TFP growth changed after 2000. In the 1981-2000 the six industries with the largest decline on TFP were in the service sector. After 2000 the three industries with the large falls in TFP were in the goods sector: mining and oil gas extraction, utilities and construction. As with labour productivity, the improved performance of a number of service sector industries is a positive development for overall productivity growth and suggests that the TFP growth slowdown was a phenomenon largely concentrated in the goods sector.

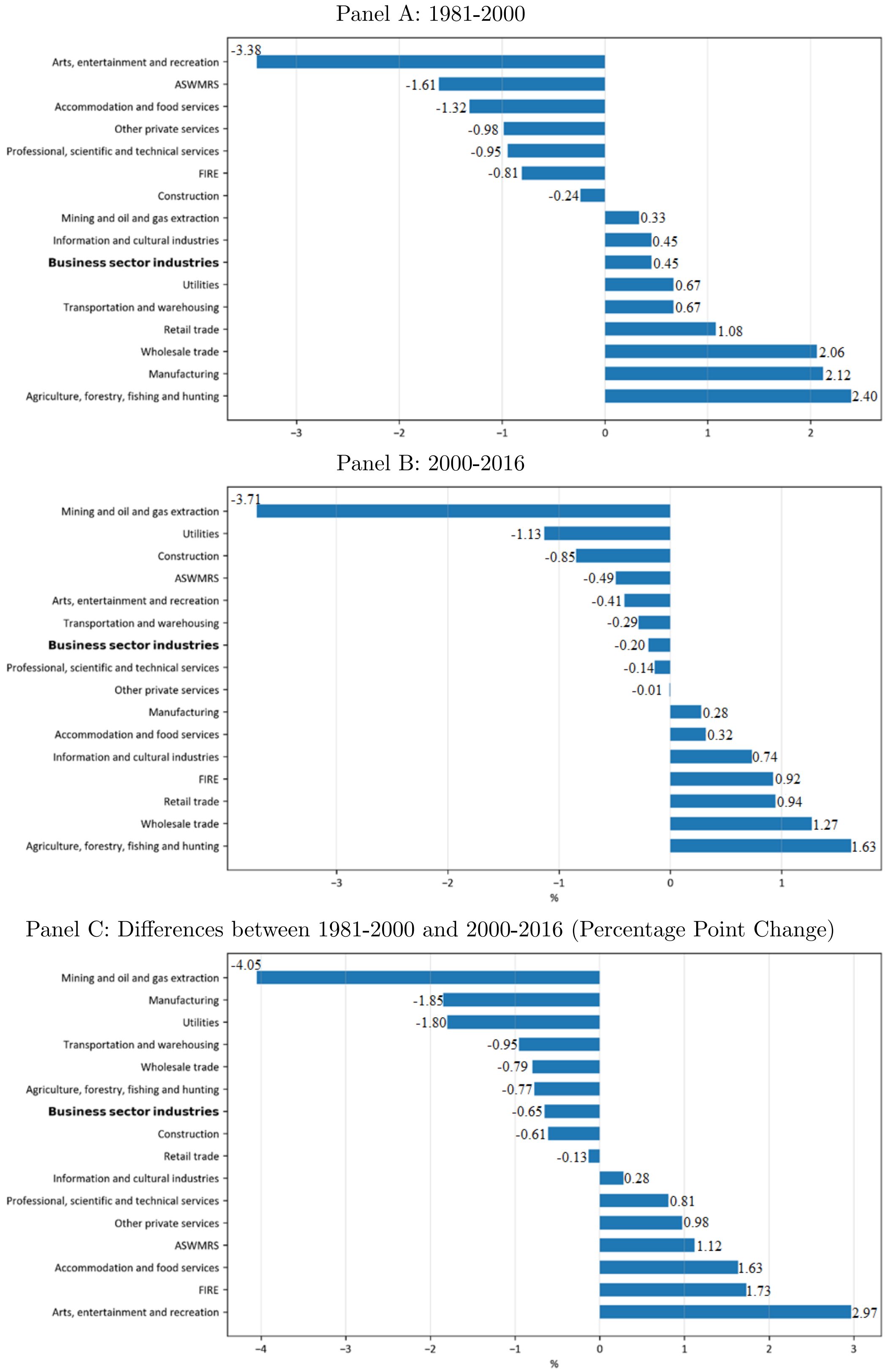
### Contributions by Industry

Panel A of Chart A6 in the Appendix shows the contributions to business sector TFP growth for the 15 industries in the 1981-2000 period, Panel B for the 2000-2008 period, and Panel C for the change between periods.

The sector that made by far the largest contribution to business sector TFP growth in the 1981-2000 period was manufacturing at 0.50 points per year, nearly equal to the overall productivity growth rate of 0.53 per cent. Six service industries made negative contributions to TFP growth in this period.

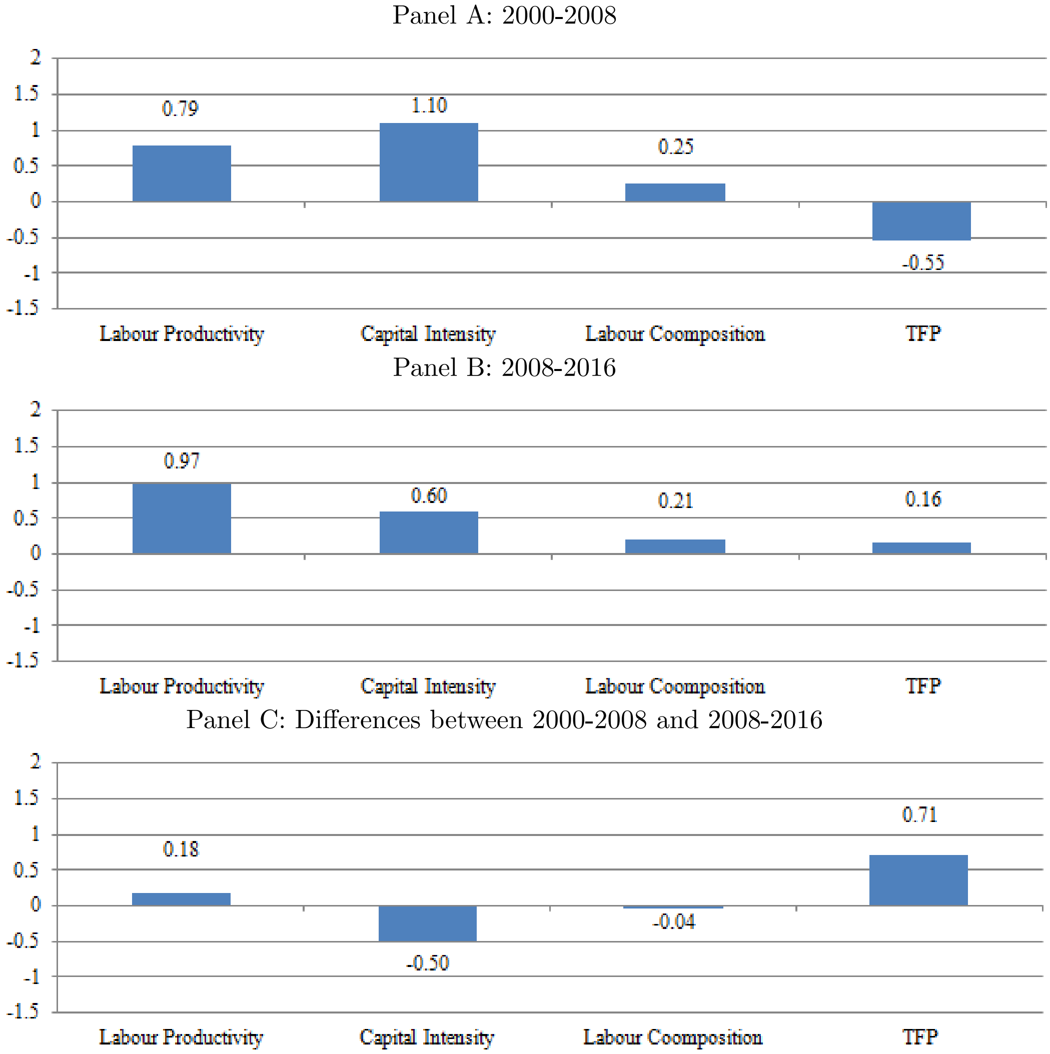
In the 2000-2016 period the largest industry contribution to TFP growth was made by FIRE at 0.14 points, followed by wholesale trade at 0.09 points. Manufacturing was fourth at only 0.03 points. On the other hand, mining, and oil and gas extraction contributed -0.43 points to TFP, more than double actual TFP growth of 0.17 per cent per year.

**Chart 11: Total Factor Productivity Compound Annual Growth Rates by Industry, 1981-2000 and 2000-2016**




Note: FIRE stands for finance, insurance, real estate, rental and leasing. ASWMRS stands for administrative support, waste management and remediation services.
Source: Table 36-10-0208-01, Statistics Canada.

**Chart 12: Sources of Labour Productivity Growth in Canada, Business Sector, 2000-2008 and 2008-2016 (percentage point contributions)**




Source: Table 36-10-0208-01, Statistics Canada.

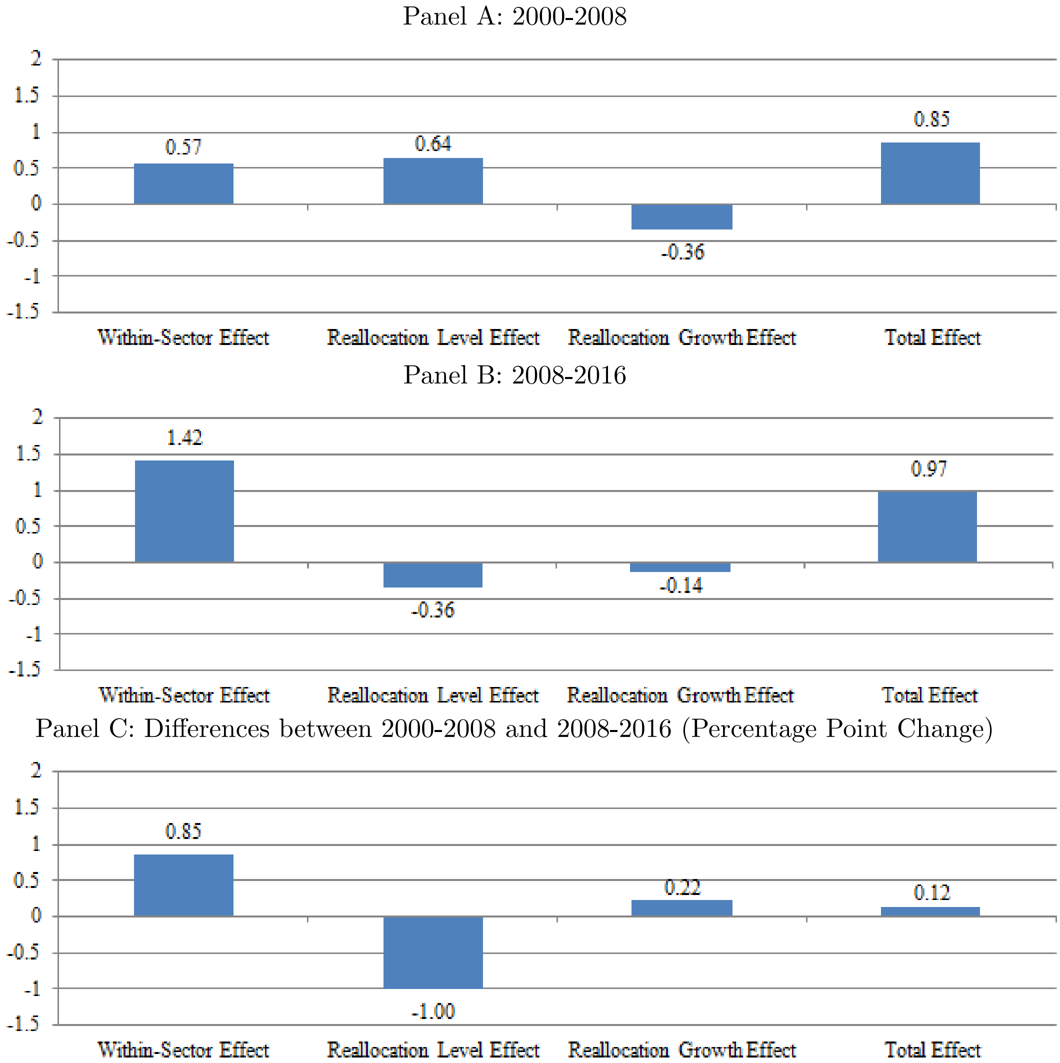
Two industries equally contributed to the TFP slowdown of 0.7 points, manufacturing contributing 0.47 points and mining and oil and gas extraction 0.46 points. FIRE on the other hand offset the slowdown by 0.25 points.

The industry contributions to TFP growth in the 1981-2000 and 2000-2016 periods and the change between periods mirror the industry contributions to labour productivity growth.

## Productivity Developments within the Post-2000 Period

Since 2000, labour productivity growth in Canada appears to have been quite similar in the sub-periods at 0.8 per cent per year in 2000-2008 and 1.0 per cent in 2008-2016. But this similarity masks underlying differences between periods in the sources of labour productivity growth, the impact of re-allocation effects, and the number of industries experiencing stronger productivity growth.

**Chart 13: Labour Productivity Decomposition, Business Sector, Compound Average Annual Growth Rates, Per Cent, Canada, 2000-2008 and 2008-2016**




Source: Table 36-10-0208-01, Statistics Canada.

## Labour Productivity

Chart 12 shows the contributions of the three sources of labour productivity growth in Canada for the 2000-2008 (Panel A) and 2008-2016 (Panel B) periods as well as the change between periods (Panel C). The contribution of capital intensity fell off 0.5 points between periods from 1.1 points in 2000-2008 to 0.6 points in 2008-2016. In contrast, the contribution of TFP increased 0.7 points from -0.6 points in 2000-2008 to 0.2 points in 2008-2016 The contribution of labour composition was stable at around 0.2 points. In other words, TFP growth, one of whose drivers is technological change picked up after 2008, even though capital accumulation faltered. This latter development is likely linked to the Great Recession.

Chart 13 shows the contributions of within-sector effects and re-allocations effects to business sector labour productivity growth in Canada in 2000-2008 (Panel A) and 2008-2016 (Panel B) subperiods and the change between periods

**Table 3: Number of 2-digit NAICS Industries with Increasing and Decreasing Labour Productivity, 2000-2008 and 2008-2016**

| **Labour Productivity** | | | | |
|---|---|---|---|---|
| **Sub-periods** | **Increasing** | **Decreasing** | **Accelerating** | **Decelerating** |
| 2000 - 2008 | 11 | 4 | | |
| 2008 - 2016 | 12 | 3 | 9 | 6 |
| **Total Factor Productivity** | | | | |
| **Sub-periods** | **Increasing** | **Decreasing** | **Accelerating** | **Decelerating** |
| 2000 - 2008 | 6 | 9 | | |
| 2008 - 2016 | 9 | 6 | 9 | 6 |

Source: Table 36-10-0208-01, Statistics Canada.

(Panel C). The patterns of productivity growth in the two periods were very different even though overall productivity growth was similar. In 2000-2008 there was a positive re-allocation effect (the sum of the level and growth effects) of 0.3 percentage points while in 2008-2018 there was a negative re-allocation effect of 0.5 points. This resulted in a swing between periods of 0.8 points, a very large number.

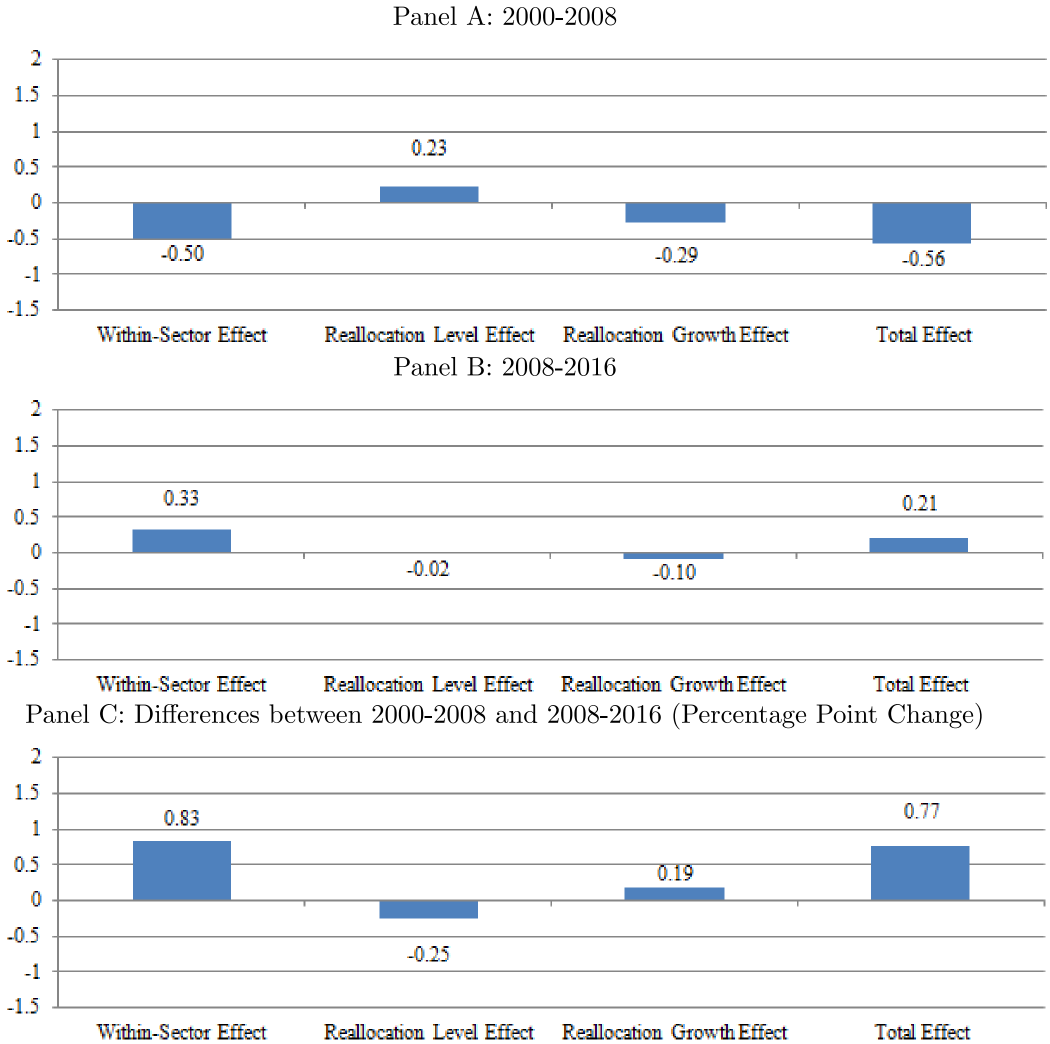
Offsetting this development was the contribution of within-sector productivity growth, to total productivity growth, increasing 0.8 points from 0.6 points in 2000-2008 to 1.4 points in 2008-2016. This pick-up in within-sector productivity growth at the level of the business sector is manifested by the productivity performance at the industry level, with nine of 15 industries enjoying faster productivity growth in the 2008-2016 period relative to the 2000-2008 period (Table 3). Since re-allocation effects tend to be offsetting over the long run this pick-up in within-sector productivity growth bodes well for future productivity developments.

Some insight into these re-allocation effects can be obtained from Table A2 in the Appendix. The labour productivity level in the mining and oil and gas sector in 2008 was 513 per cent of that of the business sector in 2008, although down from 848 per cent in 2000 due to falling productivity. The labour input share in mining and oil and gas extraction rose from 1.4 per cent of total labour input in 2000 to 2.1 per cent in 2008. This movement of resources to very high productivity activity boosted aggregate productivity growth despite the negative productivity growth in the sector. This positive re-allocation effect reversed after 2008 when the labour input share in mining and oil and gas extraction fell to 1.8 per cent by 2016.

## Total Factor Productivity

Chart 14 shows the contributions of within-sector effects and re-allocations effects to business sector TFP growth in Canada in the 2000-2008 (Panel A) and 2008-2016 (Panel B) sub-periods and the change between periods (Panel C). The contributions of the re-allocation components in the two periods differ from that of labour productivity. While there was a major fall in the re-allocation effects for labour productivity between 2000-2008 and 2008-2016, this was not the case for TFP where the re-allocation ef-

**Chart 14: CSLS Total Factor Productivity Decomposition, Business Sector, Compound Average Annual Growth Rates, Per Cent, Canada, 2000-2008 and 2008-2016**




Source: Table 36-10-0208-01, Statistics Canada.

fect was -0.1 point in both periods. This difference is explained by the capital intensive nature of the mining and oil and gas extraction, which make labour productivity differences with the business sector much greater than TFP level differences. Since there are much smaller sectoral differences in TFP, movement of capital and labour between sectors produces much smaller re-allocative gains to aggregate productivity. The within-sector contribution to TFP rose 0.8 points from -0.5 points in 2000-2008 to 0.3 points in 2008-2016. Since there was no offsetting negative development in re-allocation effect between periods, this within-sector effect translated directly into a total TFP effects, as TFP increased 0.8 points from -0.6 per cent to 0.2 per cent. This explains why TFP picked up significantly after 2008 and why labour productivity did not.

This pick-up in within-sector TFP growth at the level of the business sector is manifested by the productivity performance at the industry level, with nine of 15 industries enjoying faster TFP growth in the 2008-2016 period relative to the 2000-2008 period (Table 3).

## Summary and Conclusion

Productivity growth, whether measured in terms of labour productivity or total factor productivity (TFP), appears to have peaked in Canada around 2000. From 2000 to 2016, both business sector labour productivity and TFP growth have been approximately 0.7-0.8 percentage points per year weaker relative to the 1981-2000 period (1.7 per cent versus 0.9 per cent and 0.5 per cent versus -0.2 per cent respectively).

Slower productivity growth is not unique to Canada. Indeed, 30 out of 33 OECD countries experienced slower GDP per hour growth in the 2000-2016 period relative to 1981-2000. In terms of the magnitude of the slowdown, Canada at 0.5 percentage points was the sixth smallest among the 30 countries that experienced slower productivity growth. This reflects in part Canada's very weak relatively productivity performance in the 1981-2000 period (30th out of 33 OECD countries for GDP per hour growth).

Growth accounting estimates produced by Statistics Canada show that fourth fifths (0.65 points out of 0.82 points) of the labour productivity slowdown between the 1981-2000 and 2000-2016 periods was due to the fall in TFP growth, with one fifth from a smaller contribution from labour composition and no contribution from capital intensity. Unfortunately, TFP is a black box or "measure of our ignorance" so this finding tells little about the causes of the productivity slowdown, only that it appears not to be associated with weaker capital intensity and human capital growth.

Slower productivity growth has not been pervasive across all industries. Indeed, only eight of 15 industries experienced slower labour productivity growth in 2000-2016 period relative to 1981-2000, and seven industries enjoying faster labour productivity growth. The largest decline in mining and oil and gas production (3.4 percentage points per year), followed by manufacturing (2.2 points). Productivity growth picked up after 2000 in a number of service industries, especially arts, entertainment, and recreation (2.5 points).

Manufacturing accounted for almost all the labour productivity slowdown (91 per cent), with additional contributions from construction, agriculture, and retail trade offset by negative contribution (higher productivity growth after 2000) in a number of service industries. In terms of the industry contributions to the TFP slowdown manufacturing and mining and oil and gas extraction made equally large contributions of around 0.5 points, with FIRE making a negative contribution of around 0.3 points.

Aggregate productivity growth can be decomposed into contributions from within industry productivity growth and re-allocation effects from movement of inputs between industries with different productivity levels and growth rates. For the 2000-2016 period there was minimal effect of reallocation on aggregate productivity growth as had been the case in 1981-2000, with most all aggregate productivity growth generated within sectors.

Since 2000, productivity growth appears to have been quite similar in the 2000-2008 and 2008-2016 sub-periods at 0.8 per cent per year in 2000-2008 and 1.0 per cent in 2008-2016. But this similarity masks underlying differences between periods in the sources of labour productivity growth, the impact of re-allocation effects, and the number of industries experiences stronger productivity growth. The contribution of capital intensity fell off 0.5 points between the 2000-2008 and 2008-2016 sub-periods, while the contribution of TFP increased 0.7 points. In terms of the relative importance of within-sector productivity growth and re-allocations effects, in 2000-2008 re-allocation effects added 0.3 points to business sector labour productivity growth while in 2008-2016 these effects subtracted 0.5 points, a major turnaround. Conversely, the contribution of the within-sector productivity growth to business sector productivity growth rose from 0.6 points in 2000-2018 to 1.4 points in 2008-2016. Since within-sector productivity growth is what drives overall productivity growth in the long run, this development augurs well for future productivity growth. Nine of 15 industries experienced faster labour productivity growth in 2008-2016 relative to 2000-2008.

A detailed analysis of the causes of the slower productivity is beyond the scope of this article and will be subject to future work. However, given the importance of R&D as a driver of productivity growth, it is useful at this time to point out that the post-2000 productivity slowdown corresponds with a significant fall in BERD intensity, from 1.2 pent of GDP in 2000 to 0.7 per cent in 2016. This fall-off in entirely accounted for by the manufacturing sector, which was the sector that made the largest contribution to the productivity slowdown.

## References

de Avillez, R. (2012) "Sectoral Contributions to Labour Productivity Growth in Canada: Does the Choice of Decomposition Formula Matter?" *International Productivity Monitor*, No. 24, Fall, pp. 97-117.

Sharpe, A. and J. Tsang (2018) "Stylized Facts about Slower Productivity Growth in Canada", paper presented at CSLS-Productivity Partnership Session "Explaining Canada's Post-2000 Productivity Performance I: Setting the Stage," McGill University, Montreal, Canada, June 1-3. http://www.csls.ca/events/cea2018/sharpe.pdf.

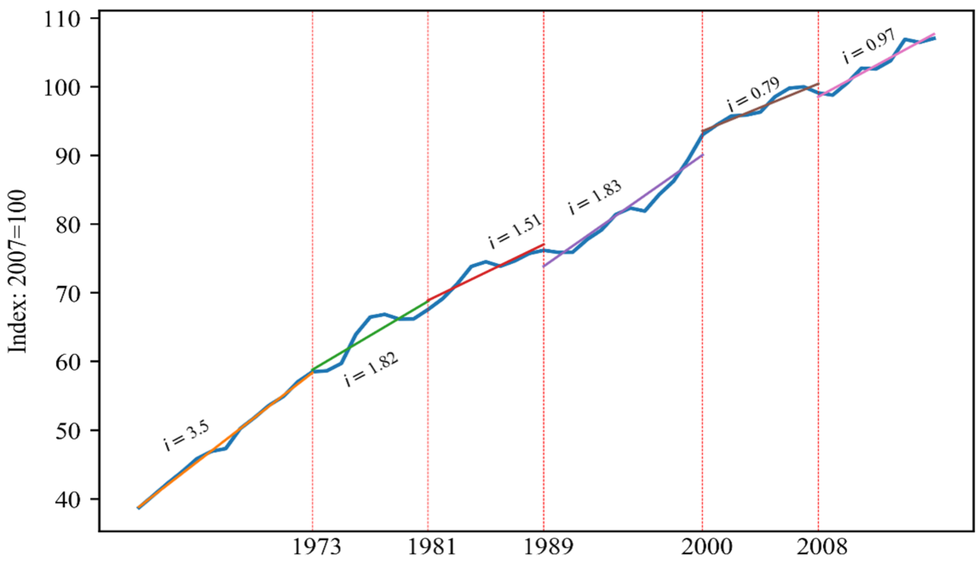
# Appendix

**Table A1: List of NAICS Industries, their Short Forms and the 2-digit NAICS Code**

| | Industries | NAICS Code |
|---|---|---|
| 1. | Agriculture, forestry, fishing and hunting | 11 |
| 2. | Mining and oil and gas extraction | 21 |
| 3. | Utilities | 22 |
| 4. | Construction | 23 |
| 5. | Manufacturing | 31-33 |
| 6. | Wholesale trade | 41 |
| 7. | Retail trade | 44-45 |
| 8. | Transportation and warehousing | 48-49 |
| 9. | Information and cultural industries | 51 |
| 10(a). | Finance, insurance, real estate, rental and leasing and management of companies and enterprises(1) | 52-53,55[2] |
| 10(b). | Finance, insurance, real estate, rental and leasing(1) | 52-53[2] |
| 11. | Professional, scientific and technical services | 54 |
| 12. | Administrative and support, waste management and remediation services | 56 |
| 13. | Arts, entertainment and recreation | 71 |
| 14. | Accommodation and food services | 72 |
| 15. | Other private services(3) | 61, 62, 81 |

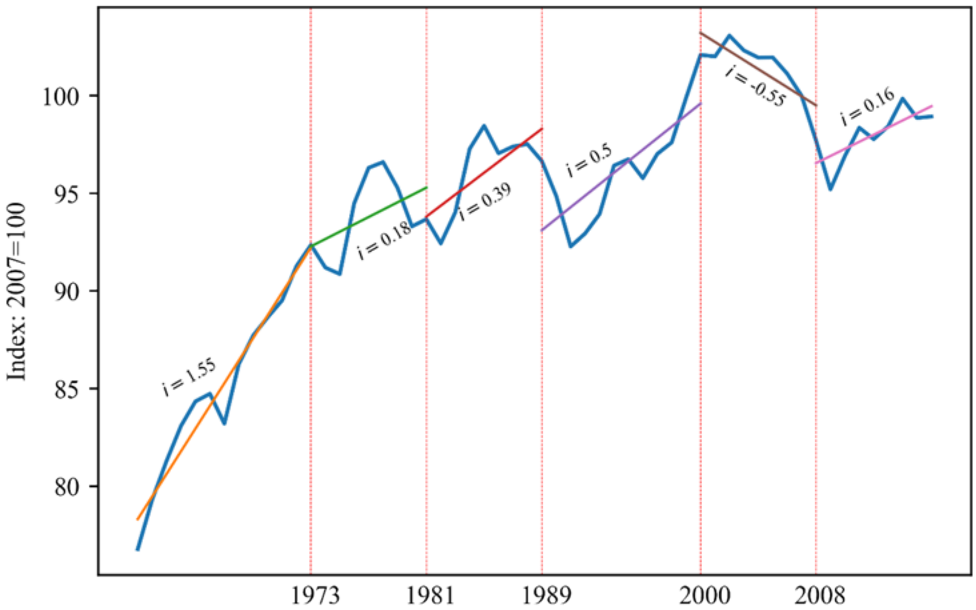
[1] Table 383-0021 (national level) uses 10(b) while table 383-0026 (provincial level) uses 10(a) instead.
[2] The industry excludes imputed rents.
[3] Other private services include educational services (61), health care and social assistance (62) and other services (except public services) (81).

**Chart A1: Business Sector Labour Productivity Compound Annual Growth Rates in Selected Sub-periods, 1961 - 2016**



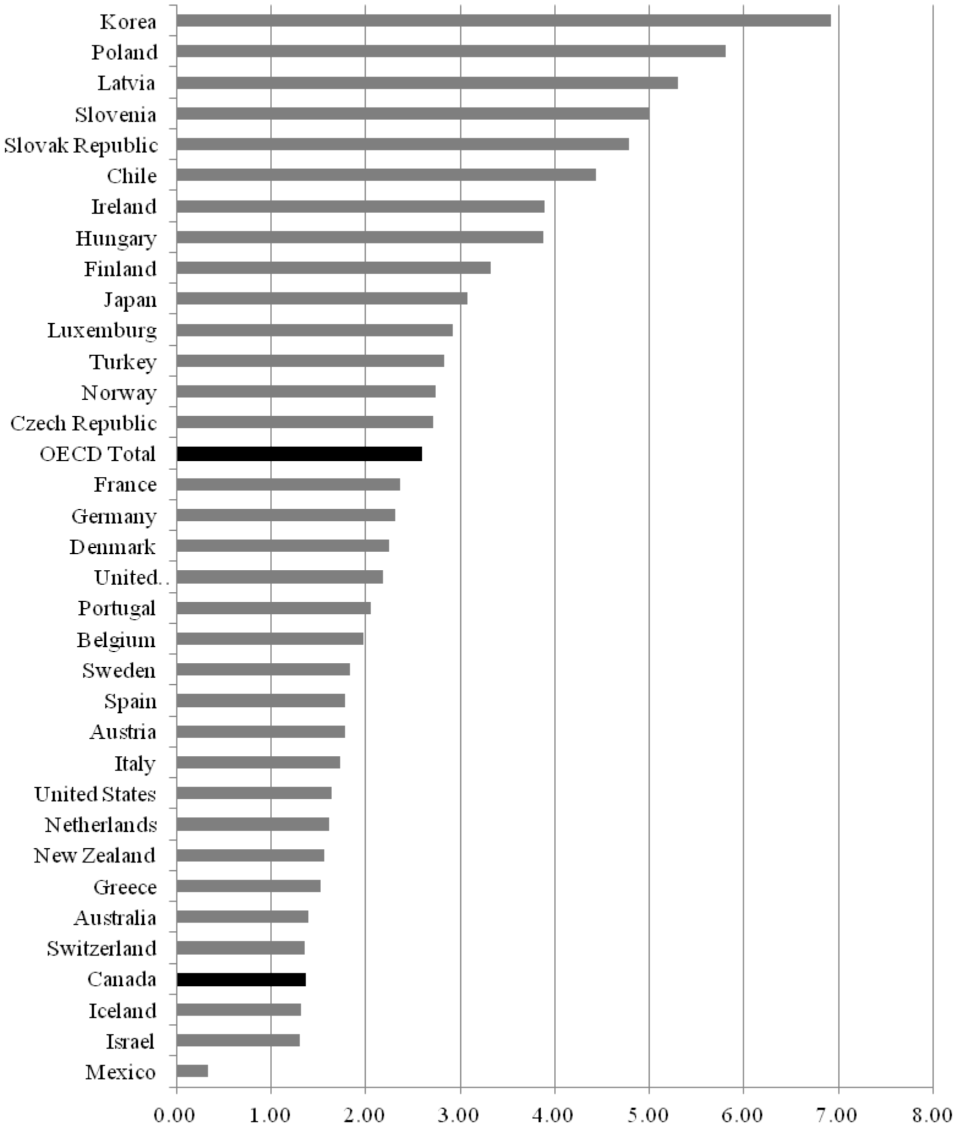

Note: Vertical dotted lines indicate labour productivity peaks.Trendlines span between output peaks (1973, 1981, 1989, 2000 and 2008). i above each trendline indicates the compound annual grwoth rate in percentage points between the output peaks.
Source: Table 36-10-0208-01, Statistics Canada.

**Chart A2: Trends in Total Factor Productivity between Output Peaks in the Business Sector in Canada, 1961 - 2016**



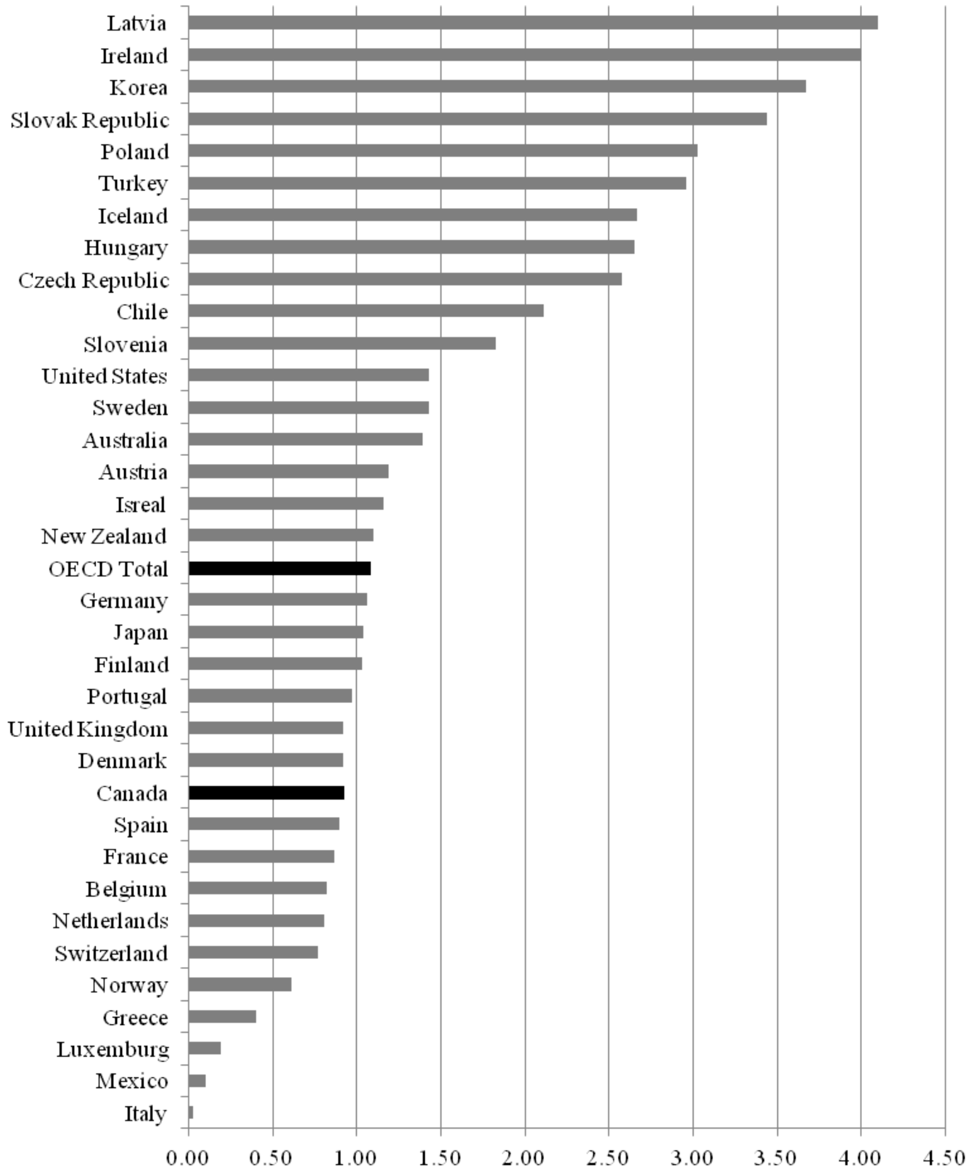

Note: Vertical dotted lines indicate ouptut peaks. Trendlines span between output peaks. i above each trendline indicates the compound annual growth rate in percentage points between the output peaks.
Source: Table 36-10-0208-01, Statistics Canada.

**Chart A3: GDP per hour, Annual Compound Growth Rate, 1981-2000**



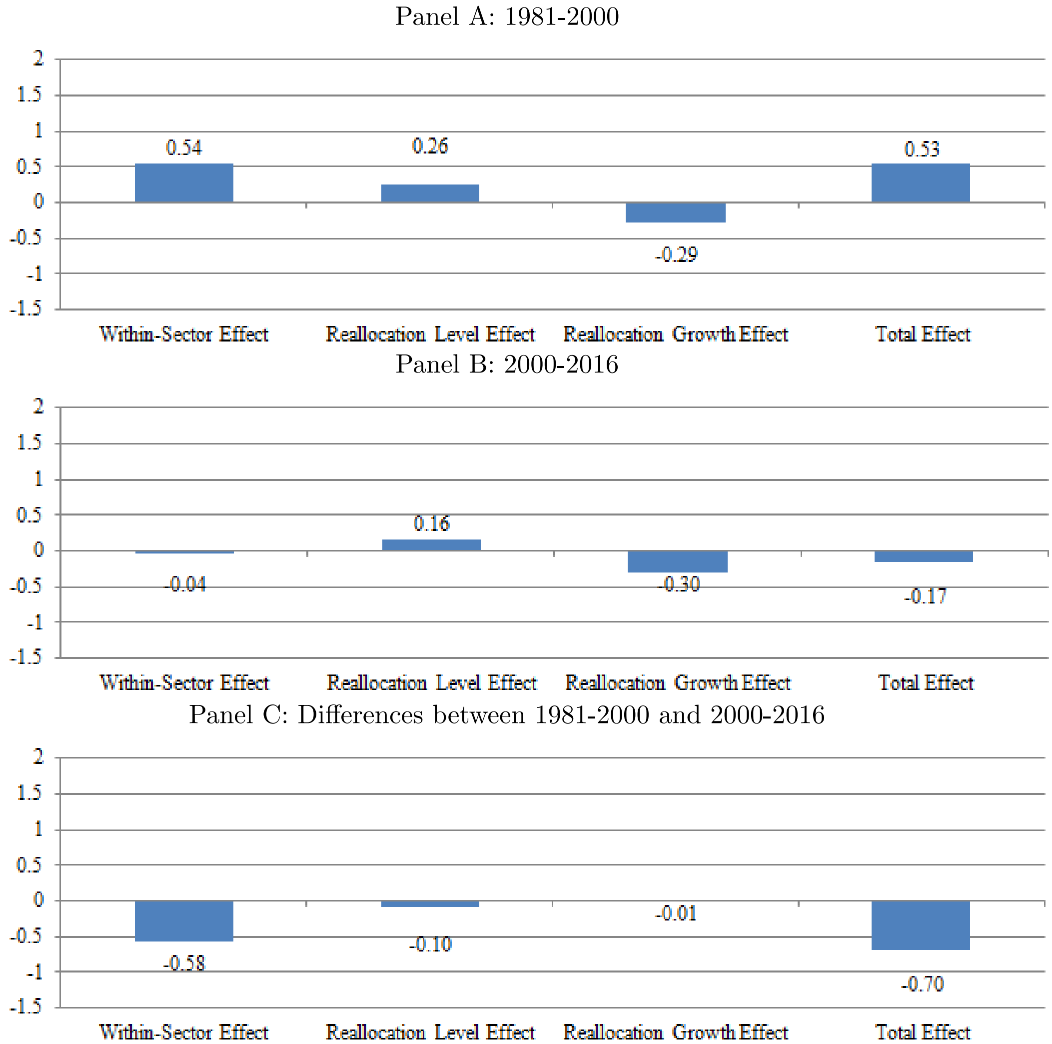

Note: Austria: 1995-2000; Czech Republic: 1993-2000; Greece: 1983-2000; Hungary: 1991-2000; Mexico: 1991-2000; Poland: 1993-2000; Slovak Republic: 1995-2000; Chile: 1986-2000; Latvia: 1995-2000; Slovenia: 1995-2000. Source: OECD. http://stats.oecd.org/Index.aspx?DataSetCode=PDB_GR

**Chart A4: GDP per hour, annual compound growth rate, 2000-2016, per cent**




Source: OECD. http://stats.oecd.org/Index.aspx?DataSetCode=PDB_GR

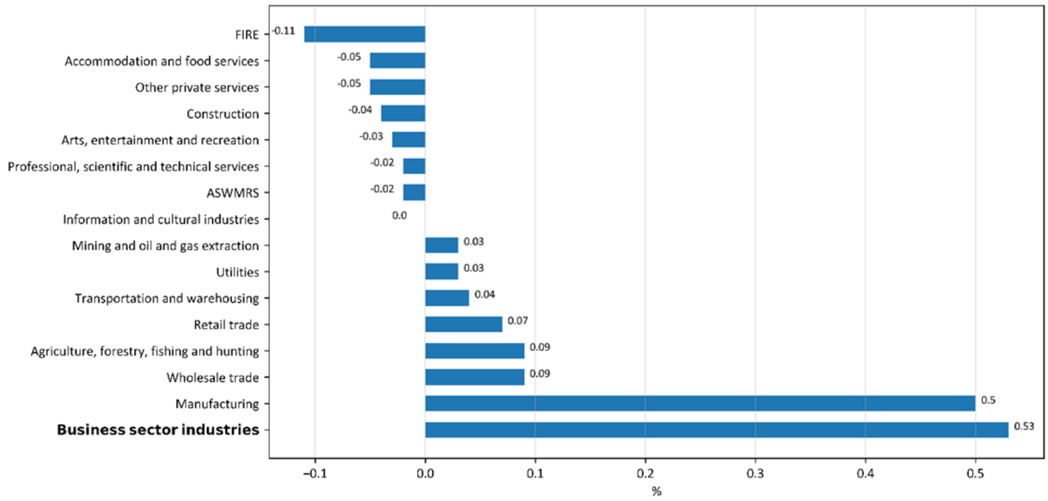
**Chart A5: CSLS Total Factor Productivity Decomposition, Business Sector, Compound Average Annual Growth Rates, Per Cent, Canada, 1981-2000 and 2000-2016**



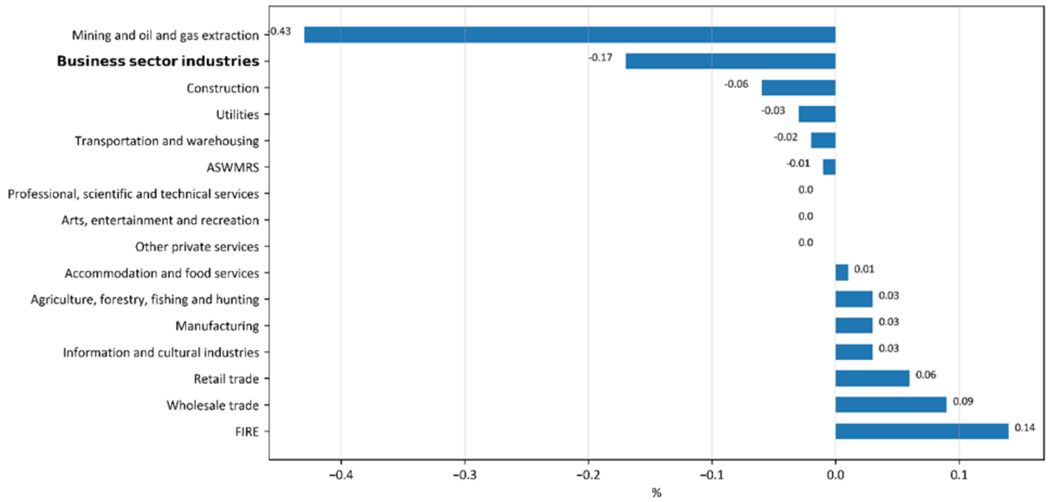

Source: Table 36-10-0208-01, Statistics Canada.
Note: Numbers may not sum due to rounding.

**Chart A6: Contributions to Total Factor Productivity Growth by Industry (percentage points)**

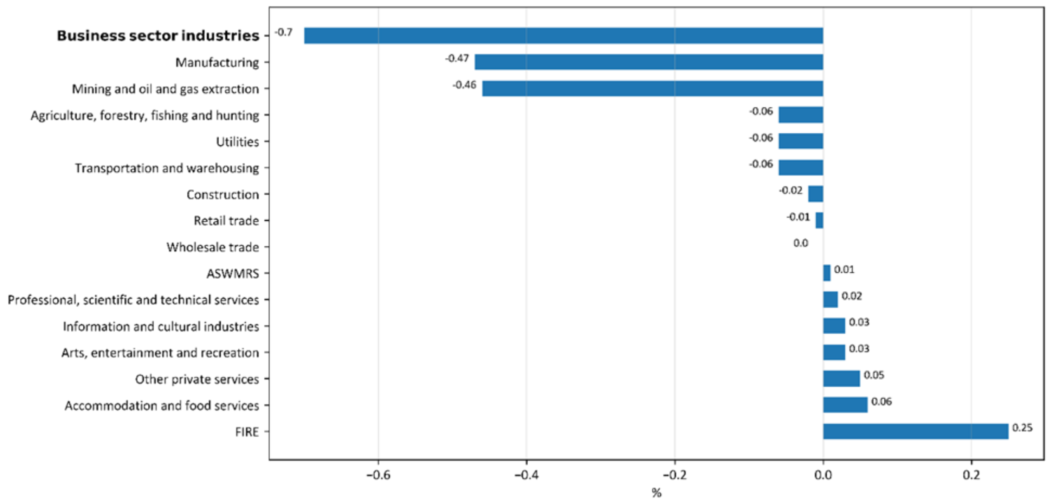
Panel A: 1981-2000




Panel B: 2000-2016




Panel C: Differences between 1981-2000 and 2000-2016 (Percentage Point Change)




Note: FIRE stands for finance, insurance, real estate, rental and leasing. ASWMRS stands for administrative support, waste management and remediation services.
Source: Table 36-10-0208-01, Statistics Canada.

**Table A2: Absolute Labour Productivity, Hours Worked and Input Shares of Mining and Oil and Gas Extraction and Manufacturing, 2000 2016**

| Years | Average Labour Productivity | Mining and oil and gas extraction | | | Manufacturing | | |
|---|---|---|---|---|---|---|---|
| | | Labour Productivity | Hours Worked | Input Share | Labour Productivity | Hours Worked | Input Share |
| | (Chained 2007 dollars per hour worked) | (Chained 2007 dollars per hour worked) | (Million Hours) | (Per Cent) | (Chained 2007 dollars per hour worked) | (Million Hours) | (Per Cent) |
| 2000 | 43.2 | 366.4 | 298.8 | 1.4 | 48.3 | 4086.9 | 18.7 |
| 2001 | 44.0 | 340.3 | 321.6 | 1.5 | 47.5 | 3985.0 | 18.3 |
| 2002 | 44.7 | 370.3 | 307.0 | 1.4 | 48.7 | 3927.8 | 17.8 |
| 2003 | 44.8 | 354.9 | 329.8 | 1.5 | 48.3 | 3924.3 | 17.5 |
| 2004 | 45.0 | 333.0 | 356.6 | 1.5 | 48.6 | 3979.7 | 17.2 |
| 2005 | 46.0 | 286.3 | 417.9 | 1.8 | 50.4 | 3898.8 | 16.8 |
| 2006 | 46.6 | 255.2 | 479.3 | 2.0 | 51.8 | 3739.5 | 15.9 |
| 2007 | 46.7 | 255.0 | 482.7 | 2.0 | 51.6 | 3639.5 | 15.2 |
| 2008 | 46.3 | 237.5 | 507.6 | 2.1 | 52.3 | 3395.7 | 14.1 |
| 2009 | 46.1 | 237.1 | 454.8 | 2.0 | 50.4 | 3042.9 | 13.3 |
| 2010 | 47.0 | 245.3 | 482.3 | 2.1 | 52.0 | 3090.6 | 13.2 |
| 2011 | 48.0 | 236.2 | 535.8 | 2.3 | 53.6 | 3098.3 | 13.0 |
| 2012 | 47.9 | 216.0 | 574.6 | 2.4 | 54.3 | 3106.3 | 12.8 |
| 2013 | 48.4 | 235.8 | 553.9 | 2.2 | 54.0 | 3110.9 | 12.6 |
| 2014 | 49.9 | 255.4 | 553.2 | 2.2 | 56.1 | 3086.5 | 12.4 |
| 2015 | 49.7 | 283.7 | 486.6 | 1.9 | 57.0 | 3039.5 | 12.1 |
| 2016 | 50.0 | 309.9 | 442.5 | 1.8 | 57.7 | 3021.6 | 12.0 |

Source: Table 36-10-0208-01, Statistics Canada.

# Productivity Growth in Canada and the United States: Recent Industry Trends and Potential Explanations

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*Statistics Canada*

Abstract

Labour productivity growth in Canada was weaker than that in the United States from the mid-1980s to 2010, leading to a decline in Canada's relative productivity level. This situation was mainly due to the lower multifactor productivity (MFP) growth experienced in most Canadian industries in that period. After 2010, however, the pattern reversed itself as labour productivity growth in Canada exceeded that of the United States. Higher labour productivity growth in Canada for the 2010-2014 period was due to a relatively larger capital deepening effect and relatively higher MFP growth. Both these developments were associated with stronger output growth and stronger demand in Canada. In addition, the contributions of ICT producing and ICT intensive using industries to U.S. labour productivity growth waned after 2010. For Canada, ICT producing industries contributed little to overall labour productivity before and after 2010, while ICT intensive using industries exhibited stronger productivity growth after 2010. The latter may reflect the more moderate ICT investment in Canada compared to the United States in the 1990s and early 2000s and the more gradual realization of benefits of ICT usage.

Canada's labour productivity declined relative to that of the United States from the mid-1980s to 2010. This relative decline tended to hold back growth in Canada's standard of living relative to that in the United States, as well as Canada's relative competiveness. However, in recent years, this pattern reversed itself. Since 2010, Canada experienced gains in relative labour produc-

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tivity growth compared to that of the United States. The reversal arises both from weaker labour productivity growth in the United States, following the financial crisis of 2008 and 2009, and from more robust labour productivity growth in Canada.

The long decline in Canada's relative labour productivity caused considerable concern in Canada, and was the source of numerous studies. Gu and Ho (2000), Faruqui *et al.* (2003), Ho, Rao and Tang (2004), and Baldwin and Gu (2007) compared industry productivity growth rates in Canada and the United States. They found that Canada's labour productivity relative to that in the United States started to decline in mid 1980s, and that the decline was mainly due to lower multifactor productivity (MFP) growth in Canada. The effect of capital deepening and the effect of changes in labour composition towards more experienced and more educated workers were similar in the two countries. They also found that ICT (information and communication technologies) service industries and high-tech manufacturing (ICT manufacturing and machinery manufacturing) were major sources of difference in relative productivity performance starting in the mid-1980s.[2] Along a similar vein, Sharpe (2003) and Baldwin and Gu (2007) traced the causes to lower innovation performance and lower investment in ICT technologies. More recently, Sharpe and Tsang (2018) and Baldwin and Willox (2016) examined recent developments for productivity growth in Canada.

This article investigates the forces that are driving the reversal after the 2008-2009 financial crisis. It provides a comparison of productivity growth in Canada and the United States over the period from 1987 to 2016, with a focus on the sources of the recent gains in Canada' relative productivity performance after 2010. To understand the sources of these differences at the industry level, industry productivity statistics published in the two countries are used.

While Statistics Canada has published MFP statistics for individual industries of the business sector since the early 1990s, those data have only become available recently in the United States. The main objective of the article is to trace the difference in aggregate labour productivity growth and its three main components into the contributions of individual industries. Those three components are: capital deepening effect, skills upgrading and MFP growth.

More comparable estimates of output, capital, labour, and intermediate input and productivity growth at the industry level for Canada and the United States have become available recently from Statistics Canada and the U.S. Bureau of Labor Statistics (BLS). The most important changes to the estimation that contribute to greater compara-

2 The ICT intensive service industries include wholesale and retail trade, finance and insurance, and communication services.

bility of the estimates come from revisions to the measurement of capital input in Canada and labour input in the United States. The revisions to Canadian data are summarized in Baldwin *et al.* (2014), which now use a method for estimating capital input that is similar to that by the U.S. BLS. Capital input and user cost of capital in both countries are estimated using a rate of return to capital that is smoothed and adjusted to industry averages when there are large and unusual movements. Similar to the estimates of labour composition and labour input from Statistics Canada, the U.S. BLS has also developed labour composition estimates at the industry level that take into account the changes in the composition of hours worked with different education levels and experience of workers. As a result, the concept and estimation of the capital and labour inputs are more comparable in the two countries than they were in the past.

This article is organized as follows. The first main section describes the data sources used for the analysis. The following session provides estimates of the sources of labour productivity growth for the Canadian and U.S. business sectors. It delves into what type of inputs make the most important contributions. The next section then examines which inputs make the largest contributions by industry and illustrates which industries make the largest contributions to business sector growth. The last section discusses the results in light of recent research and concludes.

## Data Sources

Productivity measures in Canada and the United States follow the framework laid down by Jorgenson (1966), Diewert (1976), Jorgenson, Gollop and Fraumeni (1987), Jorgenson, Ho and Stiroh (2005), and Schreyer (2001). In this framework, industry-level productivity growth is estimated using detailed data on gross output and inputs, and aggregate productivity growth is estimated using industry-level data. Industry productivity accounts and aggregate productivity accounts are fully integrated; MFP growth at the aggregate level and MFP growth at the industry level are related to one another through Domar aggregation (Domar, 1961).

At both the industry and aggregate level, MFP growth is defined as output growth that is not accounted for by the growth of inputs. It measures the extent to which inputs are efficiently used in the production process. Growth in MFP is often associated with technological change, organizational change, or economies of scale.

### Canadian Data

Productivity data for the business sector and individual industries in Canada are from the Canadian Productivity Accounts produced by Statistics Canada. Output for the business sector is measured as value added while the output for individual industries is gross output. Gross output and intermediate inputs are derived from Statistics Canada's supply-use tables (SUTs). Real value added is derived from SUTs using double deflation. For the postreference years after 2014 (for which SUTs are not yet available), real value added in the business sector is based on a measure of real value added at basic prices published by the Industry Analysis Division at Statistics Canada.

Hours worked represents the total number of hours that a person devotes to work, whether paid or unpaid. Labour input is hours worked multiplied by a labour composition index. The number of hours worked is calculated as the product of the number of jobs times average hours worked per job, which are derived from household and establishment surveys. The labour composition index estimates the effect of shifts in age (as proxy for experience), education, and class of workers (paid versus self-employed and unpaid family workers) on the total amount of labour services provided by total hours worked (Statistics Canada, 2002).

Capital service input is an estimate of the service flows derived from the stock of capital assets. The capital services measure is based on the bottom-up approach. This approach consists of three steps which involves the estimation of capital stock, the aggregation of capital stock of various asset types within each industry to estimate industry capital services with weights based on the user cost of capital, and the aggregation of capital services across industries to derive capital services in the business sector (Baldwin *et al.* 2014).

## U.S. Data

Productivity data for the private business sector and individual industries in the United States is from the U.S. BLS. Output for the business sector is value added while output for individual industries is measured by sectoral output. Sectoral output of an industry differs from gross output as sectoral output nets out the transactions of intermediate inputs between production units in the industry. The BLS publishes MFP and related variables for the private business and private non-farm business sectors. More recently, it has also released the MFP data base for individual industries back to 1987. For the purpose of this article, we focus on the productivity performance of the U.S. private business sector and compare it with the Canadian business sector. The methods for constructing MFP in the U.S. private business sector are documented in Fleck et al. (2014).[3]

The main analysis of this article focuses on the period from 1987 to 2014 when the industry productivity data are available in both countries.

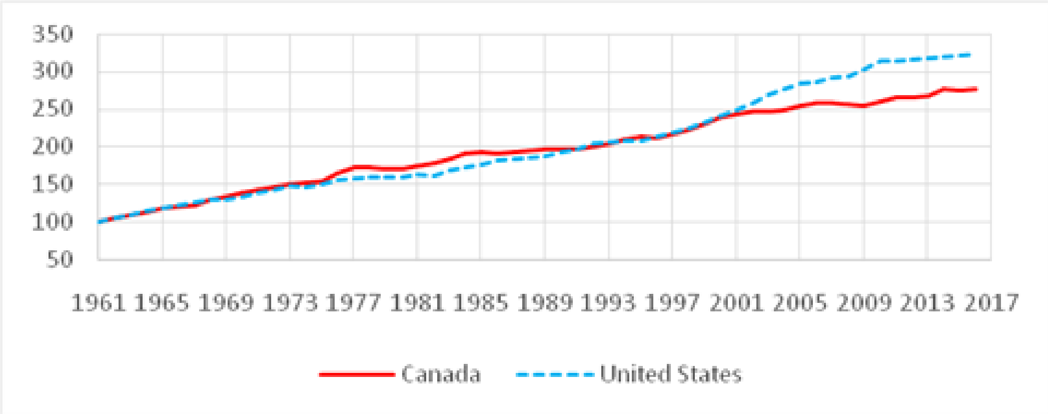
## Sources of Business Sector Labour Productivity Growth

Chart 1 presents the Canada-U.S. absolute and relative labour productivity for the business sector over the period from 1961 to 2016. Canadian labour productivity growth exceeded that of the United States up to the mid-1980s. From the mid-1980s to 2010, U.S. labour

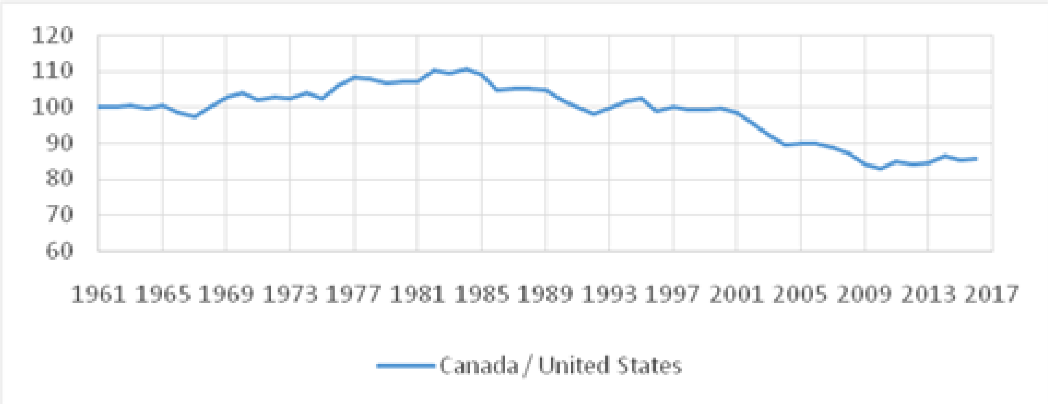
3 In the remainder of the article, the U.S. private business sector is referred to as the U.S. business sector.

**Chart 1: Labour Productivity in the Business Sector, Canada and the United States, 1961-2016**

Panel A: Labour productivity, Index (1961 = 100)




Panel B: Relative labour productivity of Canada compared to the United States, Index (1961 = 100 in both countries)




Sources. Statistics Canada and the Bureau of Labor Statistics.

productivity growth exceeded Canadian growth. The gap widened over that period, particularly for the period from 2000 to 2010. After 2010, Canadian labour productivity growth exceeded that of the United States.

Both Statistics Canada and the U.S. BLS decompose labour productivity growth into three components or sources of growth: capital intensity, the skill level of the labour force (due to changes in labour composition) and a residual (MFP growth). The first two components (both arising from investment, one in fixed capital such a machinery, structures and R&D, the other in education and training) were similar in the two countries after the mid-1980s. The third (the residual often referred to MFP growth that captures innovation, technological change and capacity utilization changes, and some measurement errors) was larger in the United States (Baldwin and Gu, 2007).

Table 1 summarizes labour productivity growth and its three main components in the Canadian and U.S. total business sectors. The results for the aggregate business sectors are presented for the period 1987 to 2014 as produc-

**Table 1: Sources of Labour Productivity Growth in the Business Sector, Canada and the United States (average annual rate of change)**

| | 1987-2010 | 2010-2014 | 2010-2014 less 1987-2010 |
|---|---|---|---|
| **Canada** | | | |
| Labour productivity growth | 1.30 | 1.53 | 0.24 |
| Contribution of capital intensity | 0.98 | 0.65 | -0.33 |
| Contribution of labour composition | 0.34 | 0.14 | -0.20 |
| Multifactor productivity growth | -0.02 | 0.75 | 0.77 |
| **United States** | | | |
| Labour productivity growth | 2.33 | 0.50 | -1.83 |
| Contribution of capital intensity | 0.98 | -0.16 | -1.14 |
| Contribution of labour composition | 0.30 | 0.17 | -0.13 |
| Multifactor productivity growth | 1.05 | 0.49 | -0.56 |
| **Canada minus the United States** | | | |
| Labour productivity growth | -1.03 | 1.04 | 2.07 |
| Contribution of capital intensity | 0.00 | 0.81 | 0.81 |
| Contribution of labour composition | 0.04 | -0.03 | -0.07 |
| Multifactor productivity growth | -1.07 | 0.26 | 1.33 |

Source: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics.

tivity data at the industry level are only available over that period in both countries, and a comparison of productivity growth at the industry level is made for that period.

For the 1987-2010 period, labour productivity growth was slower in Canada than in the United States. Labour productivity rose at 1.30 per cent per year in the Canadian business sector, while it increased 2.33 per cent per year in the U. S. business sector.

The slower labour productivity growth in Canada compared with that in the United States in the period from 1987 to 2010 reflected slower MFP growth in Canada, a fact that is well documented in previous studies (e.g. Baldwin and Gu, 2007). The effects of capital deepening, skills upgrading or changes in labour composition towards more educated and more experienced workers on productivity growth were nearly identical in the two countries.

After 2010, labour productivity growth increased in Canada, from 1.30 per cent per year in the 1987-2010 period to 1.53 per cent in the 2010-2014 period. This increase after 2010 was due to higher MFP growth. The capital deepening effect and, to a lesser extent, the effect of labour composition both declined.

In contrast, for the United States, labour productivity declined after 2010. The decline in labour productivity growth from 2.33 per cent in 1987-2010 to 0.5 per cent in 2010-2014 was mostly attributed to weaker contributions from the capital deepening effect and, to a lesser extent, from weaker MFP growth. Those results have been documented in previous studies (Baily and Montalbono, 2016, Manyika, *et al.*, 2017, and Murray, 2018). The weaker effect of labour composition after 2010 also contributed to the slowdown in aggregate labour productivity growth in the United States.

As a result of the divergent trends in labour productivity growth in the two countries, labour productivity in the business sector in Canada increased at a faster pace than in the United States for the 2010-2014 period. At the pace of 1.53 per cent per year on average in Canada over this period, was triple the 0.50 per cent average annual increase in the United States. The relatively faster growth in labour productivity in Canada over the period after 2010 was due to the relatively faster growth in capital intensity and, to lesser extent, the relatively faster growth in MFP in Canada. For the 2010-2014 period, increases in capital intensity contributed an annual average of 0.65 percentage points to labour productivity growth in Canada. By comparison, capital intensity declined in the United States, subtracting an average of 0.16 percentage points annually from U.S. labour productivity growth.

Over the same period, MFP growth was higher in Canada than in the United States. Multifactor productivity contributed an annual average of 0.75 percentage points to labour productivity growth in Canada, and it contributed an annual average of 0.49 percentage points to labour productivity growth in the United States.

The third component of labour productivity growth – the effect of skill upgrading on labour composition – was similar in the two countries after 2000. For the period from 2010 to 2014, skills upgrading contributed 0.14 percentage points annually in Canada and 0.17 percentage points in the United States.

The comparison for the business sector covering more recent years shows that labour productivity growth was also higher in Canada than that in the United States. For the period 2010 to 2017, labour productivity growth was 1.22 per year in the Canadian business sector, compared with 0.65 per year for the U.S. business sector. The relatively higher labour productivity growth in Canada for the period 2010 to 2017 reflects the high relative productivity growth in Canada for the period 2010 to 2014 (shown in Table 1) and a similar productivity growth for the period 2014 to 2017.[4] The superior labour productivity performance of Canada relative to the United States fell off significantly after 2014. The productivity growth gap was 1.04 percentage points in Canada's favour in 2010-2014, but fell to 0.57 points in 2010-2017 because of the addition of the 2014-2017 period when labour productivity growth was the same in the two countries.

4 There was a slight pickup in business sector labour productivity growth in the United States and a decline in Canada over the 2014-2017 period compared with the 2010-2014 period. As a result, labour productivity rose at a similar rate of 0.8 per cent per year in the two countries over the period 2014 to 2017.

## Sources of Labour Productivity Growth Across Industries

Output in the Canadian industry productivity database is measured using gross output while it is measured using sectoral output in the United States.[5] Multifactor productivity growth based on sectoral output is higher than MFP growth based on gross output. This will bias the comparison in favour of the United States. But it will not affect its contribution to aggregate productivity growth, a property of the Domar aggregation.[6]

Labour productivity growth at the industry level is defined as gross output (or sectoral output) per hour worked. The growth in labour productivity can be decomposed into the contributions from capital deepening, labour composition change, intermediate input deepening, and MFP growth. The effect of capital deepening measures the effect of an increase in capital intensity on labour productivity growth and is estimated as the growth in the capital-labour ratio times the share of capital compensation in gross output. The effect of labour composition changes captures the effect of skills upgrading and is estimated as the change in labour composition times the share of labour compensation in gross output. The effect of intermediate input deepening captures the effect of outsourcing on labour productivity growth and is estimated as the growth in the intermediate input-to-labour ratio times the share of intermediate inputs in gross output.

Tables A1 and A2 in the Appendix [7] present the sources of labour productivity growth by industry for Canada and the United States, respectively, over the period from 1987 to 2010. The results, averaged across industries, are summarized in Chart 2.

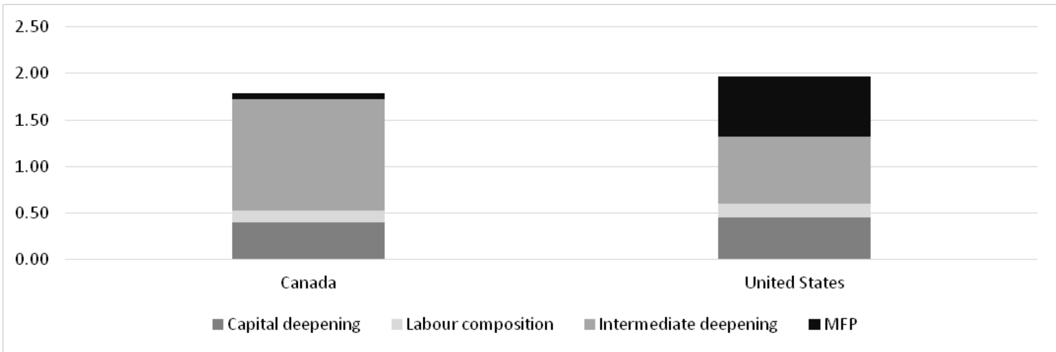
For the 1987-2010 period, in Canada and the United States, the largest contributor to labour productivity growth was intermediate input deepening across industries, reflecting the trends towards out-sourcing of intermediate inputs from domestic industries and abroad. Capital deepening was an important contributor to labour productivity growth in both countries as was the shift of workers towards higher education levels and more experience. Multifactor productivity growth was an important contributor to labour productivity growth in the United States on average, but it made a much smaller average contribution to

5 Data are comparable between Canada and the United States using 3-digit NAICS codes for the goods sector except for utilities and construction, which are defined at the 2-digit NAICS code level. Services sector industries are also defined at the 2-digit NAICS code level, except for the management of companies industry, which is included in finance and insurance. Finance and insurance also excludes the imputed rent of owner occupied dwellings. Retail trade combines NAICS codes 44 and 45. Transportation combines NAICS codes 48 and 49.

6 Multifactor productivity growth based on sectoral output is equal to MFP growth based on gross output times the ratio of nominal gross output to nominal sectoral output. The contribution of an industry to aggregate value added MFP growth is equal to industry MFP growth times the ratio of industry output to aggregate value added. Industry contributions to aggregate value added MFP growth are not affected by the choice of output used for calculating MFP growth.

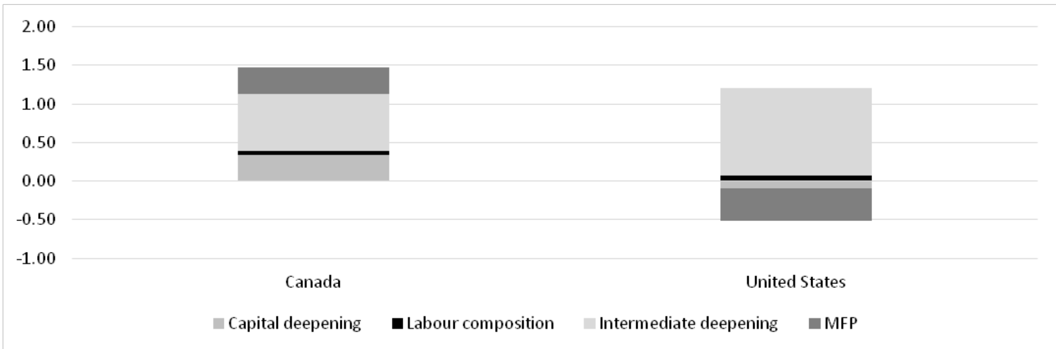
7 The Appendix is posted with this article at http://www.csls.ca/ipm/35/Gu_Willox_appendix.pdf.

**Chart 2: Sources of Labour Productivity Growth in Average Canadian and U.S. Industries, 1987-2010 (average annual rate of change)**




Source: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics.

**Chart 3: Sources of Labour Productivity Growth in Average Canadian and U.S. Industries, 2010-2014 (percentage point contribution per year)**




Source: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics.

labour productivity growth in Canada.

Tables A3 and A4 in Appendix present the sources of labour productivity growth by industry for Canada and the United States over the 2010-2014 period, which are summarized in Chart 3 for average industries.

For both Canada and the United States, intermediate input deepening remained the most important contributor, from a growth accounting (not causal) perspective, to labour productivity growth in the period 2010 to 2014.

The capital deepening effect and MFP growth made positive contributions to labour productivity growth on average in Canadian industries. But, the capital deepening effect and MFP growth made negative contributions to labour productivity growth in the U.S. industries after 2010. The decline in both the capital deepening effect and MFP growth in the United States after the financial crisis has been well documented (e.g., Baily *et al.*, 2016).

For the 1987-2010 period, labour productivity growth, capital deepening, intermediate input deepening and MFP are statistically significantly correlated across industries between Canada and the United States. For both countries, the industries with a relatively high capital deepening effect and MFP growth are those industries that are either producers of information and communication goods and services (ICT) or intensive users of ICT. This suggests that similar demand, investment, technology, and innovation factors are contributing to the growth of those industries in both countries. For example, previous studies found that MFP growth is associated with investment in information and communication technologies, and offshoring (Ho, Rao and Tang, 2004).

For the period after 2010, MFP growth, capital deepening and intermediate input deepening are not correlated across industries in the two countries. The Canadian industries with relatively higher MFP growth and input deepening differ from those industries in the United States. It could be that the effect is temporary, and simply reflects the relatively larger impact of the Great Recession on the United States. It may also reflect a de-coupling of the Canadian and American economies as U.S. firms, particularly manufacturing firms, reduce their foreign direct investment in Canada. It may also point to different factors affecting industry productivity growth in the two countries. These factors include the adjustment of the industries in the two countries to emerging technologies such as digitalization, robots, internet of things or the adoption of digital technologies and associated changes in business innovation.

## Industry Contributions to Aggregate Labour Productivity Growth

This section examines the industry contribution to Canada–U. S. differences in aggregate labour productivity growth and its three main components: capital deepening, labour composition and MFP growth in two periods, 1987-2010 and 2010-2014. Using the industry productivity database presented earlier, this section focuses on the industry contributions to the differences in aggregate labour productivity growth in the two countries identified in the previous section by addressing two main issues.

First, for the 1987-2010 period, aggregate labour productivity growth in the business sector was slower in Canada compared with that in the United States. The relatively slower growth in Canada's aggregate labour productivity was mainly due to the relatively slower MFP growth in Canada. This section addresses which industries contributed to the relatively slower labour productivity and MFP growth in Canada in the 1987-2010 period.

Second, for the 2010-2014 period, aggregate labour productivity growth was higher in Canada compared with that in the U.S. This situation was mainly due to the relatively stronger capital deepening effect and higher multifactor growth in Canada. This section also addresses which industries contributed to the relatively higher labour productivity and MFP growth, and higher capital deepening effect in Canada in the 2010-2014 period.

The contributions of industries to

aggregate labour productivity growth and its components are measured using the direct industry aggregation approach proposed by Domar (1961) and used by Jorgenson, Ho, Samuels, and Stiroh (2007), Fleck *et al.* (2014) and Gu (2018). In this approach, aggregate value-added labour productivity growth is the share-weighted growth of industry value-added labour productivity growth, where the weights used are calculated as the industry shares of nominal value added. The contribution of industry capital deepening, labour compositional changes and MFP growth to aggregate value-added labour productivity growth is the Domar-weighted contribution. Each industry's Domar weight is the ratio of the industry's current-dollar gross or sectoral output to aggregate current-dollar value added. The industry's contribution to aggregate MFP growth is the industry's MFP growth multiplied by its Domar weight. The contribution of industry intermediate input deepening cancels out.[8]

The sum of industry contributions may differ from aggregate value-added labour productivity growth and its three main components. The difference reflects the reallocation of capital input, labour input and value added output across industries. The difference is small except for industry contributions to aggregate labour and MFP growth for the United States over the 2010-2014 period. For that period, the reallocation of output across industries made a significant contribution to aggregate labour productivity and MFP growth in the United States. It contributed about 0.3 percentage points to aggregate labour productivity growth and contributed 0.4 percentage points to aggregate MFP growth (Table 3 and Table A10).[9]

Table 2 presents a comparison of the contribution to aggregate labour productivity growth by industry for Canada and the United States for the 1987-2010 period. Over that period, labour productivity growth in the business sector was slower in Canada than that in the United States. Most Canadian industries (21 of 38) contributed to Canada's lower labour productivity growth. Consistent with the findings from previous studies, the results show that the largest contributors to relatively slower labour productivity growth in Canada include: computer and electronic products, information and culture industries, finance and insurance, utilities, professional services, retail and wholesale trade. Those industries are mostly related to the production and use of ICT. When industries are classified into three main groups:

8 As the costs of inputs is not equal to the value of output when the exogenous rate of return is used to estimate the user cost of capital, modified Domar weights or cost weights are used for the aggregation for Canada (Gu, 2018).

9 For a rich discussion on this issue see Reinsdorf, Marshall (2015), Baldwin and Willox (2016), Balk (2014), de Avillez (2012), Nordhaus (2001), and Sharpe (2010). The estimated effects of reallocation on labour productivity and MFP growth appears to be large. A large and positive contribution of reallocation to labour productivity growth in the United States for the 2010-2014 period is also found in Remes *et al.* (2018) using the EUKLEMS database.

**Table 2: Contributions to Business Sector Labour Productivity Growth by Industry in Canada and the United States, 1987-2010 (percentage points per year)**

| Industry | Canada | United States | Canada - U.S. |
|---|---|---|---|
| Computer and electronic products | 0.05 | 0.52 | -0.48 |
| Information and cultural industries | 0.09 | 0.27 | -0.17 |
| Finance and insurance | 0.19 | 0.35 | -0.16 |
| Utilities | -0.01 | 0.13 | -0.13 |
| Professional service | 0.04 | 0.14 | -0.10 |
| Retail trade | 0.15 | 0.25 | -0.09 |
| Wholesale trade | 0.20 | 0.26 | -0.07 |
| Chemical manufacturing | 0.00 | 0.07 | -0.06 |
| Administration, waste management | 0.01 | 0.06 | -0.05 |
| Plastics and rubber products | 0.04 | 0.08 | -0.05 |
| Oil and gas extraction | -0.04 | 0.01 | -0.04 |
| Transportation and warehousing | 0.06 | 0.10 | -0.04 |
| Clothing, leather and allied products | 0.01 | 0.03 | -0.02 |
| Miscellaneous manufacturing | 0.01 | 0.03 | -0.02 |
| Mining (exc. oil & gas extraction) | 0.00 | 0.02 | -0.02 |
| Arts, entertainment and recreation | -0.01 | 0.01 | -0.01 |
| Petroleum and coal products | 0.00 | 0.02 | -0.01 |
| Accommodation and food services | 0.01 | 0.02 | -0.01 |
| Textile and textile products | 0.00 | 0.01 | -0.01 |
| Wood products | 0.02 | 0.02 | -0.01 |
| Support activities for mining, oil & gas | 0.00 | 0.01 | -0.01 |
| Fabricated metal products | 0.01 | 0.01 | 0.00 |
| Furniture and related products | 0.01 | 0.00 | 0.00 |
| Crop and animal production | 0.09 | 0.08 | 0.00 |
| Non-metallic mineral products | 0.01 | 0.00 | 0.01 |
| Machinery | 0.02 | 0.01 | 0.01 |
| Transportation equipment | 0.08 | 0.07 | 0.01 |
| Electrical equipment | 0.01 | 0.00 | 0.01 |
| Educational services | 0.00 | -0.01 | 0.01 |
| Food, beverage and tobacco | 0.02 | 0.01 | 0.01 |
| Forestry, fishing, and related | 0.02 | 0.00 | 0.02 |
| Paper | 0.03 | 0.00 | 0.02 |
| Other services | 0.01 | -0.01 | 0.03 |
| Primary metal | 0.05 | 0.02 | 0.03 |
| Printing and related | 0.04 | 0.01 | 0.03 |
| Health care and social assistance | -0.02 | -0.08 | 0.06 |
| Construction | 0.01 | -0.06 | 0.08 |
| Sum of industry contributions | 1.23 | 2.46 | -1.24 |
| Reallocation | 0.07 | -0.13 | 0.21 |
| Aggregate labour productivity | 1.30 | 2.33 | -1.03 |

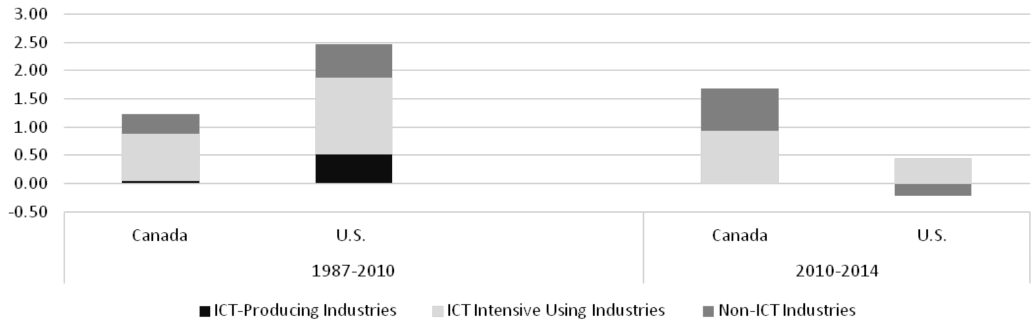
Note: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics. Industries are sorted by Canada - U.S. difference.

ICT producing industries, ICT intensive using industries and non-ICT intensive using industries, shown in Chart 4, ICT producing industries and ICT intensive using industries each accounted for 0.5 percentage points of the overall lower labour productivity growth in Canada. Non-ICT intensive using industries accounted for 0.3 percentage points.[10]

Tables A5, A6 and A7 in the appendix present industry contributions to the aggregate capital deepening effect, aggregate labour compositional changes and aggregate MFP growth by industry

10 The classification of industries to ICT-producing and ICT-using industries are adopted from Jorgenson, Ho and Samuels (2010). The ICT-producing industry is defined as computer and electronic product manufacturing industry. The ICT-using industries, more specifically ICT-intensive using industries, consist of construction, machinery, wholesale and retail, transportation, information and culture, finance and insurance, and professional service. The non-ICT using industries, more specifically low-intensive ICT-using industries, are all other industries.

**Chart 4: Contributions of Industry Groups to Aggregate Labour Productivity Growth, Canada and the United States, (percentage points per year)**




Source: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics.

for Canada and the United States for the 1987-2010 period. Chart 5 aggregates the industry contributions to capital deepening, labour composition and MFP, into contributions from three main industry groups: ICT producing industries, ICT intensive using industries and non-ICT intensive using industries.

The ICT producing and ICT intensive using industries contributed to the relatively lower aggregate capital deepening effect in Canada for the 1987-2010 period, which was partly offset by the positive contribution from higher capital deepening effect from non-ICT intensive using industries such as mining and oil and gas extraction.

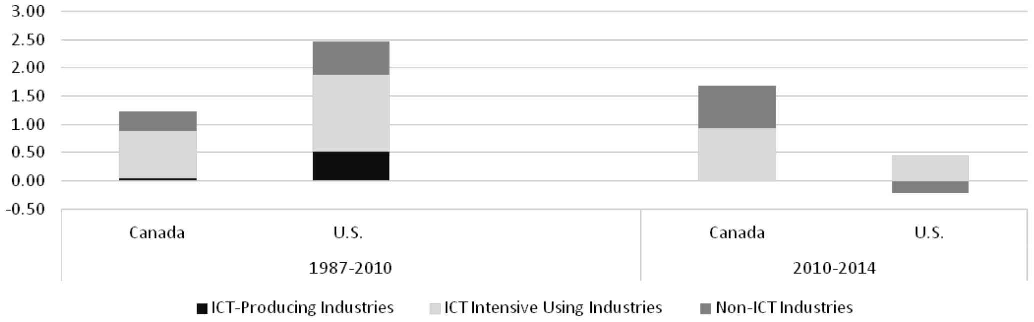
The difference in aggregate labour composition was small in the two countries during the 1987-2010 period, which was a result of positive contributions from half of the Canadian industries being offset by negative contributions from the remaining half of the industries.

Most Canadian industries contributed to the relatively lower MFP growth in Canada compared with that in the United States for the 1987-2010 period. The industries that made the largest contributions to slower MFP growth in Canada were similar to those that contributed to slower aggregate labour productivity growth. Those industries include computer and electronic products, oil and gas extraction, retail trade, transportation and warehousing, and wholesale trade. ICT producing industries and ICT intensive using industries each accounted for 0.4 percentage points of the overall lower MFP growth in Canada. Non-ICT intensive using industries accounted for 0.3 percentage points (Panel C in Chart 5).

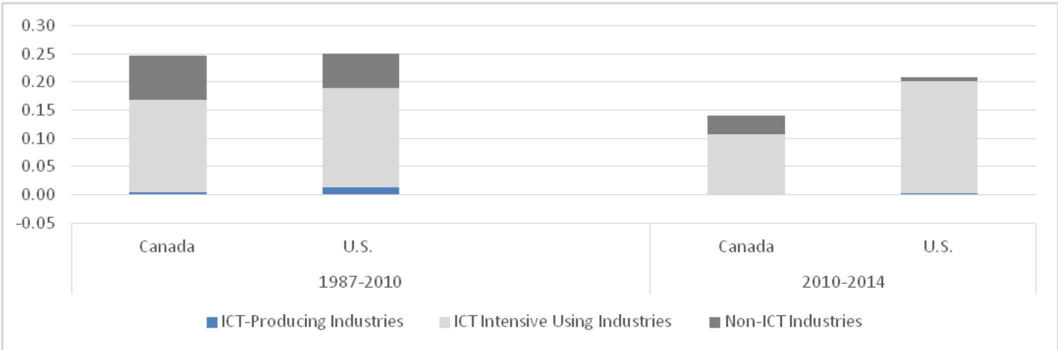
Table 3 presents industry contributions to aggregate labour productivity growth for Canada and the United States for the 2010-2014 period. Tables A8, A9 and A10 in the Appendix present industry contributions to the aggregate capital deepening effect, labour compositional changes and MFP growth. The industry contributions are aggregated into three main industry groups in charts 4 and 5: ICT producing indus-

**Chart 5: Contributions of Industry Groups to Business Sector Capital Deepening, Labour Composition, and Multifactor Productivity Growth, Canada and the United States (percentage points per year)**

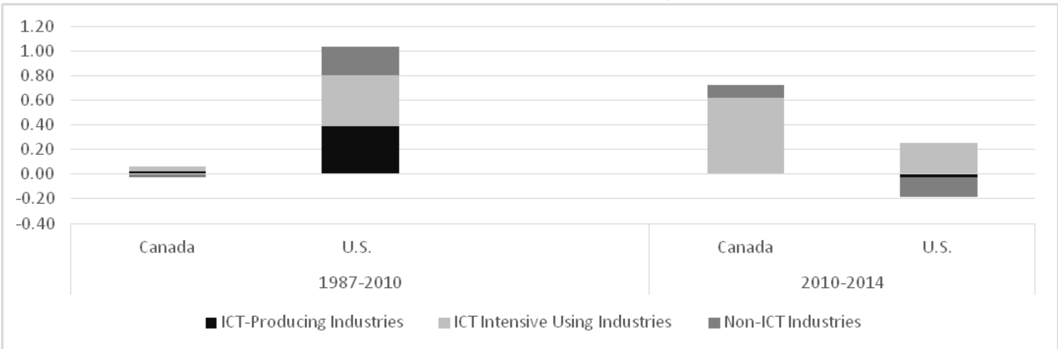
Panel A: Capital Deepening




Panel B: Labour Composition




Panel C: Multifactor Productivity Growth




Source: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics.

**Table 3: Contributions to Business Sector Labour Productivity Growth by Industry in Canada and the United States, 2010-2014 (percentage points per year)**

| Industry | Canada | United States | Canada - U.S. |
|---|---|---|---|
| Information and cultural industries | 0.03 | 0.16 | -0.14 |
| Construction | -0.16 | -0.05 | -0.11 |
| Mining (exc. oil & gas extraction) | -0.08 | -0.02 | -0.06 |
| Transportation equipment | 0.00 | 0.04 | -0.04 |
| Printing and related | -0.01 | 0.00 | -0.01 |
| Forestry, fishing, and related | -0.01 | 0.00 | -0.01 |
| Crop and animal production | -0.02 | -0.01 | -0.01 |
| Textile and textile products | 0.00 | 0.01 | -0.01 |
| Petroleum and coal products | 0.00 | 0.01 | 0.00 |
| Finance and insurance | 0.24 | 0.24 | 0.00 |
| Non-metallic mineral products | 0.01 | 0.01 | 0.00 |
| Electrical equipment | 0.00 | -0.01 | 0.01 |
| Furniture and related products | 0.01 | -0.01 | 0.01 |
| Arts, entertainment and recreation | 0.01 | 0.00 | 0.01 |
| Computer and electronic products | 0.01 | 0.00 | 0.01 |
| Accommodation and food services | 0.03 | 0.02 | 0.02 |
| Educational services | 0.00 | -0.02 | 0.02 |
| Retail trade | 0.07 | 0.05 | 0.02 |
| Primary metal | 0.03 | 0.01 | 0.02 |
| Paper | 0.02 | -0.01 | 0.03 |
| Clothing, leather and allied products | 0.00 | -0.03 | 0.03 |
| Chemical manufacturing | 0.06 | 0.03 | 0.03 |
| Support activities for mining, oil & gas | 0.04 | 0.01 | 0.03 |
| Miscellaneous manufacturing | 0.00 | -0.03 | 0.03 |
| Wood products | 0.02 | -0.03 | 0.05 |
| Machinery | 0.04 | -0.02 | 0.06 |
| Other services | 0.06 | -0.01 | 0.07 |
| Food, beverage and tobacco | 0.04 | -0.03 | 0.07 |
| Fabricated metal products | 0.03 | -0.04 | 0.07 |
| Health care and social assistance | 0.05 | -0.03 | 0.07 |
| Administration, waste management | 0.07 | -0.04 | 0.10 |
| Utilities | 0.12 | 0.01 | 0.11 |
| Professional service | 0.20 | 0.06 | 0.14 |
| Wholesale trade | 0.24 | 0.07 | 0.16 |
| Transportation and warehousing | 0.15 | -0.04 | 0.18 |
| Plastics and rubber products | 0.03 | -0.17 | 0.20 |
| Oil and gas extraction | 0.34 | 0.07 | 0.27 |
| Sum of industry contributions | 1.68 | 0.23 | 1.44 |
| Reallocation | -0.15 | 0.27 | -0.40 |
| Aggregate labour productivity | 1.53 | 0.50 | 1.04 |

Note: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics. Industries are sorted by Canada – U.S. difference.

tries, ICT intensive using industries and non-ICT intensive using industries. For the 2010-2014 period, most Canadian industries had higher labour productivity growth (30 out of 38 industries), capital deepening effects (29 of 38), and MFP growth (29 of 38) than their United States counterparts. Canada's relatively better performance in labour productivity growth, capital deepening and MFP growth occurred in both ICT and non-ICT intensive using industries. The effect of labour composition was slightly lower in ICT intensive using industries in Canada and similar in other industries.

## Potential Explanations for Canada-United States Differences in Productivity Growth

To understand the divergence in Canada-U.S. productivity performance starting in 2010, it is useful to begin with explanations for the declining labour productivity in the two countries since the early 2000s. Previous studies have proposed reasons ranging from measurement issues to technological innovation and secular stagnation.[11]

The first explanation focuses on the mismeasurement of output, inputs and productivity in the new digital economy. It is argued that GDP and productivity is increasingly difficult to measure, as it fails to capture capital input arising from intangible capital and digital technologies and to capture the benefits of intangibles and digital technologies in output measures.[12]

A second explanation focuses on the impact of technological innovation and its diffusion. On the one hand, the ICT boom of the 1990s appears to have waned in the United States while the emerging digital technologies (mobile technology, the internet, and cloud computing) have yet to generate gains in productivity (van Ark, 2016). Brynjolfsson, Rock and Syverson (2017) argue that there are long lags before digital technologies have an impact on productivity. The rise of intangibles and its macroeconomic implications for productivity growth documented by Haskel and Westlake (2017) also lends some support to the view that digital technologies combined with investment in intangibles will have an impact on productivity growth with a lag. This explanation is sometimes referred to the Solow paradox redux (Manyika *et al.* 2017). On the other hand, it has been argued that the digital technologies are unlikely to have as big effect on productivity growth compared with previous innovations such as the internal combustion engine and electricity (Gordon, 2016).

A third explanation focuses on the rise of secular stagnation and the impact of weak demand on business investment and other productivity-enhancing business innovations after the financial crisis. The shortage of demand and investment opportunities have had a negative effect on investment and capital deepening and technical progress embodied in capital investment, key drivers of productivity growth. In an environment characterized by weak demand, businesses have less incentive to investment in capital and other innovation activities.

Other explanations for slower productivity growth in advanced economies include a decline in business dynamism and an increase in mis-allocation of capital between firms, which have acted as a drag on productivity growth.[13]

Similar to the experience in the United States and other advanced economies, labour productivity growth also slowed in Canada after 2000 before the recent pickup after 2010. For

11 See, for example Adler *et al.* (2017), Baily and Montalbano (2016), Manyika *et al.* (2017), Murray (2018), and Remes *et al.* (2018)

12 Intangible capital includes computerized information, innovative property and economic competency. See Gu, Macdonald, and Rispoli (2018)

13 Adler *et al.* (2017) provided a review and empirical evidence on the root causes of declining productivity growth in advanced economies.

the period after 2010, higher labour productivity growth in Canada than in the United States begs the question: are the three explanations for slower productivity growth in the United States less important for Canada?

The mismeasurement of productivity growth thus far has not been found to be an important explanation for slow productivity growth in either Canada or the United States. MFP growth may be under-estimated for various reasons including missing growth from new firms and products (Aghion *et al.*, 2018). Gu (2018) and Gu, Macdonald and Rispoli (2018) found that issues associated with the measurement of intangible knowledge capital had little effect on labour productivity growth estimates. They increased labour productivity growth by 0.1 or 0.2 percentage points per year, but the increase was slightly larger in the period before 2010 when intangible capital increased much faster, similar to the findings reported for the United States (Byrne, Fernald and Reinsdorf, 2016).

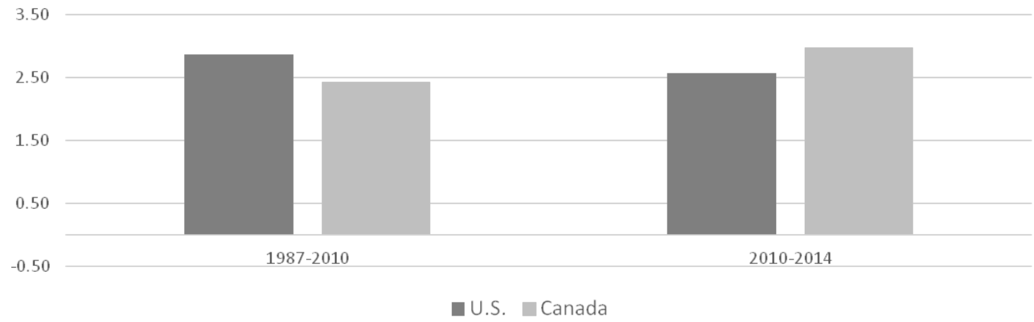
Byrne, Fernald and Reinsdorf (2016) noted that the measurement issues did not become worse over the past decade, and therefore did not account for the decline in MFP growth. It seems unlikely that the difference in measurement issues between Canada and the United States in favour of Canada would have worsened; thus contributing to the difference in MFP growth in favour of Canada.

The Solow paradox redux appears to be an important explanation for the slowdown in productivity growth in the United States as MFP growth that is commonly associated with innovation and technological progress declined in the United States after 2010. After boosting aggregate MFP growth in the United States in the late 1990s and early 2000s, productivity gains from the use and production of ICT appear to have waned in the United States (Adler *et al.* 2017). The MFP growth from ICT intensive using and ICT producing industries declined after 2010 compared with that in the 1987-2010 period (Panel C in Chart 5).

In contrast to falling MFP growth in the United States, MFP growth increased in Canada after 2010. Multifactor productivity growth in Canada was essentially zero for 1987 to 2010 period, but it posted a growth rate of 0.75 per cent year for the period from 2010 to 2014. The MFP contribution from ICT intensive using industries increased in Canada after 2010 compared with the period 1987 to 2010 (Panel C in Chart 5).

While the gains from ICT use and production appear to have waned in the United States, the gains from ICT use in Canada do not appear to have petered out. The continued strong contribution from ICT intensive using industries may reflect the fact that the ICT boom of the 1990s and the early 2000s was more modest in Canada compared with that in the United States. While U.S. industries appear to have exhausted productivity gains from ICT, Canadian industries had much lower ICT investment in the 1990s and 2000s, and therefore, continue to benefit from investment in ICT

**Chart 6: Output Growth in the Business Sector, Canada and the United States (average annual rate of change)**




Source: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics.

in the 2000s.[14]

The last explanation for the U.S. productivity slowdown focuses on the rise of secular stagnation and the impact of the weak demand on investment and MFP growth. Output growth was faster in Canada than in the United States after the financial crisis (as shown in Chart 6).[15] Strong demand growth in Canada after 2010 has led to a large increase in industrial capacity utilization rate (as measured by ratio of actual output to potential output) in Canada. Industrial capacity utilization in Canada increased 3 percentage points from 79 per cent to 82 per cent over the 2010-2014 period. There was an additional but more modest increase of 0.23 percentage points over the 2014-2017 period.[16]

According to the U.S. Federal Reserve Board, industrial capacity utilization in the U.S. was lower in the United States over that period. It increased from 74 per cent to 79 per cent from 2010 to 2014, and then declined to 76 per cent in 2017. Is it possible that stronger demand in Canada either from international trade or the domestic economy has led to a higher capital deepening effect and higher MFP growth in Canadian industries?

Examining slower productivity growth in Canada compared with the United States after 2000, Rao and Li (2013) found that most of the post-2000 slowdown in business sector labour productivity growth was a result of weak demand growth in Canada, which impacted productivity directly by reducing economies of scale and scope and

14 The "Canada-U.S. ICT Data Base" constructed by the Centre for the Study of Living Standards (CSLS) (http://www.csls.ca/data/Summary%20with%20List%20Final%202014.pdf) shows in a variety of measures that Canada's ICT capital stock and investment per worker have been below those of the United States in most areas with the exception of computer ICT investment after 2000.

15 There are a number of explanations for stronger demand growth in Canada than that in the United States. Canada did not go through as deep a recession as the United States did during the financial crisis of 2008 and 2009, nor was the financial sector as drastically affected. The role of financial frictions in the post-global financial crisis productivity slowdown is examined by Huber (2018) and Duval, Hong and Timmer (2017).

16 Statistics Canada Table 16-10-0109-01 "Industrial capacity utilization rates."

**Table 4: Regression Results on the Effects of Output Growth**

| | MFP growth | | Capital deepening | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Output growth | 0.195** | 0.166** | 0.036 | 0.048 |
| | (3.002) | (2.676) | (1.126) | (1.614) |
| Labour compositional change | | -0.34 | | 0.09 |
| | | (-0.639) | | (0.349) |
| Labour compositional change × output growth | | 0.482* | | 0.240* |
| | | (2.039) | | (2.107) |
| Dummy for 2010-14 | 1.109** | 1.028** | 0.264** | 0.259* |
| | (3.984) | (3.89) | (1.991) | (2.031) |
| Constant | -0.487* | -0.462* | -0.073 | -0.073 |
| | (-2.596) | (-2.605) | (-0.816) | (-0.850) |
| No. of Obs. | 74 | 74 | 73 | 74 |
| Adj. $R^2$ | 0.187 | 0.249 | 0.03 | 0.098 |

Note: One asterisk denotes statistical significance at 5% level and two asterisks denotes statistical significance at 1% level.

indirectly by affecting key productivity drivers such as investment and R&D.

Fay *et al.* (2017) found that weak aggregate demand was the main driver behind weakness in investment in the post-financial crisis period in nearly all advanced economies. Adler *et al.* (2017) found that the weak demand in the post financial crisis period explained the decline in investment rate and lower MFP growth is embodied in investment in advanced economies.

Remes *et al.* (2018) found that weak demand and uncertainty from the financial crisis lowered labour productivity growth in the United States and much of Western Europe by 0.9 percentage points per year for the 2010-2014 period compared with the 2000-2004 period.

To examine the role of weak demand on capital deepening and MFP growth, the Canada-U.S. difference in capital deepening and MFP growth was regressed on the Canada-U.S. difference in output growth across industries in the 1987-2010 and 2010-2014 periods. The change in labour composition is also included to examine the effect of skill upgrading and human capital on investment in physical capital and MFP growth. This specification is similar to the specification that expresses capital deepening and MFP growth in a country and a period as a function of output growth in a country and in a period with a set of country and period dummies included. The estimated coefficients on relative output growth can be interpreted as the association of capital deepening and MFP growth with output growth.

The results are presented in Table 4. The estimation results suggest that output growth is positively associated with MFP growth and capital deepening effects. The stronger output growth and strong demand growth in the 2010-2014 period was found to be associated with larger capital deepening effects and higher MFP growth in Canadian industries. The slower output growth and weak demand growth in the 1987-2010 period is associated with lower MFP growth and a lower capital deepening effect in Canadian industries in that period. The results are consistent with the previous findings on the role of demand on investment, innovation and productivity growth (Rao and Li, 2013, Remes *et al.* 2018, Fay *et al.* 2017)

Capeluck (2016) suggests that a weakening in demand slows the accumulation of both human and physical capital that weakens productivity growth. Weaker productivity growth, in turn, leads to a decline in cost competitiveness, reducing demand even further and resulting in a downward spiral. Finding what economic stimuli lead to a reversal is an important area for further theoretical and empirical research.

## Conclusion

This article provides a comparison of productivity growth in Canada and the United States for the period after 1987 using the Canadian industry productivity database and the recently released U.S. industry productivity database from the BLS.

For the 1987-2010 period, labour productivity growth was slower in Canada compared with the United States. This situation was mainly due to the relatively slower MFP growth in Canada.

Most Canadian industries contributed to lower MFP growth in Canada between 1987 and 2010 relative to the United States. The industries that made the largest contributions are: computer and electronic products, oil and gas extraction, retail trade, transportation and warehousing, and wholesale trade. ICT producing industries and ICT intensive using industries each accounted for 0.4 percentage points of the overall lower MFP growth in Canada. Non-ICT industries accounted for 0.3 percentage points.

For the 2010-2014 period, the situation reversed itself and labour productivity growth was higher in Canada than that in the United States. Relatively faster growth in Canada's labour productivity was mainly due to the relatively higher capital deepening effect and higher MFP growth in Canada.

Most Canadian industries had higher labour productivity growth, capital deepening effects and MFP growth than their U.S. counterparts for the 2010-2014 period. Canada's better performance in capital deepening and productivity growth occurred in both ICT and non-ICT intensive using industries. While MFP growth from ICT intensive using and ICT producing industries declined in the United States after 2010, MFP contribution from ICT intensive using industries increased in Canada after 2010. This suggests that the gains from ICT use and production appear to have waned in the United States, but the gains from ICT in Canada do not appear to have petered out.

The larger capital deepening effects and higher MFP growth in Canadian industries compared with those in U.S. industries in the 2010-2014 period were found to be associated with faster output growth and stronger demand in Canada during that period. Stronger demand in Canada has resulted in an increase in industrial capacity utilization in Canada. Relatively stronger demand in Canadian industries is found to be associated with higher capital deepening effects and higher MFP growth compared with those in U.S. industries.

Overall, the main sources of the relatively faster productivity growth in Canada after 2010 compared with that in the United States are found to be stronger demand and stronger productivity growth of ICT intensive using industries in Canada. The stronger demand is associated with investment in fixed capital, innovation and technological progress. A search for the determinants of productivity growth and future research on productivity should focus on the factors contributing to demand growth such as access to international markets and financial stability. It should also examine the factors that could have negative effects on demand growth such as demographic change, population aging and changes in income equality.

Research should also focus on better measurement of emerging technologies, their effect on productivity growth and economic growth and the factors that affect their adoption.

## References


Adler, G., D. A Romain, D. Furceri, S.K. Celik, K. Koloskova and M.Poplawski-Ribeiro (2017) "Gone with the Headwinds: Global Productivity," IMF Staff Discussion Note.

Aghion, P., A. Bergeaud, T. Boppart, P. Klenow and H. Li (2018) "Missing Growth from Creative Destruction." NBER Working Papers 24023.

Baily, M. N. and N. Montalbano (2016) "Why is Productivity Growth so Slow? Possible Explanations and Policy Responses," *Brookings Institution.*

Baldwin, J.R. and Gu, W. (2007) "Long-term Productivity Growth in Canada and the United States, 1961 to 2006," *Canadian Productivity Review*, Statistics Canada.

Baldwin, J.R., W. Gu, R. Macdonald, W. Wang, and B. Yan (2014) "Revisions to Multifactor Productivity Accounts," *The Canadian Productivity Review*, No. 35 (Ottawa: Statistics Canada).

Baldwin, J.R. and M. Willox (2016) "The Industry Origins of Canada's Weaker Labour Productivity Performance and the Role of Structural Adjustment in the Post-2000 Period," *International Productivity Monitor*, No. 28, Fall, pp. 3-26.

Balk, B.M. (2014) "Dissecting Aggregate Output and Labour Productivity Change," *Journal of Productivity Analysis*, No. 42. pp. 35-43.

Brynjolfsson, E., D. Rock and C. Syverson (2017) "Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics," NBER Working Papers 24001.

Byrne, D., J. Fernald and M. Reinsdorf (2016) "Does the United States Have a Productivity Slowdown or a Measurement Problem?" *Brookings Papers on Economic Activity*, Spring.

Capeluck, Evan (2016) "A Comparison of Productivity Developments in Canada and Australia: Lessons for Canada," *International Productivity Monitor*, No. 30, Spring, pp. 43-63.

de Avillez, Ricardo (2012) "Sectoral Contributions to Labour Productivity Growth in Canada: Does the Choice of Decomposition Formula Matter?" *International Productivity Monitor*, No. 24, Fall, pp. 97-117.

Diewert, W.E. (1976) "Exact and Superlative Index Numbers," *Journal of Econometrics*, Vol 4. No. 2, pp. 115-145.

Domar E. (1961) "On the Measurement of Technical Change," *Economic Journal*, Vol. 71, No. 284, pp. 709-729.

Duval, R., G.H. Hong and Y. Timmer (2017) "Financial Frictions and the Great Productivity Slowdown," IMF Working Papers 17/129, May.

Faruqui, U., W. Gu, M. Kaci, M. Laroche, and J.P. Maynard (2003) "Differences in Productivity Growth: Canadian U.S. Business Sectors, 1987-2000," *Monthly Labor Review*, April.

Fay, R. J.D. Guénette, M. Leduc, and L. Morel. (2017) "Why is Global Business Investment so Weak? Some Insights from Advanced Economies," *Bank of Canada Review*, Spring.

Fleck, S., S. Rosenthal, M. Russell, E.H. Strassner and L. Usher (2014) "A Prototype BEA/BLS Industry-Level Production Account for the United States," in Dale W. Jorgenson, J. Steven Landefeld, and Paul Schreyer (eds.) *Measuring Economic Sustainability and Progress* (Chicago: University of Chicago Press).

Gordon, R. (2016) *The Rise and Fall of American Growth: The US Standard of Living since the Civil War* (Princeton: Princeton University Press).

Gu, W. (2018) "Accounting for Slower Productivity Growth in Canada after 2000: The Role of Capital Measurement Issues," *International Productivity Monitor*, Spring, No. 21, pp. 21-39.

Gu. W. and M. Ho (2000) "A Comparison of Industry Productivity Growth in Canada and the United States," *American Economic Review: Papers and Proceedings.*

Gu, W., R. Macdonald and L. Rispoli (2018) "Intangible Capital and Productivity Growth in Canadian Industries," paper presented at the 2018 meeting of the Canadian Economics Association, Montreal, Canada.

Haskel, J. and S. Westlake (2017) *Capitalism without Capital-The Rise of the Intangible Economy* (Princeton: Princeton University Press).

Ho, M. H., S. Rao and J. Tang (2004) "Sources of Output Growth in Canadian and U.S. Industries in the Information Age," in Dale. W. Jorgenson (eds.) *Economic Growth in Canada and the United States in the Information Age* (Ottawa: Industry Canada Research Publications Program).

Huber, K. (2018) "Disentangling the Effects of a Banking Crisis: Evidence from German Firms and Counties," *American Economic Review*, Vol.108, No.3, March.

Jorgenson D.W. (1966) "Embodiment Hyhpothesis," *Journal of Political Economy*, Vol.74, No.1, pp.1-17

Jorgenson D.W., F. Gollop, and B. Fraumeni (1987) "Productivity and U.S. Economic Growth," *Harvard University Press*, 1987

Jorgenson D.W., M.S. Ho, and K.J. Stiroh (2005) "Productivity," *MIT Press*, Vol. 3. Cambridge 1987

Jorgenson, D.W., M.S. Ho and J. Samuels (2010) "Information Technology and U.S. Economic Growth; Evidence from a Prototype Industry Production Account," in Matilde Mas and Robert Stehrer (eds.) *Productivity in Europe: Growth and Crisis* (Cheltenham: Edward Elgar Publishing).

Manyika, J., J. Remes, J. Mischke, M. Krishnan (2017) "The Productivity Puzzle, A Closer Look at the United States," McKinsey Global Institute, Discussion Paper.

Murray, Alexander (2018) "What Explains the Post-2004 U.S. Productivity Slowdown?" *International Productivity Monitor*, Fall, No. 34, pp. 81-109 .

Nordhaus, W.D. (2001) "Alternative Methods for Measuring Productivity Growth," NBER Working Paper Series, no. 8095, National Bureau of Economic Research.

OECD (2017) *OECD Compendium of Productivity Indicators* (Paris: OECD).

Rao, S. and J. Li (2013) "Explaining Slower Productivity Growth: the Role of Weak Demand Growth," *International Productivity Monitor*, Fall, Vol. 26, pp. 3-19 .

Reinsdorf, M. (2015) "Measuring Industry Contributions to Labour Productivity Change: A New Formula in a Chained Fisher Framework," *International Productivity Monitor*, No. 28, Spring, pp. 3-26.

Remes. J, J. Mischke and M. Krishnan (2018) "Solving the Productivity Puzzle: The Role of Demand and the Promise of Digitalization," *International Productivity Monitor*, Fall, No.35, pp. 28-51.

Schreyer, P. (2001) "OECD Manual: Measuring Productivity: Measurement of Aggregate and Industry-Level Productivity Growth," Organisation for Economic Development and Corporation.

Sharpe, A. (2003) "Why are Americans more Productive than Canadians?" *International Productivity Monitor*, Spring, No. 6, pp. 19-37.

Sharpe, A. (2010) "Can Sectoral Reallocations of Labour Explain Canada's Abysmal Productivity Performance?" *International Productivity Monitor*, No. 19, Spring, pp. 40-49.

Sharpe, A. and Tsang, W.K. (2018) "Stylized Facts about Slower Productivity Growth in Canada", *International Productivity Monitor*, Fall, No.35, pp. 52-72.

Statistics Canada (2002) "Productivity Growth in Canada," edited by John R. Baldwin and Tarek Harchauoi.

van Ark. B. (2016) "The Productivity Paradox of the New Digital Economy," *International Productivity Monitor*, No. 31, Fall, pp. 3-18.

# Appendix: Industry Productivity Growth and Its Contributions to Aggregate Productivity Growth

**Table A1: Sources of Labour Productivity Growth in Canadian Industries, 1987-2010 (percentage points contribution per year)**

| Industry | LP | capital deepen | labour compositn | Interm. deepening | MFP |
|---|---|---|---|---|---|
| Crop and animal production | 4.50 | 0.38 | 0.11 | 2.88 | 1.13 |
| Forestry, Fishing, and Related | 2.03 | 0.32 | -0.05 | 1.15 | 0.62 |
| Oil and gas extraction | 0.50 | 1.04 | 0.06 | 1.02 | -1.62 |
| Mining (exc. oil & gas extraction) | 0.46 | 0.71 | 0.10 | 0.62 | -0.98 |
| Support activities for mining, oil & gas | 0.34 | 0.33 | 0.06 | 0.34 | -0.39 |
| Utilities | 0.39 | 0.18 | 0.11 | 0.50 | -0.40 |
| Construction | 0.45 | 0.10 | 0.08 | 0.41 | -0.15 |
| Food, beverage and tobacco | 1.21 | 0.16 | 0.07 | 1.19 | -0.21 |
| Textile and textile products | 1.42 | 0.19 | 0.09 | 0.93 | 0.21 |
| Clothing, leather and allied products | 1.64 | 0.39 | 0.12 | 0.94 | 0.19 |
| Paper | 2.70 | 0.35 | 0.10 | 1.63 | 0.61 |
| Printing and related | 2.95 | 0.25 | 0.11 | 1.95 | 0.63 |
| Petroleum and coal products | 0.75 | 0.39 | 0.20 | 0.55 | -0.40 |
| Chemical manufacturing | 0.40 | 0.08 | 0.03 | 0.19 | 0.09 |
| Plastics and rubber products | 1.93 | 0.23 | 0.09 | 1.11 | 0.50 |
| Wood products | 1.79 | 0.19 | 0.16 | 0.97 | 0.46 |
| Non-metallic mineral products | 1.68 | 0.39 | 0.04 | 1.12 | 0.13 |
| Primary metal | 4.14 | 0.25 | 0.08 | 3.23 | 0.58 |
| Fabricated metal products | 0.49 | 0.05 | 0.12 | 0.14 | 0.19 |
| Machinery | 2.11 | 0.33 | 0.19 | 1.27 | 0.32 |
| Computer and electronic products | 6.65 | 0.56 | 0.22 | 4.70 | 1.16 |
| Electrical equipment | 2.28 | 0.38 | 0.17 | 1.45 | 0.28 |
| Transportation equipment | 3.26 | 0.32 | 0.09 | 2.51 | 0.33 |
| Furniture and related products | 1.83 | 0.26 | 0.12 | 1.09 | 0.36 |
| Miscellaneous manufacturing | 2.30 | 0.30 | 0.10 | 1.42 | 0.49 |
| Wholesale trade | 3.16 | 0.78 | 0.20 | 1.32 | 0.86 |
| Retail trade | 2.43 | 0.55 | 0.23 | 1.08 | 0.57 |
| Transportation and warehousing | 1.33 | 0.53 | 0.14 | 0.75 | -0.08 |
| Information and cultural industries | 2.92 | 1.13 | 0.11 | 1.46 | 0.22 |
| Finance and insurance | 1.26 | 0.63 | 0.13 | 0.53 | -0.04 |
| Professional service | 1.62 | 0.71 | 0.20 | 1.26 | -0.55 |
| Administration, waste management | 1.10 | 0.69 | 0.15 | 0.98 | -0.72 |
| Educational services | 0.50 | 0.18 | 0.68 | -0.72 | 0.37 |
| Health care and social assistance | 0.33 | 0.19 | 0.01 | 0.86 | -0.74 |
| Arts, entertainment and recreation | 0.56 | 0.50 | 0.19 | 1.02 | -1.16 |
| Accommodation and food services | 1.04 | 0.10 | 0.16 | 0.91 | -0.12 |
| Other services | 1.81 | 0.42 | 0.14 | 1.45 | -0.20 |
| Average | 1.79 | 0.39 | 0.13 | 1.20 | 0.07 |

Source: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics.

**Table A2: Sources of Labour Productivity Growth in U.S. Industries, 1987-2010 (percentage points contribution per year)**

| Industry | LP | capital deepen | labour composition | Interm. deepening | MFP |
|---|---|---|---|---|---|
| Crop and animal production | 2.71 | 0.42 | 0.04 | 0.55 | 1.71 |
| Forestry, Fishing, and Related | 0.03 | 0.18 | 0.27 | -0.04 | -0.38 |
| Oil and gas extraction | 0.92 | 0.10 | 0.00 | 0.54 | 0.28 |
| Mining (exc. Oil & gas extraction) | 1.97 | 0.37 | 0.04 | 0.03 | 1.53 |
| Support activities for mining, oil & gas | 1.78 | -0.65 | -0.15 | 0.32 | 2.27 |
| Utilities | 2.93 | 1.10 | 0.06 | 0.82 | 0.96 |
| Construction | -0.66 | 0.22 | 0.15 | -0.12 | -0.91 |
| Food, beverage and tobacco | 1.05 | 0.23 | 0.06 | 0.92 | -0.15 |
| Textile and textile products | 2.55 | 0.30 | 0.13 | 1.39 | 0.73 |
| Clothing, leather and allied products | -0.35 | 0.48 | 0.71 | -3.06 | 1.52 |
| Paper | 1.28 | 0.16 | 0.18 | 0.89 | 0.06 |
| Printing and related | 1.90 | 0.49 | 0.10 | 1.32 | 0.00 |
| Petroleum and coal products | 1.26 | 0.33 | 0.13 | -0.01 | 0.81 |
| Chemical manufacturing | 2.75 | 0.35 | 0.05 | 1.10 | 1.24 |
| Plastics and rubber products | 2.05 | 1.54 | 0.08 | 0.71 | -0.29 |
| Wood products | 2.14 | 0.43 | 0.17 | 1.02 | 0.52 |
| Non-metallic mineral products | 0.86 | 0.35 | 0.07 | 0.51 | -0.07 |
| Primary metal | 3.01 | 0.20 | 0.11 | 2.24 | 0.46 |
| Fabricated metal products | 1.38 | 0.29 | 0.13 | 0.97 | 0.00 |
| Machinery | 2.46 | 0.49 | 0.17 | 2.12 | -0.32 |
| Computer and electronic products | 10.51 | 1.23 | 0.29 | 0.66 | 8.33 |
| Electrical equipment | 2.43 | 0.70 | 0.19 | 2.47 | -0.93 |
| Transportation equipment | 3.03 | 0.50 | 0.16 | 2.19 | 0.19 |
| Furniture and related products | 1.65 | 0.40 | 0.22 | 1.10 | -0.07 |
| Miscellaneous manufacturing | 2.89 | 0.69 | 0.28 | 1.01 | 0.91 |
| Wholesale trade | 3.42 | 0.72 | 0.18 | 0.90 | 1.62 |
| Retail trade | 2.64 | 0.58 | 0.15 | 0.59 | 1.34 |
| Transportation and warehousing | 1.54 | 0.08 | 0.13 | 0.20 | 1.13 |
| Information and cultural industries | 4.50 | 1.80 | 0.15 | 1.51 | 1.04 |
| Finance and insurance | 2.52 | 1.21 | 0.16 | 0.92 | 0.23 |
| Professional service | 1.75 | 0.48 | 0.26 | 0.87 | 0.14 |
| Administration, waste management | 1.84 | 0.29 | 0.28 | 0.79 | 0.48 |
| Educational services | -2.88 | -0.23 | 0.04 | -2.40 | -0.29 |
| Health care and social assistance | -0.16 | 0.05 | -0.08 | 0.57 | -0.70 |
| Arts, entertainment and recreation | 1.88 | 0.25 | 0.18 | 1.38 | 0.07 |
| Accommodation and food services | 2.03 | 0.58 | 0.09 | 0.46 | 0.91 |
| Other services | 1.10 | 0.10 | 0.06 | 1.31 | -0.38 |
| Average | 1.97 | 0.45 | 0.14 | 0.72 | 0.65 |

Source: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics.

**Table A3: Sources of Labour Productivity Growth in Canadian Industries, 2010-2014 (percentage points contribution per year)**

| Industry | LP | capital deepen | labour compositn | Interm. deepening | MFP |
|---|---|---|---|---|---|
| Crop and animal production | -3.13 | -0.48 | 0.30 | -2.68 | -0.27 |
| Forestry, Fishing, and Related | -2.11 | -0.47 | 0.05 | -1.35 | -0.34 |
| Oil and gas extraction | 5.94 | 3.15 | -0.01 | 3.10 | -0.30 |
| Mining (exc. Oil & gas extraction) | -3.55 | 1.33 | 0.04 | -0.72 | -4.20 |
| Support activities for mining, oil & gas | 2.67 | 0.81 | 0.08 | 0.83 | 0.96 |
| Utilities | 4.03 | 3.64 | 0.03 | 0.93 | -0.56 |
| Construction | -1.91 | -0.05 | 0.03 | -1.34 | -0.55 |
| Food, beverage and tobacco | 2.39 | 0.15 | 0.14 | 1.82 | 0.28 |
| Textile and textile products | -0.79 | -0.44 | -0.22 | -0.35 | 0.23 |
| Clothing, leather and allied products | 2.49 | 0.59 | 0.14 | 0.84 | 0.92 |
| Paper | 3.57 | -0.31 | -0.02 | 2.36 | 1.55 |
| Printing and related | -0.95 | -0.27 | -0.07 | -0.61 | 0.01 |
| Petroleum and coal products | 0.46 | -0.15 | 0.04 | 0.36 | 0.21 |
| Chemical manufacturing | 4.97 | 0.64 | -0.02 | 3.99 | 0.36 |
| Plastics and rubber products | 1.56 | -0.25 | 0.01 | 0.94 | 0.85 |
| Wood products | 2.47 | -0.09 | -0.03 | 1.41 | 1.17 |
| Non-metallic mineral products | 1.40 | 0.05 | 0.19 | 0.86 | 0.30 |
| Primary metal | 3.23 | 0.53 | -0.01 | 2.67 | 0.04 |
| Fabricated metal products | 2.01 | -0.31 | -0.02 | 0.83 | 1.50 |
| Machinery | 3.37 | -0.04 | 0.02 | 1.79 | 1.60 |
| Computer and electronic products | 2.67 | 0.88 | -0.12 | 1.65 | 0.26 |
| Electrical equipment | 1.22 | 0.57 | 0.04 | 0.67 | -0.06 |
| Transportation equipment | 0.35 | -0.58 | 0.00 | 0.30 | 0.63 |
| Furniture and related products | 1.98 | -0.18 | -0.13 | 1.31 | 0.98 |
| Miscellaneous manufacturing | 2.14 | 0.43 | 0.10 | 1.84 | -0.23 |
| Wholesale trade | 3.00 | 0.93 | 0.15 | 0.93 | 1.00 |
| Retail trade | 1.43 | 0.20 | 0.07 | 0.78 | 0.39 |
| Transportation and warehousing | 2.96 | 1.24 | -0.04 | 1.44 | 0.33 |
| Information and cultural industries | 0.55 | -0.02 | 0.07 | 0.22 | 0.29 |
| Finance and insurance | 1.25 | -0.29 | 0.13 | 0.38 | 1.02 |
| Professional service | 2.55 | 0.43 | 0.18 | 0.96 | 0.97 |
| Administration, waste management | 1.32 | 0.65 | 0.12 | 0.22 | 0.34 |
| Educational services | -0.90 | -0.60 | 0.15 | -0.29 | -0.16 |
| Health care and social assistance | 1.58 | 0.42 | 0.15 | 0.73 | 0.29 |
| Arts, entertainment and recreation | 1.06 | 0.53 | -0.17 | 0.25 | 0.45 |
| Accommodation and food services | 0.50 | -0.03 | 0.08 | -0.08 | 0.53 |
| Other services | 2.52 | 0.11 | 0.16 | 0.72 | 1.54 |
| Average | 1.47 | 0.34 | 0.04 | 0.75 | 0.33 |

Source: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics.

**Table A4: Sources of Labour Productivity Growth in U.S. Industries, 2010-2014 (percentage points contribution per year)**

| Industry | LP | capital deepen | labour composition | Interm. deepening | MFP |
|---|---|---|---|---|---|
| Crop and animal production | -0.30 | 0.87 | -0.04 | 0.19 | -1.33 |
| Forestry, Fishing, and Related | 0.92 | 0.55 | -0.63 | 0.03 | 0.96 |
| Oil and gas extraction | 1.30 | -5.04 | 0.07 | -1.76 | 8.04 |
| Mining (exc. Oil & gas extraction) | 1.10 | 1.86 | 0.08 | 3.34 | -4.18 |
| Support activities for mining, oil & gas | 5.39 | -1.73 | -0.03 | 4.24 | 2.91 |
| Utilities | -1.11 | 0.73 | 0.06 | -1.19 | -0.71 |
| Construction | -0.76 | -0.32 | 0.01 | -0.26 | -0.18 |
| Food, beverage and tobacco | -0.81 | 0.13 | 0.05 | -0.40 | -0.60 |
| Textile and textile products | 2.00 | -0.13 | 0.21 | 0.75 | 1.18 |
| Clothing, leather and allied products | -0.49 | -0.03 | 0.49 | 14.29 | -15.24 |
| Paper | 0.32 | -0.24 | 0.02 | 1.12 | -0.59 |
| Printing and related | 1.95 | 0.10 | 0.01 | 1.71 | 0.13 |
| Petroleum and coal products | 1.14 | -0.10 | 0.01 | 0.38 | 0.85 |
| Chemical manufacturing | -0.50 | 0.04 | 0.01 | -0.89 | 0.34 |
| Plastics and rubber products | -0.54 | 0.93 | -0.02 | 2.13 | -3.58 |
| Wood products | -0.28 | -0.26 | 0.09 | 1.14 | -1.25 |
| Non-metallic mineral products | 1.93 | -0.12 | -0.39 | 0.97 | 1.47 |
| Primary metal | 0.24 | -0.30 | 0.17 | -0.12 | 0.50 |
| Fabricated metal products | -0.52 | -0.36 | -0.02 | 0.97 | -1.12 |
| Machinery | 0.66 | -0.24 | 0.04 | 1.23 | -0.37 |
| Computer and electronic products | -0.08 | 0.71 | 0.09 | -0.10 | -0.78 |
| Electrical equipment | 0.73 | -0.28 | 0.03 | 1.20 | -0.22 |
| Transportation equipment | 2.15 | -0.47 | -0.14 | 1.43 | 1.33 |
| Furniture and related products | 0.19 | -0.30 | -0.10 | 1.24 | -0.65 |
| Miscellaneous manufacturing | -2.21 | 0.01 | -0.30 | 0.11 | -2.02 |
| Wholesale trade | 1.95 | 0.16 | 0.04 | 1.30 | 0.45 |
| Retail trade | 1.64 | 0.05 | 0.06 | 1.21 | 0.32 |
| Transportation and warehousing | 0.21 | -0.27 | 0.06 | 0.68 | -0.27 |
| Information and cultural industries | 4.46 | 1.19 | 0.23 | 2.82 | 0.22 |
| Finance and insurance | 1.19 | -0.06 | 0.20 | 0.10 | 0.95 |
| Professional service | 0.62 | -0.25 | -0.10 | 0.32 | 0.64 |
| Administration, waste management | 0.44 | 0.01 | 1.80 | 1.02 | -2.39 |
| Educational services | -1.71 | 0.23 | 0.08 | -0.60 | -1.42 |
| Health care and social assistance | 0.42 | -0.01 | 0.14 | 0.61 | -0.32 |
| Arts, entertainment and recreation | 0.08 | -0.37 | 0.13 | 0.03 | 0.30 |
| Accommodation and food services | 2.55 | -0.36 | 0.11 | 1.43 | 1.38 |
| Other services | 1.27 | -0.02 | -0.02 | 1.40 | -0.10 |
| Average | 0.69 | -0.10 | 0.07 | 1.14 | -0.42 |

Source: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics.

**Table A5: Contributions of Capital Deepening by Industry to Business Sector Labour Productivity Growth in Canada and the United States, 1987-2010 (percentage points per year)**

| Industry | Canada | U.S. | Canada - U.S. |
|---|---|---|---|
| Finance and insurance | 0.16 | 0.25 | -0.09 |
| Plastics and rubber products | 0.01 | 0.10 | -0.08 |
| Information and cultural industries | 0.08 | 0.15 | -0.08 |
| Utilities | 0.01 | 0.07 | -0.06 |
| Computer and electronic products | 0.01 | 0.06 | -0.05 |
| Chemical manufacturing | 0.00 | 0.02 | -0.01 |
| Retail trade | 0.06 | 0.07 | -0.01 |
| Professional service | 0.06 | 0.08 | -0.01 |
| Machinery | 0.01 | 0.02 | -0.01 |
| Fabricated metal products | 0.00 | 0.01 | -0.01 |
| Transportation equipment | 0.03 | 0.04 | -0.01 |
| Miscellaneous manufacturing | 0.00 | 0.01 | -0.01 |
| Electrical equipment | 0.01 | 0.01 | -0.01 |
| Wood products | 0.00 | 0.01 | -0.01 |
| Construction | 0.02 | 0.03 | 0.00 |
| Accommodation and food services | 0.01 | 0.01 | 0.00 |
| Food, beverage and tobacco | 0.02 | 0.02 | 0.00 |
| Textile and textile products | 0.00 | 0.00 | 0.00 |
| Clothing, leather and allied products | 0.00 | 0.01 | 0.00 |
| Furniture and related products | 0.00 | 0.00 | 0.00 |
| Petroleum and coal products | 0.00 | 0.00 | 0.00 |
| Printing and related | 0.01 | 0.01 | 0.00 |
| Non-metallic mineral products | 0.01 | 0.00 | 0.00 |
| Health care and social assistance | 0.01 | 0.01 | 0.00 |
| Educational services | 0.00 | 0.00 | 0.00 |
| Arts, entertainment and recreation | 0.01 | 0.00 | 0.00 |
| Crop and animal production | 0.02 | 0.01 | 0.00 |
| Forestry, Fishing, and Related | 0.01 | 0.00 | 0.01 |
| Wholesale trade | 0.08 | 0.08 | 0.01 |
| Paper | 0.01 | 0.00 | 0.01 |
| Support activities for mining, oil & gas | 0.01 | 0.00 | 0.01 |
| Other services | 0.01 | 0.00 | 0.01 |
| Primary metal | 0.01 | 0.00 | 0.01 |
| Administration, waste management | 0.03 | 0.01 | 0.02 |
| Mining (exc. Oil & gas extraction) | 0.02 | 0.00 | 0.02 |
| Transportation and warehousing | 0.06 | 0.01 | 0.06 |
| Oil and gas extraction | 0.08 | 0.00 | 0.08 |
| Sum of industry contributions | 0.89 | 1.10 | -0.22 |
| Reallocation | 0.09 | -0.12 | -0.21 |
| Aggregate capital deepening effect | 0.98 | 0.98 | 0.00 |

Note: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics. Industries are sorted by Canada-U.S. difference.

**Table A6: Contributions of Labour Composition by Industry to Business Sector Labour Productivity Growth in Canada and the United States, 1987-2010 (percentage points per year)**

| Industry | Canada | U.S. | Canada - U.S. |
|---|---|---|---|
| Professional service | 0.018 | 0.041 | -0.023 |
| Computer and electronic products | 0.004 | 0.014 | -0.009 |
| Administration, waste management | 0.007 | 0.014 | -0.007 |
| Clothing, leather and allied products | 0.001 | 0.008 | -0.006 |
| Information and cultural industries | 0.008 | 0.013 | -0.005 |
| Miscellaneous manufacturing | 0.001 | 0.004 | -0.003 |
| Transportation equipment | 0.009 | 0.012 | -0.003 |
| Forestry, Fishing, and Related | -0.001 | 0.001 | -0.002 |
| Machinery | 0.005 | 0.006 | -0.001 |
| Chemical manufacturing | 0.002 | 0.003 | -0.001 |
| Textile and textile products | 0.001 | 0.001 | -0.001 |
| Fabricated metal products | 0.004 | 0.004 | -0.001 |
| Furniture and related products | 0.001 | 0.002 | -0.001 |
| Electrical equipment | 0.002 | 0.003 | -0.001 |
| Plastics and rubber products | 0.005 | 0.005 | 0.000 |
| Non-metallic mineral products | 0.001 | 0.001 | 0.000 |
| Wood products | 0.004 | 0.004 | 0.000 |
| Arts, entertainment and recreation | 0.003 | 0.003 | 0.000 |
| Construction | 0.019 | 0.018 | 0.000 |
| Finance and insurance | 0.034 | 0.034 | 0.000 |
| Petroleum and coal products | 0.002 | 0.002 | 0.001 |
| Paper | 0.003 | 0.002 | 0.001 |
| Utilities | 0.005 | 0.004 | 0.001 |
| Educational services | 0.002 | 0.001 | 0.001 |
| Other services | 0.004 | 0.003 | 0.002 |
| Support activities for mining, oil & gas | 0.001 | -0.001 | 0.002 |
| Primary metal | 0.004 | 0.003 | 0.002 |
| Wholesale trade | 0.021 | 0.019 | 0.002 |
| Food, beverage and tobacco | 0.007 | 0.005 | 0.002 |
| Printing and related | 0.005 | 0.002 | 0.003 |
| Mining (exc. Oil & gas extraction) | 0.003 | 0.000 | 0.003 |
| Crop and animal production | 0.006 | 0.001 | 0.004 |
| Oil and gas extraction | 0.005 | 0.000 | 0.005 |
| Retail trade | 0.025 | 0.019 | 0.007 |
| Transportation and warehousing | 0.016 | 0.009 | 0.007 |
| Accommodation and food services | 0.009 | 0.001 | 0.008 |
| Health care and social assistance | 0.001 | -0.009 | 0.010 |
| | | | |
| Sum of industry contributions | 0.25 | 0.25 | -0.00 |
| Reallocation | 0.09 | 0.05 | 0.04 |
| Aggregate labour composition | 0.34 | 0.30 | 0.04 |

Note: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics. Industries are sorted by Canada-U.S. difference.

**Table A7: Contributions of Multifactor Productivity Growth by Industry to Business Sector Labour Productivity Growth in Canada and the United States, 1987-2010 (percentage points per year)**

| Industry | Canada | U.S. | Canada - U.S. |
|---|---|---|---|
| Computer and electronic products | 0.02 | 0.39 | -0.37 |
| Oil and gas extraction | -0.12 | 0.01 | -0.13 |
| Retail trade | 0.06 | 0.17 | -0.11 |
| Transportation and warehousing | -0.01 | 0.08 | -0.09 |
| Wholesale trade | 0.09 | 0.17 | -0.08 |
| Utilities | -0.02 | 0.06 | -0.08 |
| Information and cultural industries | 0.02 | 0.09 | -0.07 |
| Professional service | -0.05 | 0.02 | -0.07 |
| Finance and insurance | -0.01 | 0.05 | -0.06 |
| Administration, waste management | -0.03 | 0.02 | -0.06 |
| Chemical manufacturing | 0.00 | 0.06 | -0.06 |
| Mining (exc. Oil & gas extraction) | -0.03 | 0.01 | -0.05 |
| Accommodation and food services | -0.01 | 0.01 | -0.02 |
| Arts, entertainment and recreation | -0.02 | 0.00 | -0.02 |
| Support activities for mining, oil & gas | -0.01 | 0.01 | -0.02 |
| Petroleum and coal products | 0.00 | 0.01 | -0.02 |
| Clothing, leather and allied products | 0.00 | 0.02 | -0.01 |
| Miscellaneous manufacturing | 0.01 | 0.01 | -0.01 |
| Food, beverage and tobacco | -0.02 | -0.01 | -0.01 |
| Textile and textile products | 0.00 | 0.01 | -0.01 |
| Crop and animal production | 0.06 | 0.06 | 0.00 |
| Wood products | 0.01 | 0.01 | 0.00 |
| Non-metallic mineral products | 0.00 | 0.00 | 0.00 |
| Educational services | 0.00 | 0.00 | 0.00 |
| Furniture and related products | 0.00 | 0.00 | 0.00 |
| Fabricated metal products | 0.01 | 0.00 | 0.01 |
| Other services | -0.01 | -0.02 | 0.01 |
| Forestry, Fishing, and Related | 0.01 | 0.00 | 0.01 |
| Paper | 0.02 | 0.00 | 0.02 |
| Transportation equipment | 0.03 | 0.01 | 0.02 |
| Electrical equipment | 0.00 | -0.01 | 0.02 |
| Machinery | 0.01 | -0.01 | 0.02 |
| Primary metal | 0.03 | 0.01 | 0.02 |
| Printing and related | 0.03 | 0.00 | 0.03 |
| Plastics and rubber products | 0.03 | -0.02 | 0.04 |
| Health care and social assistance | -0.03 | -0.08 | 0.05 |
| Construction | -0.03 | -0.11 | 0.08 |
| | | | |
| Sum of industry contributions | 0.04 | 1.04 | -0.99 |
| Reallocation | -0.06 | 0.01 | -.0.07 |
| Aggregate MFP | -0.02 | 1.05 | -1.07 |

Note: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics. Industries are sorted by Canada-U.S. difference.

**Table A8: Contributions of Capital Deepening by Industry to Business Sector Labour Productivity Growth in Canada and the United States, 2010-2014 (percentage points per year)**

| Industry | Canada | U.S. | Canada - U.S. |
|---|---|---|---|
| Information and cultural industries | 0.00 | 0.12 | -0.12 |
| Plastics and rubber products | -0.01 | 0.06 | -0.07 |
| Finance and insurance | -0.08 | -0.01 | -0.07 |
| Crop and animal production | -0.02 | 0.03 | -0.05 |
| Transportation equipment | -0.05 | -0.03 | -0.02 |
| Computer and electronic products | 0.01 | 0.02 | -0.01 |
| Forestry, Fishing, and Related | -0.01 | 0.00 | -0.01 |
| Printing and related | -0.01 | 0.00 | -0.01 |
| Educational services | 0.00 | 0.00 | -0.01 |
| Paper | -0.01 | 0.00 | 0.00 |
| Textile and textile products | 0.00 | 0.00 | 0.00 |
| Petroleum and coal products | 0.00 | 0.00 | 0.00 |
| Furniture and related products | 0.00 | 0.00 | 0.00 |
| Clothing, leather and allied products | 0.00 | 0.00 | 0.00 |
| Non-metallic mineral products | 0.00 | 0.00 | 0.00 |
| Fabricated metal products | -0.01 | -0.01 | 0.00 |
| Wood products | 0.00 | 0.00 | 0.00 |
| Food, beverage and tobacco | 0.01 | 0.01 | 0.00 |
| Miscellaneous manufacturing | 0.00 | 0.00 | 0.00 |
| Accommodation and food services | 0.00 | -0.01 | 0.00 |
| Other services | 0.00 | 0.00 | 0.00 |
| Machinery | 0.00 | -0.01 | 0.01 |
| Electrical equipment | 0.00 | 0.00 | 0.01 |
| Retail trade | 0.02 | 0.01 | 0.02 |
| Arts, entertainment and recreation | 0.01 | -0.01 | 0.02 |
| Construction | -0.01 | -0.03 | 0.02 |
| Health care and social assistance | 0.02 | 0.00 | 0.02 |
| Mining (exc. Oil & gas extraction) | 0.04 | 0.02 | 0.03 |
| Primary metal | 0.03 | -0.01 | 0.03 |
| Support activities for mining, oil & gas | 0.02 | -0.02 | 0.03 |
| Chemical manufacturing | 0.04 | 0.00 | 0.04 |
| Administration, waste management | 0.04 | 0.00 | 0.04 |
| Wholesale trade | 0.11 | 0.02 | 0.09 |
| Professional service | 0.05 | -0.05 | 0.10 |
| Utilities | 0.14 | 0.04 | 0.10 |
| Transportation and warehousing | 0.15 | -0.02 | 0.17 |
| Oil and gas extraction | 0.35 | -0.13 | 0.48 |
| | | | |
| Sum of industry contributions | 0.84 | -0.03 | 0.87 |
| Reallocation | -0.19 | -0.13 | -0.06 |
| Aggregate capital deepening | 0.65 | -0.16 | 0.81 |

Note: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics. Industries are sorted by Canada-U.S. difference.

**Table A9: Contributions of Labour Composition by Industry to Business Sector Labour Productivity Growth in Canada and the United States, 2010-2014 (percentage points per year)**

| Industry | Canada | U.S. | Canada - U.S. |
|---|---|---|---|
| Administration, waste management | 0.007 | 0.120 | -0.113 |
| Information and cultural industries | 0.005 | 0.023 | -0.018 |
| Health care and social assistance | 0.008 | 0.020 | -0.012 |
| Finance and insurance | 0.035 | 0.044 | -0.009 |
| Transportation and warehousing | -0.004 | 0.004 | -0.009 |
| Arts, entertainment and recreation | -0.003 | 0.002 | -0.005 |
| Computer and electronic products | -0.002 | 0.003 | -0.004 |
| Primary metal | 0.000 | 0.003 | -0.004 |
| Oil and gas extraction | -0.001 | 0.002 | -0.002 |
| Wood products | -0.001 | 0.002 | -0.002 |
| Utilities | 0.001 | 0.003 | -0.002 |
| Chemical manufacturing | -0.001 | 0.001 | -0.002 |
| Printing and related | -0.001 | 0.000 | -0.002 |
| Textile and textile products | -0.001 | 0.001 | -0.002 |
| Paper | 0.000 | 0.000 | -0.001 |
| Educational services | 0.001 | 0.001 | -0.001 |
| Furniture and related products | -0.001 | -0.001 | -0.001 |
| Machinery | 0.001 | 0.001 | 0.000 |
| Clothing, leather and allied products | 0.000 | 0.001 | 0.000 |
| Retail trade | 0.007 | 0.008 | 0.000 |
| Fabricated metal products | 0.000 | 0.000 | 0.000 |
| Electrical equipment | 0.000 | 0.000 | 0.000 |
| Petroleum and coal products | 0.000 | 0.000 | 0.000 |
| Mining (exc. Oil & gas extraction) | 0.001 | 0.001 | 0.001 |
| Plastics and rubber products | 0.001 | -0.001 | 0.001 |
| Support activities for mining, oil & gas | 0.002 | 0.000 | 0.002 |
| Accommodation and food services | 0.005 | 0.002 | 0.003 |
| Forestry, Fishing, and Related | 0.001 | -0.002 | 0.003 |
| Miscellaneous manufacturing | 0.001 | -0.004 | 0.005 |
| Non-metallic mineral products | 0.002 | -0.003 | 0.006 |
| Other services | 0.005 | -0.001 | 0.006 |
| Construction | 0.008 | 0.001 | 0.008 |
| Food, beverage and tobacco | 0.011 | 0.004 | 0.008 |
| Transportation equipment | 0.000 | -0.009 | 0.009 |
| Wholesale trade | 0.017 | 0.004 | 0.012 |
| Crop and animal production | 0.013 | -0.001 | 0.015 |
| Professional service | 0.022 | -0.019 | 0.041 |
| Sum of industry contributions | 0.14 | 0.21 | -0.07 |
| Reallocation | 0.00 | -0.04 | 0.04 |
| Aggregate labour composition | 0.14 | 0.17 | -0.03 |

Note: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics. Industries are sorted by Canada-U.S. difference.

**Table A10: Contributions of Multifactor Productivity Growth by Industry to Business Sector Labour Productivity Growth in Canada and the United States, 2010-2014 (percentage points per year)**

| Industry | Canada | U.S. | Canada - U.S. |
|---|---|---|---|
| Oil and gas extraction | -0.03 | 0.21 | -0.25 |
| Construction | -0.13 | -0.02 | -0.11 |
| Mining (exc. Oil & gas extraction) | -0.13 | -0.04 | -0.09 |
| Transportation equipment | 0.05 | 0.08 | -0.03 |
| Non-metallic mineral products | 0.00 | 0.01 | -0.01 |
| Forestry, Fishing, and Related | 0.00 | 0.00 | -0.01 |
| Primary metal | 0.00 | 0.01 | -0.01 |
| Professional service | 0.12 | 0.12 | -0.01 |
| Support activities for mining, oil & gas | 0.02 | 0.03 | -0.01 |
| Textile and textile products | 0.00 | 0.01 | 0.00 |
| Petroleum and coal products | 0.00 | 0.01 | 0.00 |
| Printing and related | 0.00 | 0.00 | 0.00 |
| Information and cultural industries | 0.02 | 0.02 | 0.00 |
| Chemical manufacturing | 0.02 | 0.02 | 0.00 |
| Electrical equipment | 0.00 | 0.00 | 0.00 |
| Arts, entertainment and recreation | 0.01 | 0.01 | 0.00 |
| Retail trade | 0.04 | 0.04 | 0.01 |
| Accommodation and food services | 0.03 | 0.02 | 0.01 |
| Furniture and related products | 0.01 | 0.00 | 0.01 |
| Utilities | -0.02 | -0.04 | 0.01 |
| Educational services | 0.00 | -0.02 | 0.02 |
| Miscellaneous manufacturing | 0.00 | -0.03 | 0.02 |
| Clothing, leather and allied products | 0.00 | -0.02 | 0.03 |
| Computer and electronic products | 0.00 | -0.02 | 0.03 |
| Crop and animal production | -0.01 | -0.04 | 0.03 |
| Paper | 0.03 | 0.00 | 0.03 |
| Wood products | 0.02 | -0.02 | 0.05 |
| Machinery | 0.04 | -0.01 | 0.05 |
| Other services | 0.05 | 0.00 | 0.06 |
| Transportation and warehousing | 0.04 | -0.02 | 0.06 |
| Health care and social assistance | 0.02 | -0.04 | 0.06 |
| Food, beverage and tobacco | 0.02 | -0.04 | 0.06 |
| Wholesale trade | 0.12 | 0.05 | 0.07 |
| Finance and insurance | 0.28 | 0.21 | 0.07 |
| Fabricated metal products | 0.04 | -0.03 | 0.07 |
| Administration, waste management | 0.02 | -0.16 | 0.18 |
| Plastics and rubber products | 0.04 | -0.22 | 0.25 |
| | | | |
| Sum of industry contributions | 0.72 | 0.07 | 0.65 |
| Reallocation | 0.03 | 0.41 | -0.38 |
| Aggregate MFP | 0.75 | 0.49 | 0.26 |

Note: Authors' calculation using industry productivity databases from Statistics Canada and the Bureau of Labor Statistics. Industries are sorted by Canada-U.S. difference.

# The Productivity Slowdown in Canada: an ICT Phenomenon?

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Abstract

We ask whether a weaker contribution of information and communication technologies (ICT) to productivity growth could account for the productivity slowdown observed in Canada since the early 2000s. To answer this question, we consider several models which capture channels by which ICT could affect productivity growth. Our results indicate that ICT continues to contribute to productivity growth, but that this contribution has declined and consequently accounts for part of the productivity growth slowdown. However, the productivity slowdown and the change in the contribution of ICT do not seem to have the same timing. While productivity growth slowed in the early 2000s, the ICT contribution does not appear to have fallen until around the Great Recession. This prompts the conclusion that while ICT had little to no role in the initial productivity slowdown, it has been a major determinant of the subdued productivity growth since 2007-2009.

After averaging 1.6 per cent per year from 1993 to 2003, labour productivity growth in Canada only rose 1.0 per cent from 2003 to 2014.[2] The slowdown is not unique to Canada, as it has affected most OECD countries (Syverson, 2017). This is illustrated in Chart 1 for Canada, the United States, and the G-7. Various explanations have been proposed. For instance, some have exam-

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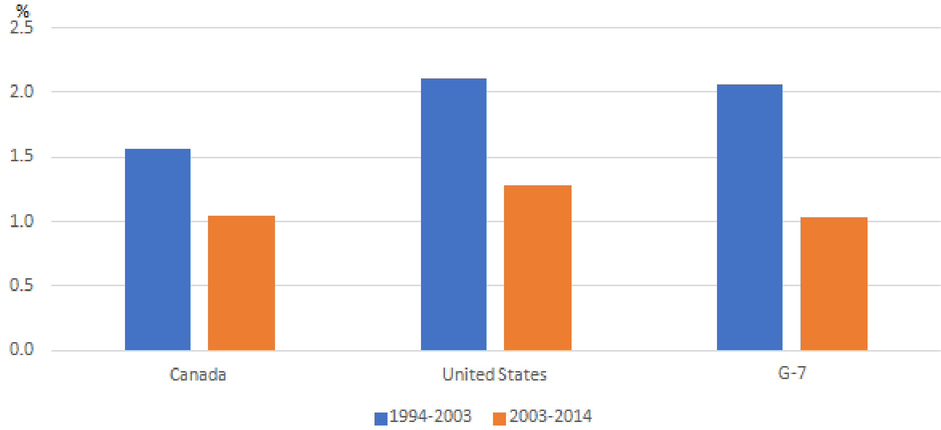
2 Lack of data availability for some of the models we study is the reason for the focus on the 1993 to 2014 period. The data up to 2016 show an even more accentuated slowdown in Canada. We calculate the slowdown from 2003 because we want two samples of reasonable length for the pre- and post-slowdown periods. We recognize that productivity in Canada began to decline after 2000, but our focus is on steady-state periods of growth, and labour productivity growth was still relatively high in 2000-2002. A further advantage of our choice of dates is that it facilitates comparison with one of the papers we build upon (Cette *et al.*, 2015). Nonetheless, the article discusses the effects of changing the dating of the weaker productivity growth period, including assuming that it started in 2000 (Sharpe and Tsang, 2018). Real GDP data are in constant dollars, not chain-weighted. All labour productivity data used in this article are in terms of output per hour worked for the total economy.

**Chart 1: Labour Productivity Growth for the Total Economy in Canada, the United States and G-7 (average annual rate of change)**




Source: OECD. Stat.

ined the role played by reduced business dynamism (Decker *et al.*, 2017; St-Amant and Tessier, 2018). Others have studied country-specific factors. For instance, Gu (2018) finds that in Canada the productivity slowdown can be partly explained by the higher cost of extracting natural resources and by a decline in the utilization of capital in the manufacturing sector.

Some researchers have argued that technology developments explain productivity trends. In particular, Gordon (2012) claims that the fundamental problem with productivity growth in recent years is that today's innovations do not compare in scale or impact with the breakthroughs of the 1990s, let alone the waves of earlier transformations. Some have tried to quantify the contribution of technology to the productivity slowdown. For example, using one-sector growth accounting, Cette *et al.* (2015) assess the contribution of information and communication technologies (ICT) capital deepening to labour productivity growth. They conclude that after rising significantly in the 1995-2004 period, the contribution of ICT fell after 2004 in Canada, the United States, the Euro zone, and the United Kingdom.

The Cette *et al.* model is intuitive, and represents the traditional approach applied in the literature to measure the contribution of a specific type of capital use. However, ICT capital deepening is not the only channel through which ICT can affect the growth of aggregate labour productivity. For instance, productivity growth in the ICT-producing sector (Appendix A, Chart A.2),[3] and resource reallocation to and from that sector, could affect aggregate productivity. A simple shift-share exercise (presented in Appendix A) suggests that the latter has not been a significant factor in accounting for the productivity slowdown in Canada.

3 All Appendices are found at www.csls.ca/ipm/ipm35/mollins_and_st_amant.pdf.

Changes in the developments of ICT prices can also be important. Oulton (2012) indeed builds a two-sector (ICT and non-ICT) model to measure various channels through which ICT can contribute to productivity growth. His main contribution is to highlight the impact of relative ICT price declines. Specifically, Oulton argues that the relative growth of ICT prices embodies the difference between total factor productivity (TFP) growth in the ICT and non-ICT sectors. Although Oulton does not compare periods, he finds that ICT's contribution to productivity has been strong in the 2000s in a group of OECD countries including Canada. Byrne and Corrado (2017) extend Oulton's model to include intermediate business services and make corrections for ICT prices mismeasurement. Focusing on the United States, they too conclude that the contribution of ICT has continued to be strong post-2003.

In this article, we ask whether a weaker contribution of ICT to productivity growth could account for the productivity slowdown observed in Canada since the early 2000s. To answer this question, our first approach is to update the analysis of Cette *et al.* (2015) for Canada. This informs us about the contribution of ICT capital deepening to aggregate productivity growth. In a second approach, we combine, in a two-sector steady-state model, a use effect based on ICT-capital deepening with a contribution coming from the production of ICT in Canada. We call this the simple two-sector (STS) approach.

Recognizing that declining ICT prices are a distinctive feature of technological progress, we then turn to the Oulton (2012) model with Canadian data for the periods 1993-2003 (pre-slowdown) and 2003-2014 (post-slowdown). However, this model assumes that the production functions of the ICT and non-ICT sectors are identical, except for different TFP growth rates. We show that this assumption is clearly inconsistent with Canadian data and propose an alternative approach allowing the production functions to differ in their input factor growth rates and income shares. This approach combines use, production, and price effects. We call it the Combined Use, Production and Price (CUPP) effects approach.

In our base case we compare the 1993-2003 period with the 2003-2014 period. However, we recognize that some uncertainty exists in the identification of separate steady-states, so we test the robustness of our conclusion with different starting dates for the post-slowdown period.

Our main conclusion is that while ICT is still contributing positively to labour productivity growth in Canada, this contribution has declined. Overall, we find that a reduced ICT contribution explains around 20-40 per cent of the productivity slowdown in Canada. However, the slowdown in productivity growth and in the contribution of ICT do not seem to coincide. The lower contribution seems to be stemming from developments starting around the Great Recession. ICT prices and the use of ICT consequently do not explain any of the initial slowdown in productivity growth, but instead offer insight into weak productivity growth since around 2008. Robustness checks with alternative data suggest that the contribution of ICT to the productivity slowdown could be even larger.

The article proceeds as follows: we first present our methodology, we then discuss the data, and present our results before concluding.

## Methodology

Our objective is to determine whether ICT developments have contributed to the productivity slowdown in Canada. In answering this question, we consider existing methodologies identifying the main channels through which ICT affects productivity. We also propose two new approaches aimed at capturing multiple channels.

### An Approach Focused on the Use of ICT

The contribution of ICT to aggregate labour productivity growth comes partly from the contribution of ICT investment to the economy's stock of capital. This is the "use effect" (UE). Cette *et al.* (2015) focus on this channel in assessing the contribution of ICT to labour productivity growth in Canada, the United States, and European countries. For each ICT component they consider (hardware, software, and communications equipment), the contribution of the use of capital to labour productivity growth for type of ICT capital $j$ in year $t$ ($\mathrm{UE}_t^j$) can be expressed as follows:

$$\mathrm{UE}_t^j = \alpha_t^j(\dot{k}_{t-1}^j) \tag{1}$$

In equation (1), $k^j$ is ICT capital type $j$ divided by the total number of hours worked. The dot over a variable indicates the growth rate. The coefficient $\alpha^j$ corresponds to the share of type $j$ ICT capital cost in nominal GDP.

Cette *et al.* (2015) find that after having risen significantly in 1995-2004 compared with 1974-1995, the contribution of ICT to labour productivity growth in Canada subsequently fell in the 2004-2013 period. We revisit the issue for Canada later in the article.

### A Simple Two-sector (STS) Approach

We propose a two-sector approach that allows us to combine the channels by which ICT affects productivity through its use and its domestic production. Beginning with Cobb-Douglas production functions for labour productivity, the non-ICT ($N$) and ICT ($T$) sectors can be expressed as follows:

$$\begin{gathered} y_N = B_N(k_N^N)^\gamma(k_N^T)^\sigma(h_N)^{1-\gamma-\sigma} \\ 0 < \gamma, \sigma < 1; \gamma + \sigma < 1 \end{gathered} \tag{2}$$

$$\begin{gathered} y_T = B_T(k_T^N)^\theta(k_T^T)^\eta(h_T)^{1-\theta-\eta} \\ 0 < \theta, \eta < 1; \theta + \eta < 1 \end{gathered} \tag{3}$$

In equations (2) and (3), $\gamma$, $\sigma$, $\theta$, and $\eta$ are the capital income shares, $y_N$ is labour productivity in the non-ICT sector, and $y_T$ is labour productivity in the ICT sector. $B_i$ is total factor productivity in sector $i = N, T$. Variables $k_i^j$

represent capital stock of type $j = N, T$ in per hour terms being used in sector $i = N, T$. Finally, $h_i$ is the average level of skill (human capital) in sector $i$.

In the steady-state, aggregate labour productivity growth can be expressed as a weighted average of labour productivity growth in the two sectors:[4]

$$\bar{\dot{y}} = (1 - \bar{q}_T)\bar{\dot{y}}_N + \bar{q}_T\bar{\dot{y}}_T \tag{4}$$

In equation (4), $q_T$ is the hours share of the ICT sector. Bars indicate steady-state values, calculated as period averages.

The non-ICT sector production function can be expressed in growth rate terms as follows:

$$\dot{y}_N = \mu_N + \gamma\dot{k}_N^N + \sigma\dot{k}_N^T + (1 - \gamma - \sigma)\dot{h}_N, \tag{5}$$

where $\mu_N$ is TFP growth in the non-ICT sector and the term $\sigma\dot{k}_N^T$ captures the contribution of ICT capital to productivity in the non-ICT sector. Substituting (5) into (4) and isolating for the effect of ICT capital, we can express the steady-state total contribution of ICT to aggregate productivity growth ($CO$) as

$$CO_{1,T} = (1 - \bar{q}_T)\sigma\bar{\dot{k}}_N^T + \bar{q}_T\bar{\dot{y}}_T \tag{6}$$

The first term on the right-hand side of equation (6) captures the contribution of ICT capital in the non-ICT sector (use effect) and the second term captures the contribution of productivity in the ICT sector (production effect). Note that the contribution of ICT capital deepening to productivity in sector $T$ is captured within the term $\bar{q}_T\bar{\dot{y}}_T$. This is an important difference from the one-sector model as the term $(1 - \bar{q}_T)\sigma\bar{\dot{k}}_N^T$ specifically captures ICT capital deepening in the non-ICT sector. The approach presented in this section would not capture reallocation effects (the effects on productivity of reallocating resources between sectors), but a simple shift-share decomposition, presented in Appendix A, suggests that reallocation was not a significant factor accounting for the 2003-2014 period of slower productivity growth. Also, the STS approach may not account for relative prices effects. This is discussed later in the article.

#### Oulton's Approach

The effects of changes in ICT prices may not be fully captured by equation (6). Oulton (2012) proposes a two-sector model that explicitly accounts for relative ICT prices when measuring the ICT contribution.[5]

He shows that, in a steady-state, ICT price changes relative to non-ICT price changes ($p = \dot{p}_T - \dot{p}_N$) equal (the negative of) the two sectors' relative TFP growth rates,[6] i.e.

4 Following Oulton (2012), we define a steady-state as a state in which the real interest rate and the depreciation rates are constant, and in which hours worked in each sector grow at the same constant rate.

5 See Appendix A in Oulton (2012) for a full presentation and derivation.

6 The intuition is that, because the production functions are identical except for TFP growth, and because nominal GDP shares of the two sectors are constant in a steady-state, differences in growth in prices have to reflect differences in TFP growth.

**Table 1: ICT and Income Shares in the Total Economy in Canada (per cent, averages)**

| | 1993-2003 | 2003-2014 |
|---|---|---|
| **ICT nominal capital income share** | 6.26 | 5.22 |
| Non-ICT sector | 5.67 | 4.77 |
| ICT sector | 19.12 | 15.52 |
| **ICT nominal capital stock growth** | 7.57 | 4.18 |
| Non-ICT sector | 7.85 | 5.45 |
| ICT sector | 7.21 | 1.06 |
| **Nominal labour income share** | 54.50 | 53.57 |
| Non-ICT sector | 53.96 | 52.79 |
| ICT sector | 64.81 | 68.60 |
| **ICT sector hours share**[a] | 3.79 | 3.89 |
| **ICT sector nominal GDP share** | 4.94 | 4.95 |
| **ICT sector real GDP share**[b] | 4.10 | 4.94 |

Source: Statistics Canada and author's calculations. Section 3 discusses the data in more detail.
*a*: Note that the non-ICT sector hours share, as well as non-ICT nominal and real GDP shares, are simply 100 minus the ICT shares shown in Table 1. *b*: Real GDP is in 2007 constant dollars.

$$\dot{p} = \mu_N + \mu_T \quad (7)$$

Oulton also shows that his model's steady-state solution, for the contribution of ICT to the growth of labour productivity, can be expressed as follows:

$$CO_{2,T} = \frac{\bar{v}_{K_T}}{\bar{v}_L}(-\dot{p}) + \bar{w}_T(-\dot{p}) \quad (8)$$

In equation (8), the first term represents a use effect, where $\bar{v}_{K_T}$ and $\bar{v}_L$ are, respectively, the shares of ICT capital and labour income in total income. The second term, where $\bar{w}_T$ denotes the relative size of the ICT production sector in nominal output, represents the "production effect." Oulton's main conclusion is that ICT has been an important source of productivity growth. His model, which he applies to 15 European and four non-European countries, suggests that the main boost to growth has come from ICT use, not ICT production. For Canada, he finds that while the contribution of ICT use to labour productivity has been 0.58 percentage points per year, that of ICT production has been 0.09 percentage points per year.[7] Oulton does not compare historical episodes. In the results section of this article we present estimates based on his model for the pre- and post-slowdown periods.[8]

An important assumption made by Oulton (and by Byrne and Corrado, 2017) is that the production functions of the two sectors are identical, except for the different TFP growth rates. However, this assumption is inconsistent with Canadian data, as is illustrated by Table 1. The ICT capital income share

7 This is based, for Canada, on ICT-capital and labour shares calculated as their 2000-2004 average, and on declines of 7 per cent in relative ICT prices. These are Oulton's assumptions.

8 Byrne and Corrado (2017) propose a model that differs from Oulton (2012) in that it incorporates the effects of ICT services (e.g. cloud services and data analytic services) as an intermediate input. They apply their model to U.S. data and find that the contribution of ICT has remained strong after 2003. Unfortunately, data limitations (data on ICT services in Canada are affected by a definitional change in 2008) prevent us from applying this model to Canadian data. Also, like Oulton (2012), these authors assume that the ICT and non-ICT sectors are identical, except for TFP growth rates. But this is inconsistent with Canadian data.

of the ICT sector has been, on average in 2003-2014, 15.5 per cent compared to 4.8 per cent for the non-ICT sector. Labour shares have also been different. Interestingly, nominal ICT capital growth has been considerably faster for the non-ICT sector in the post-slowdown period (5.5 per cent vs 1.1 per cent).

#### An Alternative Approach Combining Use, Production, and Price Effects (CUPP Approach)

An interesting feature of Oulton's (2012) approach is that it explicitly measures the impact of relative ICT prices on aggregate labour productivity. However, as we just saw, the assumption of identical production functions seems much too strong. Therefore, we derive a different equation that retains the relative price component of the Oulton model but makes less restrictive assumptions.

We begin with production functions as expressed in equations (2) and (3), where income shares and the growth rates of capital inputs are now allowed to differ. Assuming perfect competition and a simple Jorgenson user cost formula, we can develop a new expression for $\dot{y}_N$ (see Appendix B):[9]

$$\dot{\bar{y}}_N = \frac{\mu_N}{(1-\gamma-\sigma)} + \dot{\bar{h}} + \frac{\sigma}{(1-\gamma-\sigma)}(-\dot{p}) \tag{9}$$

The first two terms of equation (9) reflect the effects on labour productivity growth in the non-ICT sector from TFP growth and labour quality growth in that sector. The third term is the use effect of ICT capital in the non-ICT sector. As in Oulton, this effect says that as ICT prices fall relative to prices in the rest of the economy, and as the income share of ICT capital increases (for a given $\gamma$), labour productivity growth increases.

Lastly, we can substitute the use effect of equation (9) into (4) and obtain an expression for the contribution of ICT capital that is the sum of use and production effects:

$$CO_{3,T} = (1-\bar{q}_T)\frac{\sigma}{(1-\gamma-\sigma)}(-\dot{p}) + \bar{q}_T\dot{\bar{y}}_T \tag{10}$$

As noted earlier in equation (6), we label the second term on the right-hand side as the production effect.

Equation (10) differs from Oulton's formulation in several ways. First, the use effect is now in terms of the non-ICT sector, and is weighted by that sector's share of hours worked.[10] However,

9 See Appendix B for the derivation of a model where the production function for the ICT and non-ICT sectors differ.

10 Oulton weighs real output growth rates in the two sectors with nominal output shares because he measures real output using a Divisia (chained) index. We elect to use fixed-weighted constant GDP for our base case due to the complications that arise when summing chained GDP across sectors (in this case, the nominal weighted GDP growth rates across sectors do not add up to aggregate real GDP), and also because of some data limitations that are introduced when using chained investment (these data limitations are discussed later in the article).

in our model we do not relax the assumption, also made by Oulton, that in a steady-state the growth rate of hours worked in both sectors is the same.[11] Thus, equation (10) is constant in the steady-state. Defining labour productivity growth as the sum of the hours weighted shares of growth in the two sectors does not seem unreasonable, and allows us to solve the model for the steady-state.[12] Later in the article we perform a robustness check using chained prices for investment and GDP as well as nominal output shares.

A second key difference is that our production effect does not have a relative price term and is identical to the production effect described earlier. We make the change here because, as mentioned, this term in the Oulton model reflects the relative growth rates of TFP in the two sectors. In our model, where the production functions are different, the ICT sector's production effect includes more factors than just its relative TFP growth. For example, it now contains the contribution to labour productivity of the use of ICT capital *within* the ICT sector, because this term now differs from the use in the non-ICT sector.

In the traditional one-sector model and the STS approach presented earlier, the impact of prices is implicitly and partly captured in the capital income share through the user cost formula. Of course, the impact of prices is also captured as firms will likely invest and use more ICT capital (presumably a very efficient form of capital) as it becomes more affordable. In the CUPP approach, as ICT prices become cheaper compared with other investment goods and consumption goods, the efficiency gains are passed through to the users as they are not only able to purchase more ICT capital but other types of capital as well. Therefore, the price growth difference reflects efficiency gains that ICT users are able to incorporate into their production functions which has an effect on aggregate labour productivity growth.

## Data

The data used to calibrate the models are either taken from publicly accessible data from Statistics Canada or received by special request from Statistics Canada. All data are for the total economy.

The ICT-production sector is defined as the aggregation of NAICS codes 51 (information and cultural services), 334 (computer and electronic product manufacturing), and 5415 (computer system design and related services). This differs somewhat from the usual Statistics Canada definition, which is classified at a more granular level. Data constraints explain our choice of definition, but we also note that it is consistent with some literature (Syverson, 2017).

11 This assumption is necessary given that in the steady-state the hours share cannot be increasing for one sector simply because the share cannot exceed 1.

12 The ICT sector's hours share increased in the late 1990s but has not changed much in the post-slowdown period (Chart A.1 in Appendix A).

There exists a debate in the literature on the most appropriate measure of output for two-sector models. Byrne and Corrado (2017) define the output of the ICT sector by summing the consumption, investment, and net exports of specific ICT goods and services in the United States. However, we elect to use GDP from the System of National Accounts for the three NAICS codes described above, which will be consistent with data reported in Statistics Canada's Productivity Accounts.

In the Oulton model, and in the CUPP model, the choice of the definition of prices is crucial. We follow Oulton and use the implicit investment price index for the price of ICT, and use the non-ICT sector GDP deflator as a proxy for the non-ICT sector prices (Table A.1 in Appendix A).[13] We obtained these data, along with capital cost and stock data, from the publicly available capital accounts, as well as by special request to Statistics Canada. Additionally, as previously mentioned, we use real capital and real investment data calculated with fixed-weighted constant 2007 dollars, instead of a Fisher chain-weighted index. This is because chain-weighted data are not disaggregated into the three ICT capital components, and we can also easily sum when using constant dollars. However, we can estimate the CUPP model with some additional assumptions using chain-weighted dollars, the results of which are shown in the next section.

Capital per hour is calculated as the capital stock divided by total hours. Ideally, capital services would be used to obtain a measure of the services derived per hour worked. However, capital input is unavailable at the granular level we require either by industry or by type of capital (i.e. computer hardware, telecommunications equipment, and software). We recognize that using capital services has become the standard practice in the literature. We also note, though, that because the CUPP is a two-sector model, capital composition differences between non-ICT capital and the different ICT capital types is accounted for in the capital income share coefficients.

Capital cost is calculated assuming constant returns to scale and thus subtracting labour compensation from nominal GDP for the total economy as well as for the two sectors. Shares of the capital cost attributed to ICT are taken from Statistics Canada's Multifactor Productivity program at the business sector level and then applied to the aggregate economy capital share. More information on constructed or custom variables is provided in Appendix C.

## Results

### Traditional One-Sector Model

The first method we use to examine the impact of ICT on productivity follows that employed by Cette *et al.*

13 Although Oulton uses private fixed investment, we use total fixed investment prices as we analyze the total economy.

**Table 2: One-sector Model Results for the Contributions of ICT Components to Labour Productivity Growth for the Total Economy Labour Productivity in Canada, (percentage points per year)**

| | Computer Hardware | Telecommunications Equipment | Software | Total Contribution |
|---|---|---|---|---|
| 1993-2003 | 0.19 | 0.06 | 0.22 | 0.47 |
| 2003-2014 | 0.11 | 0.01 | 0.15 | 0.27 |
| 2003-2016 | 0.09 | 0.00 | 0.13 | 0.22 |

Source: Statistics Canada and authors calculations.

(2015) and others (equation 1). The growth accounting equation enables researchers to measure the impact of the total use of ICT capital on labour productivity. Results are presented in Table 2.

Estimation of equation (1) yields results similar to those of Cette *et al.* (2015). The contribution of ICT capital use to labour productivity growth in this model declined from 0.47 percentage points per year in the pre-slowdown period to 0.27 percentage points per year in the post-slowdown period (Table 2). One advantage of using this approach over the two-sector models is that the data requirements are less demanding, and we can therefore update the results to 2016, which decreases the contribution further in the post-slowdown period.

In absolute terms, the decline since 2003 comes largely from both computer hardware and software, and to a lesser extent telecommunications equipment. Most of the decline in the growth of use of these capital types came after the Great Recession. In fact, in the mid-2000s growth of real ICT capital rose to that of the late 1990s, but this growth had not recovered since it fell dramatically in 2008.[14] Unsurprisingly, much of this decline came from within the finance, insurance, real estate, rental and leasing sector, as well as from information and cultural industries. These two sectors represented 47 per cent of the total real ICT capital stock in 2007, but had average growth rates for their ICT capital stock of -5.5 per cent and -2.7 per cent from 2009 to 2016, respectively.

#### Two Sector Growth Accounting

We calibrate the three two-sector approaches described earlier, namely: STS, Oulton, and CUPP. Results are shown in Table 3.

First, our baseline results in the STS approach (equation 6) suggest that the contribution of ICT to labour productivity growth was 0.49 percentage points per year in the pre-slowdown period, and then fell to 0.27 percentage points per year in the post-slowdown period. While the use effect is quantitatively much larger, about a quarter of the decline in contribution comes from the production effect. This is important be-

14 The implications of this are discussed later in the article.

Table 3: **Two-sector Model Results for the Contribution of ICT to Total Economy Labour Productivity in Canada, (percentage points per year)**

| | | STS | Oulton | CUPP |
|---|---|---|---|---|
| | **Total Contribution** | **0.49** | **0.62** | **0.54** |
| **1993-2003** | Use effect | 0.35 | 0.47 | 0.41 |
| | Production effect | 0.13 | 0.15 | 0.13 |
| | **Total Contribution** | **0.27** | **0.60** | **0.41** |
| **2003-2014** | Use effect | 0.20 | 0.39 | 0.34 |
| | Production effect | 0.07 | 0.22 | 0.07 |
| | **Total Contribution** | **0.21** | **0.02** | **0.13** |
| **Differences** | Use effect | 0.15 | 0.08 | 0.07 |
| | Production effect | 0.06 | -0.07 | 0.06 |

Source: Statistics Canada and authors calculations.

cause, as mentioned, a key difference in this methodology compared with the one-sector approach is that the use effect is specifically for the non-ICT sector, while the one-sector model amalgamates all ICT capital use into one coefficient. While the contribution is almost identical to the one-sector model, the two-sector model points to the fact that a large portion of the decline in the use of ICT capital is coming from the ICT sector itself, given its large share of ICT capital income and the decline in the growth rate of ICT capital in that sector (Table 1).

Next, we estimate the Oulton approach. While we ultimately do not put much stock in this method, we want to see if the simplifying assumptions this method uses have meaningful effects on results (we drop this approach in subsequent analyses). It is interesting to find that in the world where the Oulton assumptions hold true, the contribution of ICT to productivity growth remains stable between the 1993-2003 and 2003-2014 periods. Any decline that occurs comes entirely from the use effect in this model, while the production effect increases between the two periods. This is because the average nominal output share of the ICT-producing sector is almost identical in the pre- and post-slowdown periods, while the relative price growth of ICT is larger in absolute terms, leading to a larger production effect (the second term in equation 8). On the other hand, the declining ICT capital income share (Table 1) combined with a stable labour share more than compensates for declining prices within the use effect.

Lastly, we calibrate the CUPP approach. We find that the contribution to labour productivity growth was 0.54 percentage points per year in the pre-slowdown period before declining to 0.41 percentage points per year post-slowdown. This indicates that relaxing the assumption used by Oulton that the two sectors are identical (except for steady-state TFP growth) makes a difference. As can be seen in Table 3, many of the qualitative conclusions are similar to the STS approach. However, note that the contribution to productivity growth is larger in the CUPP approach for both periods. This seems to indicate that relative ICT prices contain additional information about how

**Table 4: Estimation of Models with Different Years for Regime Shift of Steady States (contributions to labour productivity growth in percentage points per year)**

| | STS | | CUPP | |
|---|---|---|---|---|
| | Pre-slowdown | Post-slowdown | Pre slowdown | Post slowdown |
| 2000 | 0.57 | 0.27 | 0.49 | 0.46 |
| 2002 | **0.48** | **0.28** | **0.49** | **0.45** |
| 2004 | 0.49 | 0.24 | 0.60 | 0.35 |

Source: Statistics Canada and authors calculations.

**Table 5: Use Effect by ICT Component for Two-sector Models with Different Steady States Periods to Total Economy Labour Productivity in Canada, (percentage points per year)**

| | **1993-2000** | | **2000-2008** | | **2008-2014** | |
|---|---|---|---|---|---|---|
| | STS | CUPP | STS | CUPP | STS | CUPP |
| **Use effect** | **0.42** | **0.34** | **0.37** | **0.67** | **0.02** | **0.10** |
| Computer | 0.17 | 0.26 | 0.17 | 0.38 | 0.00 | 0.09 |
| Telecommunications | 0.10 | 0.03 | 0.08 | 0.18 | -0.01 | 0.03 |
| Software | 0.16 | 0.05 | 0.13 | 0.15 | 0.03 | -0.01 |

Notes: The use effects by asset do not add up to the total because they are multiplied by $(1 - \bar{q}_T)$ as shown in equations 6 and 10.
Source: Statistics Canada and authors calculations.

ICT affects aggregate labour productivity growth. More importantly, perhaps, is that the CUPP approach indicates that the decline in the contribution is less pronounced than in the STS approach. This seems to indicate that declining ICT prices are relatively more important in the post-slowdown era as the non-ICT sector's use of ICT capital becomes relatively larger. Note that while the ICT contribution declined in absolute terms, the relative contribution actually increased slightly in the CUPP model. This perspective may suggest that ICT simply declined in proportion to the rest of the economy.

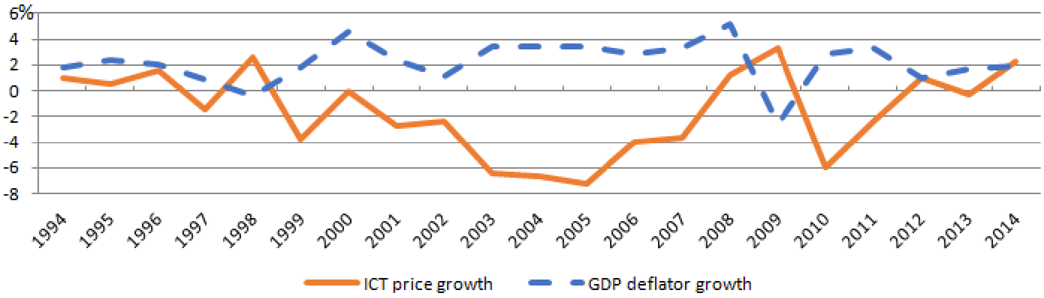
Up to this point, we have specified "pre-slowdown" as the period 1993-2003 and "post-slowdown" as 2003-2014. However, while the regime shift happened in the early 2000s, the exact timing of the beginning of the slow productivity growth period is ambiguous. While some researchers make the point that labour productivity growth slowed after 2000 (Sharpe and Thomson, 2010, and Baldwin *et al.*, 2015). Cette *et al.* (2015) chose a timing similar to ours. Of course, determining when the economy enters a new steady-state, or the date of the "regime shift," is a difficult endeavour; due to this uncertainty, we calibrate the models with varying timings for the regime shift. In Table 4, the results are summarized for the STS and CUPP models, with the date on the vertical axis representing the date at which the economy is assumed to move to a new steady-state.[15]

Table 5 indicates that in the STS approach, pushing the moment of regime shift to 2000 widens the gap between the

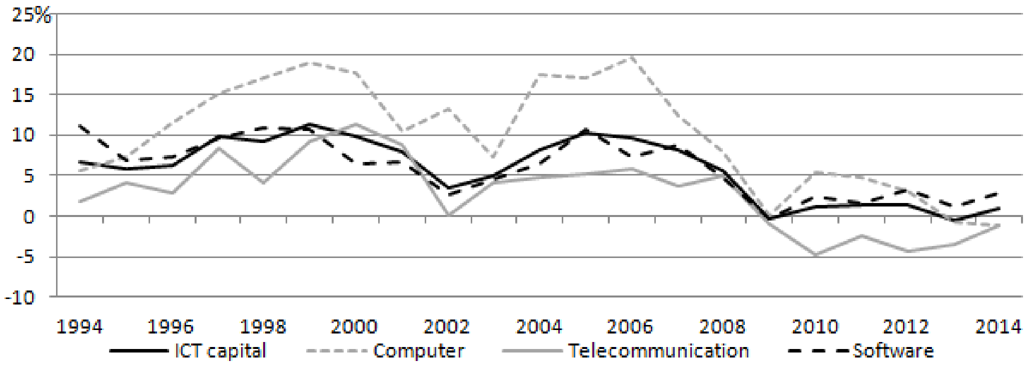
15 For example, the row for 2000 indicates that the results are for steady-states of 1993-2000 for the pre-slowdown period, and 2000-2014 for the post-slowdown period (growth rates would start in 2001 for post-slowdown).

**Chart 2: GDP Deflator, ICT Prices and Real ICT Capital Growth in Canada (per cent), 1994 - 2014**

Panel A. GDP Deflator and ICT Prices




Panel B. Real ICT Capital Growth




Source: Statistics Canada and author's calculations.

contributions of ICT in the two periods. This is because the STS approach captures largely the effect of capital deepening which began to decline in 1999, and ICT sector labour productivity growth was very weak in 2001. On the other hand, the CUPP approach indicates that specifying an earlier date for the regime shift practically eliminates the gap between pre- and post-slowdown ICT contributions.

## Weaker ICT Contribution and the Recession

Based on the results above, both the STS and CUPP approaches seem to indicate that a declining contribution of ICT can explain part of the slower productivity growth after the early 2000s. Furthermore, particularly in the CUPP model, the more recent the date used for the regime shift, the more of the total decline in productivity growth that ICT seems to explain. This is likely because the timing of slower productivity growth and a declining contribution of ICT do not coincide. Panel A in Chart 2 shows that the relative price of ICT actually declined in the early 2000s, and only converged to GDP deflator growth during the recession. Similarly, Panel B indicates that while the growth of ICT capital in Canada declined in the early 2000s, it began to recover very shortly afterwards only to fall and remain subdued after 2009. Tables 3 and 4 point to a declining growth of productivity in the ICT sector and a less important ICT use effect. However, these parameters seem to be reacting to the adverse pres-

**Table 6: ICT Contribution to Total Economy Labour Productivity Growth in Canada across Different Steady States with Constant and Chained Prices**

| | STS (percentage points) | | | CUPP (percentage points) | | | Labour Productivity (%) |
|---|---|---|---|---|---|---|---|
| Panel A: Using Constant Prices | | | | | | | |
| | Use effect | Production effect | Total contribution | Use effect | Production effect | Total contribution | |
| **1993-2000** | 0.42 | 0.15 | 0.57 | 0.34 | 0.15 | 0.49 | 1.89 |
| **2000-2008** | 0.37 | 0.10 | 0.47 | 0.67 | 0.10 | 0.77 | 0.86 |
| **2008-2014** | 0.02 | 0.04 | 0.07 | 0.10 | 0.04 | 0.14 | 1.19 |
| Panel B: Using Chained Prices | | | | | | | |
| **1993-2000** | 0.39 | 0.22 | 0.60 | 0.70 | 0.22 | 0.92 | 1.85 |
| **2000-2008** | 0.37 | 0.14 | 0.51 | 0.69 | 0.14 | 0.84 | 0.89 |
| **2008-2014** | 0.03 | 0.07 | 0.10 | 0.08 | 0.07 | 0.15 | 1.23 |

Source: Statistics Canada and authors calculations.

sure on ICT coming from the recession.[16] In other words, while productivity in Canada appears to have entered a state of slow growth in the early 2000s, this may not have been initially caused by a lower contribution of ICT.

To determine whether the declines in the ICT contribution and in labour productivity growth coincide, we propose that the contribution of ICT be broken into three periods: 1993-2000, 2000-2008, and 2008-2014. Of course, because these models are derived from a Cobb-Douglas equation of the total economy, this analysis must assume that there are, in fact, three separate steady states over the 20-year period in question. This is a bold claim; however, we believe the illustrative nature of this exercise justifies the flexibility.

Panel A of Table 6 shows that it is only in the 2008-2014 period that we see evidence of a significant decline in the contribution of ICT to labour productivity growth. In fact, in the CUPP model, the ICT contribution increases after 2000. While the production effect seems to show a gradual decline across the three periods, the use effect is the main determinant of a dramatic decline in contribution in the most recent period.

We can further break down the use effect from Panel A of Table 6 into the three components as shown in Table 5. One of the major differences between the use effects in the STS and the CUPP approaches is the relative impact of software. In the STS approach, the use of software contributes strongly to productivity growth, and in the 2008-2014 period is the only positive contributor. In the CUPP approach, though, it is relatively small, and is negative following the recession. This is because the price growth of software is positive (it is negative for the other assets in most periods, particularly computer hardware), so that the relative price term in the CUPP model subdues the positive im-

16 The convergence in the rate of increase in ICT prices relative to that of the GDP deflator seems to begin before the recession, and therefore it could be argued that the flow of causation is ambiguous.

pact of the incorporation of software into production in most periods.

The spike in the use effect in the CUPP approach in the 2000-2008 period points to the fact that the gap between ICT price growth and prices in the rest of the economy was wide in the early 2000s but began to close around 2008.[17] In the CUPP approach, the relative price growth is largely (although not exactly) an indicator of efficiency in the use and production of ICT assets.

This may suggest that innovation was still occurring in the ICT sector even as productivity growth was slowing in the rest of the economy in the early 2000s. Perhaps the weaker ICT productivity gains observed since around 2008 are linked to the 2008-09 recession. These weaker gains could have partly caused it if, for instance, they contributed to weaker expectations about future productivity growth, with immediate effects on spending.[18] The recession may also be responsible for price convergence if the weaker investment growth and spending on innovation that the recession triggered contributed to smaller declines in ICT prices. Our approaches cannot really shed light on these issues. However, it is interesting to note that ICT prices started to converge before the recession, which may suggest that slower ICT innovation was a cause of the recession.

Ultimately, splitting the two-sector models into three periods suggests that the decline in ICT's contribution to labour productivity growth did not coincide with the overall productivity slowdown, and therefore was not a factor in the initiation of the slow productivity growth period. However, it seems obvious that ICT has been a significant factor in the continuation of subdued productivity growth since around the recession.

#### Chained versus Constant Prices

The above analyses expresses all real variables in constant 2007 dollars. This is done because of the complications that arise from summations across sectors as well as data limitations.[19] However, it is possible to obtain an approximation of the CUPP approach using chained investment and GDP.[20] While this relies on some additional assumptions, we believe this robustness check is necessary given that there seems to exist a significant difference in prices in the 1993-2000 period (Charts A.3 and A.4 in Appendix A). We summarize the results of the two-sector models using chained indices in

17 Although when using chained prices, the period 1993-2000 also had very weak relative ICT price growth.

18 Blanchard *et al.*, 2017, discuss the channels by which changes in expectations about future growth could cause large short-term declines in GDP growth

19 Computer hardware and telecommunications equipment do not have separate chained dollar investment data, and splitting them is therefore difficult especially given the fact that we require the data for estimates of price growth.

20 It is considerably more difficult to obtain an estimate of the STS approach with chained prices given that the data requirements are at the sectoral level, and chained capital does not exist at this level of granularity.

Panel B of Table 6.[21]

The larger contribution in the 1993-2000 period using chained dollars is coming from both the use and production effects as prices are declining more rapidly in the 1993-2000 period and labour productivity growth in the ICT-producing sector is higher compared with constant-dollar data. Here, we assume that chained GDP growth is a nominal output weighted sum of the growth rates in each sector (the most appropriate weighting when using chained dollars). We also split the chained investment series between computer hardware and telecommunications using the ratio of investment in constant dollars for the two capital types. While these assumptions are cumbersome, results indicate that when using chained dollars, ICT is still heavily responsible for slow growth following the recession. The narrative here is that because fixed-weighted (i.e. constant dollar) investment assumes the same quantity mix throughout the entire 1993-2014 series (it assumes the basket is the same as in 2007, while chained investment would update the quantity mix each year), it may be that the investment goods that had rapid price declines in the late 1990s were not as heavily represented in 2007 when the quantity index was constructed.[22]

Nevertheless, the conclusions remain similar whether using chained or constant dollars. While the ICT contribution is higher in both models for each period, particularly in 1993-2000 in the CUPP model, it still remains true that it was not until after 2008 that the contribution seems to have fallen significantly for ICT.

## Conclusion

In this article, we asked whether a weaker contribution of ICT to productivity growth could account for the labour productivity slowdown observed in Canada since the early 2000s. To answer this question, we examined several models which capture various channels through which ICT could affect aggregate productivity.

Our main conclusion is that while ICT is still contributing positively to productivity growth, this contribution has declined, explaining part of the slower aggregate productivity growth. In our base case, we calculate that about 0.1 to 0.2 percentage points per year of the productivity slowdown (around 20-40 per cent of the total 0.58 percentage point slowdown) is explained by the weaker ICT contribution. ICT-use (ICT-capital deepening and price effects) and ICT-production (productivity in the ICT sector) both account for the ICT contribution. Results using chained dollars indi-

21 For a more complete discussion on the differences between using chained-aggregated and fixed-weighted data see, Whelan (2002).

22 Note, however, that we split the chained investment series for computer hardware and telecommunications according to the constant index due to data limitations. It is thus not clear that the price growth is applied correctly to each type of capital. Both capital types have much slower growth with chained prices in the 1993-2000 period, but applying the ratio from investment in constant dollars may be incorporating an additional bias into the model.

cate that a weaker contribution of ICT may be explaining even more of the aggregate productivity slowdown.

However, the slowdown in productivity growth and in the contribution of ICT do not seem to have the same timing. While productivity growth slowed in the early 2000s, ICT's contribution does not appear to fall until around the Great Recession. The fall in contribution is caused mostly by the convergence of ICT prices with non-ICT prices (a direct input into the use effect of the CUPP model), and the lower adoption rates of ICT assets. This prompts the conclusion that while ICT had little to no role in the initial productivity slowdown, it has been a major determinant of the subdued productivity growth in the period since 2008-2009.

A limitation of our analysis is that it is performed at an aggregate level and may overlook some important nuances. It may be that lower use effects hide the concentration of ICT capital in certain industries (not unlike the superstar firm hypothesis proposed by Autor *et al.* (2017) and others). This limitation highlights the need for further analysis at a more disaggregated level.

Another limitation is that while the convergence of ICT and non-ICT prices seems to indicate that efficiency improvements in the production of ICT products has slowed in recent years, it may also be subject to price mismeasurement issues raised by some researchers (e.g. Byrne and Corrado, 2017). Note, however, that mismeasurement issues would need to have worsened, when compared with the pre-slowdown period, to account for the productivity slowdown.[23] Unfortunately, we have little information regarding price mismeasurement for Canada and therefore leave it to future research to examine this issue in Canada.

Another issue is that the nature of technology has changed. ICT services (e.g. cloud computing) may act more like investment and capital in an increasingly digitalized economy, but they may not be categorized as such in Canadian data.[24] Nevertheless, if produced in Canada, they would be captured through the production effect in our two-sector models. However, if these services are imported from another country, they may not be captured in our models.[25] Also, it may be that the intangible capital needed to properly utilize ICT and digital technology (some of which is not captured in national accounts data), has taken the place of much of the resources previously devoted to ICT capital. We also leave the investigation of these fac-

23 Byrne *et al.* (2016) examine the issue in U.S. data and conclude that measurement issues do not explain the U.S. productivity slowdown.

24 Kim (2018) discusses the issue

25 According to Rostami (2018), the imports of ICT services are somewhere between 5 per cent and 8.5 per cent of our estimates of real ICT capital. However, much of this is likely already an intermediate input into the ICT-producing sector, which would be captured by our model. Note also that adding services imports as a capital asset would be a level effect, and it would only impact the ICT capital income share (and a smaller effect on the capital deepening component, which is in growth terms).

tors to future research.

## References


Autor, D., D. Dorn, L. F. Katz, C. Patterson and J. Van Reenen (2017) "The Fall of the Labor Share and the Rise of Superstar Firms," CEP Discussion Papers dp1482, Centre for Economic Performance, London School of Economics.

Baldwin, J., H. Liu and M. Tanguay (2015) "An Update on Depreciation Rates for the Productivity Accounts," *The Canadian Productivity Review*, No. 39, Statistics Canada Catalogue no. 15-206-X. Ottawa: Statistics Canada.

Bergeaud, A., G. Cette and R. Lecat (2016) "Productivity Trends in Advanced Countries between 1890 and 2012," *Review of Income and Wealth*, Vol. 62, No. 3, pp. 420-444.

Blanchard, O., G. Lorenzoni and J-P. LHuillier (2017) "Short-run Effects of Lower Productivity Growth: A Twist on the Secular Stagnation Hypothesis," *Journal of Policy Modeling*, Vol. 39, No.4, pp. 639-649.

Byrne, D. and C. Corrado (2017) "ICT Services and Their Prices: What do They Tell US About Productivity and Technology?" *International Productivity Monitor*, No. 33, Fall, pp. 150-181. http://www.csls.ca/ipm/33/Byrne_Corrado.pdf.

Byrne, D., J. Fernald and M. Reinsdorf (2016) "Does the United States Have a Productivity Slowdown or a Measurement Problem?" *Brookings Papers on Economic Activity*, Spring.

Cette, G., C. Clerc, and L. Bresson (2015) "Contribution of ICT Diffusion to Labour Productivity Growth: The United States, Canada, the Eurozone, and the United Kingdom, 1970-2013," *International Productivity Monitor*, No. 28, Spring, pp. 81-88. http://www.csls.ca/ipm/28/cetteetal.pdf.

de Avillez, R. (2012) "Sectoral Contributions to Labour Productivity Growth in Canada: Does the Choice of Decomposition Formula Matter?" *International Productivity Monitor*, No. 24, Fall, pp. 97-117. http://www.csls.ca/ipm/24/IPM-24-Avillez.pdf.

Decker, R., J. Haltiwanger, R. Jarmin and J. Miranda (2017) "Declining Dynamism, Allocative Efficiency, and the Productivity Slowdown," *American Economic Review: Papers and Proceedings*, Vol. 107, No. 5, May, pp. 322-326.

Hatzius, J. (2016) "Productivity Paradox v2.0 Revisited," US Economic Analyst. Goldman Sachs, September.

Gordon, R. (2012) "Is U.S. Economic Growth Over? Faltering Innovation Confronts the Six Headwinds," NBER Working Paper No. 18315. August.

Gu, W. (2018) "Accounting for Slower Productivity Growth in the Canadian Business Sector After 2000: The Role of Capital Measurement Issues," *International Productivity Monitor*, No. 34, Spring, pp. 21-39. http://www.csls.ca/ipm/34/Gu.pdf.

Kim, Myeongwan (2018) "Weak ICT Investment in Canada and the United States: The Role of Cloud Computing," CSLS Research Report 2018-04, August.

Oulton, N. (2012) "Long Term Implications of the ICT Revolution: Applying the Lessons of Growth Accounting and Growth Theory," *Economic Modeling*, Vol. 29, No. 5, pp. 17221736.

Reinsdorf, M. (2015) "Measuring Industry Contributions to Productivity Change: A New Formula in a Chained Fisher Framework," *International Productivity Monitor*, No. 28, Spring. http://www.csls.ca/ipm/28/reinsdorf.pdf.

Rostami, M. (2018) "Canada's International Trade in Information and Communications Technologies (ICT) and ICT-enabled services," Statistics Canada Catalogue no. 13-605-X: Latest Developments in the Canadian Economic Accounts, Ottawa, Ontario.

Sharpe, A. and E. Thomson (2010) "Insights into Canadas Abysmal Post-2000 Productivity Performance from Decompositions of Labour Productivity Growth by Industry and Province," *International Productivity Monitor*, Vol. 20, Fall, pp. 48-67. http://www.csls.ca/ipm/20/IPM-20-Sharpe-Thomson.pdf.

Sharpe, A. and J. Tsang (2018) "Stylised Facts about Slower Productivity Growth in Canada," *International Productivity Monitor*, Vol. 35, Fall, pp. 52-72. http://www.csls.ca/ipm/35/IPM-35-Sharpe-Tsang.pdf.

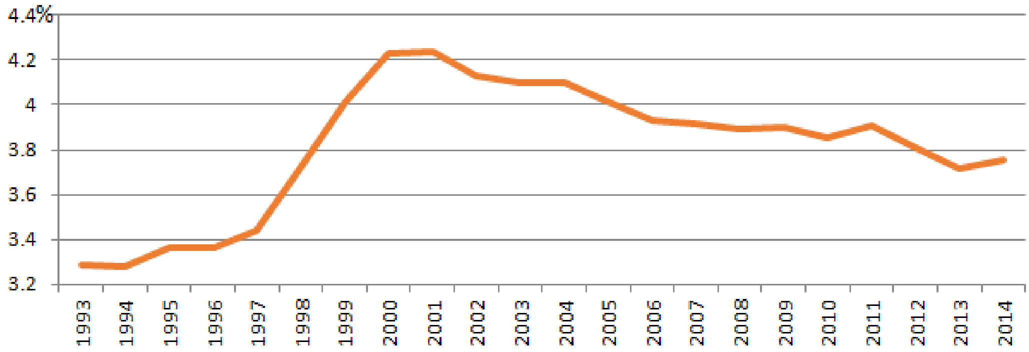
St-Amant, Pierre and David Tessier (2018) "Firm Dynamics and Multifactor Productivity: An Empirical Exploration," Staff Working Papers, Bank of Canada.

Syverson, C. (2017) "Challenges to Mismeasurement Explanations for the US Productivity Slowdown," *Journal of Economic Perspectives*, Vol. 31, No. 2, pp. 165-86.

Whelan, K. (2002) "A Guide to U.S. Chain Aggregated NIPA Data," *Review of Income and Wealth*, No. 48, pp. 217-233. http://www.roiw.org/2002/217.pdf

## Appendix A: Supplementary Data and Analysis

**Chart A1: ICT Sector Share of Total Hours Worked (annual data)**

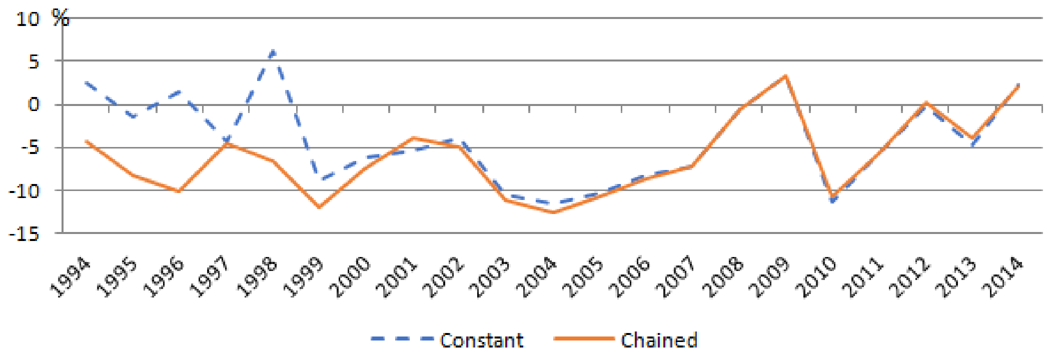



Source: Statistics Canada.

**Chart A2: ICT Sector Share of Total Hours Worked (annual data)**


Source: Statistics Canada.

**Chart A3: Computer and Telecommunication Price Growth (annual data)**



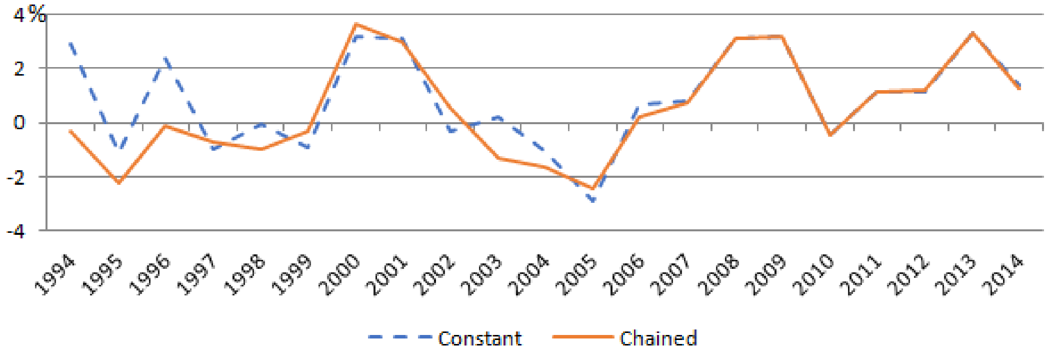

Source: Statistics Canada.

**Table A1: Price Growth (constant dollars)**

| | 1993-2003 | 2003-2014 |
|---|---|---|
| **Non-ICT sector GDP deflator growth** | **1.99** | **2.38** |
| **ICT investment price growth** | **-1.09** | **-2.03** |
| Computer hardware | -8.13 | -6.25 |
| Telecommunications equipment* | -0.53 | -2.69 |
| Software | 0.85 | 0.93 |

Source: Statistics Canada and authors calculations.
Notes: Indicates data received from Statistics Canada through special request.

**Chart A4: Software Price Growth (annual data)**




Source: Statistics Canada.

**Table A2: Shift-share Results**

| | 1993-2003 | 2003-2014 |
|---|---|---|
| ***Labour productivity growth*** | 1.59 | 1.03 |
| ***ICT sector contribution (p.p.p.y)*** | **0.14** | **0.08** |
| *Reallocation* | 0.01 | -0.01 |
| *Within-sector* | 0.14 | 0.09 |
| ***All else*** | 1.45 | 0.95 |

Source: Statistics Canada and authors calculations.
Note that the shift-share was performed using the CSLS method as described by de Avillez (2012), where reallocation is the sum of the reallocation growth effect and the reallocation level effect. The exercise uses constant 2007 dollars. The labour productivity level for the ICT sector was $48 (GDP per hour worked) in the 19932003 compared with $44 in the non-ICT sector. In the 20032014 period, the ICT sector had a productivity level of $64 while the non-ICT sector was $50.

## Appendix B: Relaxing the Assumption of Identical Production Functions in the ICT and non-ICT Sectors

In this Appendix, we examine the implications, in an approach " la Oulton (2012)", of relaxing the assumption that the production functions of the ICT and non-ICT sectors are identical. We show that this gives expressions that do not capture the contribution of ICT to productivity growth. We also propose an alternative approach, "CUPP", more consistent with the contribution of ICT in a world with different production functions.

We start with the two production functions described in Section 2.2:

$$y_N = B_N (k_N^N)^{\gamma} (k_N^T)^{\sigma} (h_N)^{1-\gamma-\sigma} \qquad \text{(A1)}$$
$$0 < \gamma, \sigma < 1; \gamma + \sigma < 1$$

$$y_T = B_T (k_T^N)^{\theta} (k_T^T)^{\eta} (h_T)^{1-\theta-\eta} \qquad \text{(A2)}$$
$$0 < \theta, \eta < 1; \theta + \eta < 1$$

In equations (A1) and (A2), the variables are as defined in Section 2.2.

We can obtain expressions for the growth rates of equations (A1) and (A2) by taking total derivatives:

$$\dot{y}_N = \mu_N + \gamma \dot{k}_N^N + \sigma \dot{k}_N^T + (1-\gamma-\sigma)\dot{h}_N \qquad \text{(A3)}$$

$$\dot{y}_T = \mu_T + \gamma \dot{k}_T^N + \sigma \dot{k}_T^T + (1-\gamma-\sigma)\dot{h}_T \qquad \text{(A4)}$$

Again, in equations (A3) and (A4), the variables are as defined in Section 2.2.

In the non-ICT sector, the use cost can be approximated by $(r+\delta_N-\dot{p}_N)p_N$, $r$ is the real interest rate and $\delta_N$ is the rate of depreciation of non-ICT capital. Normalizing to non-ICT prices and setting the marginal product of capital equal to the user cost, we have

$$(r+\delta_N) = \gamma \frac{y_N}{k_N^N}$$
$$(r+\delta_T-\dot{p})p = \sigma \frac{y_N}{k_N^T}$$

where $p = \frac{p_T}{p_N}$. Given that in the steady-state interest rates and depreciation rates are fixed, we have that

$$\bar{\dot{y}} = \bar{\dot{k}}_N^N = \bar{\dot{k}}_N^T + \dot{p} \qquad \text{(A5)}$$

Similarly, $(r+\delta_T+\dot{p}) = \eta \frac{y_T}{k_T^T}$ implies that $\bar{\dot{y}}_T = \bar{\dot{k}}_T^T$.

Assuming that in a steady-state $\sigma \frac{y_N}{k_N^T} = \eta \frac{y_T}{k_T^T} p$, implies that

$$\bar{\dot{y}}_N - \bar{\dot{k}}_N^T = \bar{\dot{y}}_T - \bar{\dot{k}}_T^T + \dot{p} \qquad \text{(A6)}$$

Rearranging (A6), we get that

$$\bar{\dot{y}}_T = \bar{\dot{y}}_N + (\bar{\dot{k}}_T^T - \bar{\dot{k}}_N^T) - \dot{p} \qquad \text{(A7)}$$

Substituting equations (A5) into (A3) we obtain an expression for labour productivity growth in the non-ICT sector

$$\bar{\dot{y}}_N = \mu_N + \gamma \bar{\dot{y}}_N + \sigma(\bar{\dot{y}}_N - \dot{p}) + \bar{\dot{h}}(1-\gamma-\sigma) \qquad \text{(A8)}$$

In the steady-state, we assume that

aggregate labour productivity growth can be expressed as a weighted average of the two sectors' productivity growth rates, i.e.

$$\dot{\bar{y}} = (1-\bar{q}_T)\dot{\bar{y}}_N + \bar{q}_T\dot{\bar{y}}_T = \dot{\bar{y}}_N + \bar{q}_T(\dot{\bar{y}}_T - \dot{\bar{y}}_N). \tag{A9}$$

Oulton's original model assumes instead that steady-state labour productivity growth is the sum of labour productivity growth in the two sectors weighted by their respective nominal output share. We use the hours share because when we assume different production functions, aggregate nominal output is no longer constant. But we still assume that hours growth is the same in the ICT and the non-ICT sector in the steady-state.

Substituting equation (A7) into (A9)

$$\dot{\bar{y}} = \dot{\bar{y}}_N + \bar{q}_T([\dot{\bar{k}}_T^T - \dot{\bar{k}}_N^T] - \dot{p}). \tag{A10}$$

Re-arranging equation (A8) gives

$$\dot{\bar{y}}_N = \frac{\mu_N}{(1-\gamma-\sigma)} + \dot{\bar{h}} + \frac{\sigma}{(1-\gamma-\sigma)}(-\dot{p}) \tag{A11}$$

Substituting (A11) into (A10) gives

$$\begin{aligned}\dot{\bar{y}} = {} & \frac{\mu_N}{(1-\gamma-\sigma)} + \dot{\bar{h}} + \\ & \frac{\sigma}{(1-\gamma-\sigma)}(-\dot{p}) + \\ & \bar{q}_T([\dot{\bar{k}}_T^T - \dot{\bar{k}}_N^T] - \dot{p})\end{aligned} \tag{A12}$$

where, if we followed Oulton's approach, the last two terms would reflect the contribution of ICT to labour productivity, as is expressed in equation (10) of Section 2.4. But these two terms are clearly different from the solution to the original Oulton model. This is made clear by the presence of $[\dot{\bar{k}}_T^T - \dot{\bar{k}}_N^T]$. Why would stronger ICT capital investment in the non-ICT sector, as reflected in $\dot{\bar{k}}_T^T$, be negative for productivity?

We therefore take a different approach. Substituting equation (A11) in equation (A9) gives

$$\begin{aligned}\dot{\bar{y}} = \bar{q}_T\dot{\bar{y}}_T + (1-\bar{T})\frac{\sigma}{(1-\gamma-\sigma)}(-\dot{p}) + \\ (1-\bar{q}_T)[\frac{\mu_N}{(1-\gamma-\sigma)} + \dot{\bar{h}}]\end{aligned} \tag{A13}$$

The first two terms on the right-hand side of equation (A12) measure the contribution of ICT to aggregate labour productivity as expressed in equation (9) and discussed in Section 2.4.

## Appendix C: Information on Constructed or Custom Variables

In this appendix, we expand on Section 3 to discuss several data issues that we experience when estimating the models used in this paper with Canadian data.

## Gross Domestic Product

As mentioned in Section 3, we use three NAICS codes to approximate the ICT sector: NAICS 334, 51, and 5415.

Whenever real GDP is required, we use 2007 constant dollars, as opposed to a Divisia index, in order to allow for the summation of real goods and services across sectors.

The ICT GDP series that is created concatenates data from three different CANSIM tables. GDP for NAICS 5415 is unavailable pre-1997, and so from 1993-1996 we backcast under the assumption that the growth rate of this sectors output is equal to that of NAICS 54.

## Capital, Capital Cost, and the Labour Share

ICT capital is defined as computer hardware, telecommunication equipment, and software. We received the disaggregation from Statistics Canada by special request for telecommunication and computer hardware for the total economy, as well as for the NAICS codes 51 and 334. Computer system design and related services, however, did not have capital data as it was aggregated at the two-digit level. Therefore, to construct a series for ICT capital stock and ICT capital cost we first assume that, like the rest of the economy, this sector has constant returns to scale. Given this assumption and that data exists for nominal GDP and labour compensation, we are able to obtain total capital cost for the sector. Next, using data acquired from Statistics Canadas MFP program, we are able to break down the share of the cost of capital services that is ICT up until 2008, which we extend to 2014 using the shares from NAICS 54.[26] To get the real ICT capital in the sector, we calculate a ICT user cost by dividing the ICT capital cost in the total economy by real capital, and then applying that to NAICS 5415 to get an estimate of the real ICT capital in the sector.

ICT capital cost can be calculated using a simple Jorgenson user cost as shown in Appendix B. To calculate the capital cost for the total economy, however, we decided to use the capital cost series from Statistics Canadas MFP program for the business sector, and apply the ratio of ICT capital cost out of total capital cost to the aggregate economy after assuming constant returns to scale (we also tested the robustness of our results to this by using ratios from Statistics Canadas MFP program with very similar results). We then disaggregated the ICT capital cost by type of capital

26 We also test using the average share of ICT from 2004-2008, as well as using the shares from the other two ICT- producing sector, which yields the same qualitative conclusion.

by using the shares calculated using the Jorgenson formulas.

The constant returns to scale is an important assumption as much of the data we use will depend upon the labour share. We calculate the labour share simply as the labour compensation divided by nominal GDP at basic prices. This gives a slightly lower labour share than is sometimes calculated, for example in Statistics Canadas Productivity Accounts.

# Canadian Productivity Growth, Secular Stagnation, and Technological Change

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Abstract

In this article, we show first that the recent slowdown in productivity growth in Canada, similar to that in the United States, can be attributed at least in part to the fall-off in the commercialization of new technologies. Using our book-based indicators of technological change, we are able to show that this is true for both aggregate measures of technology and, at the disaggregate level, for mechanical/manufacturing and electrical technologies. Our results also indicate that the productivity impact of the slowdown in Canada is much greater on goods-producing industries than it is on services. Second, our latest results suggest that, contrary to the concerns of some that we are entering a new period of secular stagnation characterized by low productivity and economic growth, we are actually on the threshold of significant new technological breakthroughs, associated largely, but not only, with advances in artificial intelligence (AI) and robotics. Provided that Canadian firms adopt these innovations, we can anticipate not a continuation of slow productivity growth but an acceleration.

Since the early 2000s Canada's productivity growth has been poor relative to historical and international performance. While there is no general agreement about the causes of this slowdown, there is concern among a number of prominent economists that it may presage the beginning of an extended period of secular stagnation.[2] Many contend, moreover, that technological change, which, for the last 150 or so years, through good times and bad, had been a main source of productivity advances and output growth is no longer up to the task. Gordon (2015), among others, maintains that the great inventions and innovations of the second industrial revolution — electricity,

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2 See, e.g., Gordon (2012, 2015), Summers (2015), Fernald (2016, 2018).

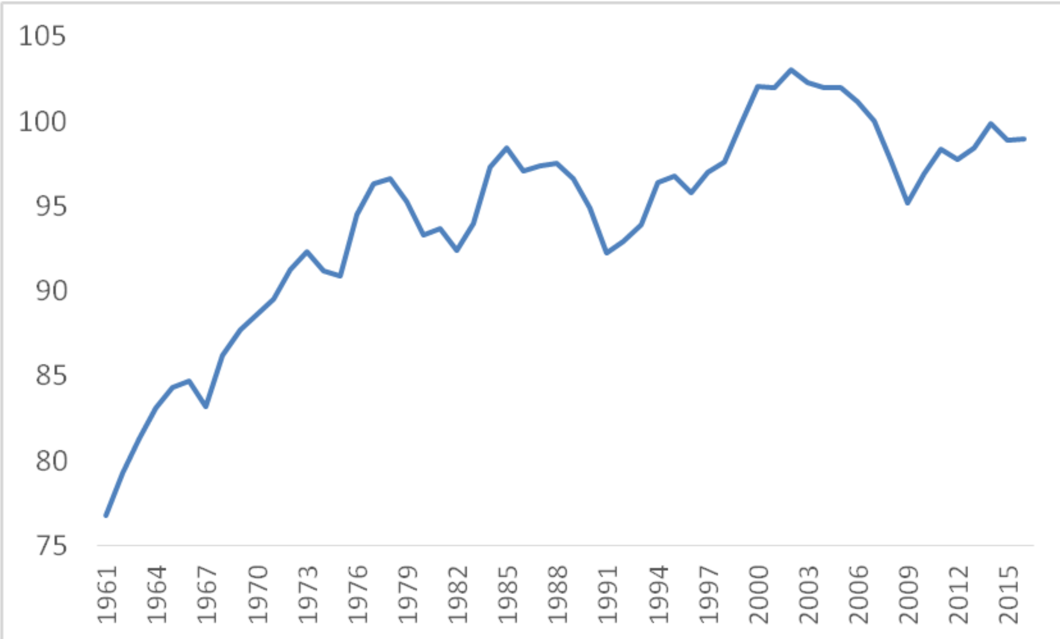
the internal combustion engine, organic chemicals — are spent forces and nothing evenly remotely comparable to their transformative impact, with the possible exception of the ICT revolution, also over, is conceivable for the foreseeable future. From this point of view, then, lackluster technical change has been a major contributor to the recent fall-off in productivity growth and there is little reason to believe that a turnaround is imminent.

This argument raises two fundamental questions about growth and productivity in Canada. First, can the post-2000 slowdown in Canadian productivity growth be attributed, at least in part, to a fall-off in the pace of technical change? The answer, as we show, is, by and large, yes. The second, which flows directly from the first, is the following. Can we infer from the marked drop in innovative activity in the first decade or so of the new century that Canada, along with other developed economies, faces a dismal future of modest (at best) technological advances and, therefore, very low rates of productivity and economic growth?

Although the answer to this question is less definitive for Canada than it is for the United States, we are able to show that even here the pace of technological change has begun to rebound and is likely to accelerate, not moderate further in the next few years. If the trend continues, the issues that Canada must deal with are not those linked to slow productivity growth and secular stagnation but are, instead, those related to the changing nature of employment opportunities, skills requirements, educational demands, and, most probably, income distribution.

We proceed as follows. In the first section, we review the evidence on the recent slump in productivity growth in Canada and display recent trends in the multifactor productivity (MFP) of the goods and service producing sectors. In the following section, building on our past work, we present measures of innovative activity derived from books held in Canadian libraries in the different fields of technology (based on an analysis of OCLC holdings and WorldCat data). These book-based measures indicate that the fall-off in innovative activity in the early 2000s closely parallels the productivity growth decline in terms of both timing and areas of economic activity. In short, the data show a drop in technological advances beginning around 2002-3, centered primarily (but not exclusively) in electronics and goods-producing technologies. In section four, we estimate a series of vector autoregressive (VARs) equations to determine the relationship between our technology indicators and measures of MFP, and then estimate how much of the slowdown can be attributed to the slowdown in technical change. We find, first, that there is a positive relationship between our aggregate technology measures and business sector MFP. Second, our results indicate that innovations related to electrical goods (including computer networks and telecommunications) as well as those linked to mechanical machinery have a significant positive impact on productivity, and

**Chart 1: Business Sector Multifactor Productivity in Canada, 1961-2016 (2007 = 100)**




Source: Statistics Canada, Productivity Measures, Table: 36-10-0208-01.

have been the most important drivers of Canadian MFP. In section five, we review evidence on the current pace of technical change. We, first, present indicators based on computer and technical titles available for sale at Amazon.com and Amazon.ca. These data show that there are tentative signs of a rebound in technical change (more marked at present in the United States than in Canada). Next, through textual analysis of book data and other printed sources, we pinpoint the specific areas — artificial intelligence (AI), robotics, etc. — where the resurgence is occurring. Given that these innovations are, for the most part, located in areas that are likely to be the main drivers of Canadian productivity in the near future (if adopted), we foresee a recovery in productivity and a substantial improvement in the economy's growth prospects. Section six offers some concluding remarks.

## The Recent Slowdown in MFP Growth in Canada

While Canada, like other countries, has witnessed a number of productivity slowdowns in the past, we focus here on the most recent one which, according to Statistics Canada data reported in Chart 1, dates from the early 2000s.[3]

As in past instances of productivity slowdowns (e.g. the mid-1970s and the 1930s when, it is worth noting, similar concerns about secular stagnation were raised), Canada's recent productivity fall-off is mirrored in a number of other countries. In particular, as can be seen in Table 1, both total factor produc-

3 MFP data was retrieved from http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=3830021.

Table 1: U.S. Output and TFP Growth in the U.S. Business Sector (average annual rate of change)

| | TFP growth | Utilization adjusted TFP growth | Output growth |
|---|---|---|---|
| 1947:2-2018:2 | 1.24 | 1.27 | 3.31 |
| 1974:2-2000:4 | 1.40 | 1.45 | 3.69 |
| 1995:4-2018:2 | 0.99 | 1.03 | 2.78 |
| 1995:4-2000:4 | 1.85 | 2.02 | 4.88 |
| 2001:1-2018:2 | 0.73 | 0.73 | 2.15 |
| 2001:1-2016:2 | 0.67 | 0.70 | 2.05 |
| 2016:3-2018:2 | 1.21 | 1.03 | 2.94 |

Source: Data from Fernald (2014) updated Sept 7, 2018 available from Federal Reserve Bank of San Francisco.

tivity (TFP)[4] corrected for utilization, and output growth in the United States fell sharply after 2001.[5] In short, then, whatever forces are dragging down productivity and economic growth rates in Canada are doing the same thing elsewhere, most significantly in our large neighbor to the south.

The Canadian data shown in Chart 2 indicate that MFP growth fell off much more in the goods sector than in the service sector.[6] The disaggregated numbers reveal, for example, that the largest contributors to the decline in business sector MFP were the goods producing industries such as mining and quarrying, utilities, manufacturing, construction, agriculture, fishing and forestry where, after 2002, MFP actually fell in absolute terms.[7] In contrast, as can be seen in Chart 2, MFP in the service sectors — wholesale and retail trade, transportation, information, finance and insurance, real estate, education, health care, arts and entertainment, recreation and tourism, public administration and other services — suffered an absolute drop in MFP in the 1980s but has, since then, experienced modest year over year increases.

The key question raised by these descriptive statistics: can the recent drop in productivity growth in Canada (and in the United States) be attributed, as Gordon contends (2015), to the fall-off in the pace of innovative activity? We attempt to answer this question in the following section.

## Was There a Slowdown in the Pace of Technological Change

A little background is useful. Most would agree that the Second Industrial Revolution (beginning more or less in the third quarter of the 19th century) ushered in a stunning array of new technologies, including electricity, the internal combustion engine, synthetic dyes,

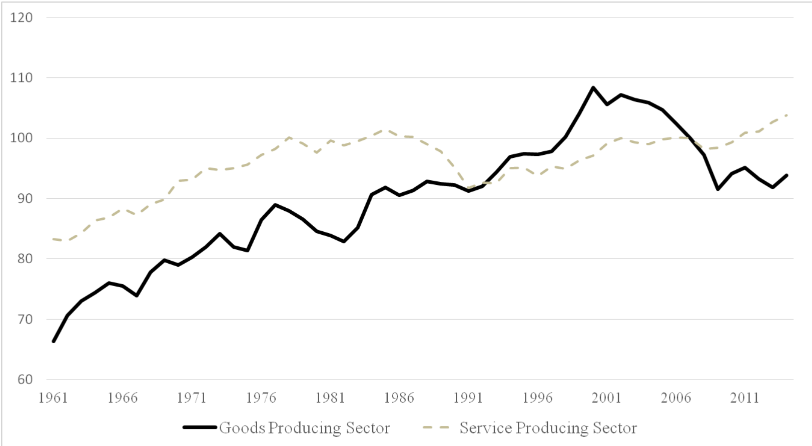
4 Note that the term multifactor productivity (MFP) and total factor productivity (TFP) are synonymous. The former term is used primarily by statistical offices such as Statistics Canada and the U.S. Bureau of Labour Statistics while the latter term is used largely by academic researchers.

5 For additional US-Canada productivity comparisons, see Baldwin and Gu (2013, Table 3) and Gu and Willox (2018). As expected, the data reveal a slowdown at the end of the 20th century in both countries.

6 See Gu and Lee (2013) for additional evidence on the variation in sectoral MFP growth rates.

7 The definition of goods producing industries in Canada can be found in Statistics Canada's North American Industry Classification System (NAICS) Version 3.0, 2017

**Chart 2: Business Sector Multifactor Productivity in Canada: Goods vs Service Sectors, 1961-2016 (2007=100)**




Sources: Statistics Canada, Productivity Measures Table: 36-10-0208-01.

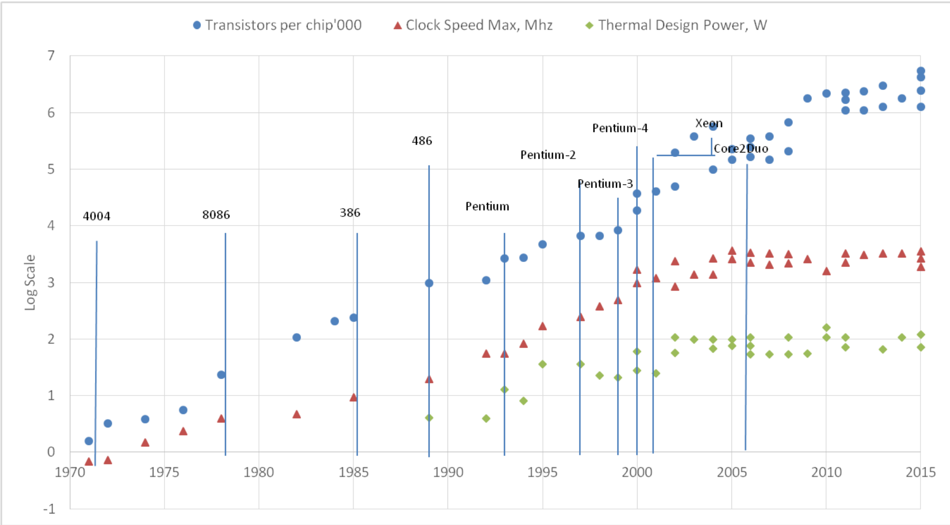
clean water and effective sewer systems. Together they dramatically altered the way most people in the West lived and worked.[8] According to the technological pessimists such as Gordon (2015), however, by the 1960s the economic growth generated by these advances was, for the most part, over and those that followed lacked the transformative force of the earlier breakthroughs. The one exception may have been computer and information technologies (the so-called "Third Industrial Revolution") but, as Gordon and others point out, while their impact on output and productivity may have been substantial it was also relatively short-lived (1996 to 2004 in the United States).

There may be some merit to this argument. It is, after all, true that while the innovations in information technology (IT) were largely responsible for productivity growth in the last years of the 20th century, advances in a number of IT areas has slowed and, computers, once the *wunderkinder* of the modern age, are now more properly thought of as commodities. Moreover, Moore's Law (i.e. the doubling of transistors and related computing power per circuit every two years) may be less of a law than was once thought (Chart 3). Despite these observations, given that Industrial Revolutions 1 and 2 each took over 100 years to play out, with ebbs and flows in the pace of innovations, it would seem that it is too early in the process to warrant writing the obituary of the Third Industrial Revolution.[9] Indeed, as we show below, while there clearly was a slowdown in innovative activity in the early years of this century, our metrics suggest

8 It is worth pointing out that these urban public health initiatives were not in themselves technological advances. The real advances were associated with the germ theory of disease and other breakthroughs in medicine and biology

9 For example, recent articles stemming from statements and research from the computer industry suggest that Moore's Law may still hold; it just needs to be altered to reflect current advances in the industry. See, for example, McGoogan (2017).

**Chart 3: Changes in Processors Over Time**




Notes: Vertical lines represent introduction dates for various processors. Thermal design power is based on the maximum safe poser consumption levels.
Sources: The Economist (2016), Intel, Linley group, IB consulting and Bob Colwell.

that AI and robotic technologies, direct progeny of the IT revolution, are at the initial stages of their development and diffusion.

## Quantifying Technical Change

We use in this article, as we have done elsewhere, book-based measures of technical change (Alexopoulos, 2011; Alexopoulos and Cohen, 2011). The idea behind this approach is simple and intuitive. Books are written and published on new technologies because authors earn royalties by spreading the word and publishers profit by selling the titles. Timing, of course, matters: too early to market and there is no demand, too late, and demand is already satisfied by competitors. It is not surprising, then, that the first appearance of books on a new innovation coincides with its commercialization date, which, in turn, means that changes in the number of new technology titles over time provides a compelling measure of technological advances.

These measures have other attractive properties. They are available at least on an annual basis over a very long time horizon; they are objective in that their classification is determined by specialists in the field (librarians, publishers and/or booksellers); and they weight technologies according to their importance because the number of titles tend to vary with the significance of the innovation and thus with the size of the market.[10] As a final bonus, they are more likely than other indicators to cover the full range of both product and process innovations because both types of ad-

10 The weighting occurs because publishers make well-informed forecasts about the size of market for a technology and thus the potential demand for related titles. The larger and more important the technology, *ceteris paribus*, the greater the number of titles.

vances appeal to readers and potential adopters.

These measures also overcome many of the shortcomings associated with more traditional indicators of technical change such as cleansed residuals,[11] patent counts, and R&D expenditures when attempting to track commercialized technologies. The problem with the cleansed residual is that while they may pick up technology-induced changes in productivity (MFP or labour), they can also be driven by factors totally unrelated to new production techniques.[12] While patent counts and/or citations do provide some indication of potential advances, many do not result in commercially viable innovations and, even for those that do, the lag between the patent date and the diffusion of the technology varies widely and unpredictably. As a result, even in the best case scenario, the link between them, commercialized innovations, and changes in aggregate productivity is difficult to uncover (e.g. Shea, 1998). Finally, R&D expenditures, which typically pre-date patents, are similarly plagued by problems of timing and realization and thus make it difficult to use them as proxies for the commercialization of new technologies.

To employ our book based approach for Canada, we need first to identify an appropriate data source. Unlike in the United States, where the Library of Congress is essentially the literary depository of record for all published materials, no one such institution exists in Canada. Therefore, as we did in our previous work on IT innovation in Canada (Alexopoulos and Cohen, 2012), we employ book data collected from the catalogues of over 1,000 Canadian libraries covered in the WorldCat database of the Online Computer Library Centre (OCLC). Although not all Canadian libraries belong to OCLC, membership includes most of the major collections in the country, including the National Library of Canada, the largest public libraries (e.g. those in Toronto, Montreal and Vancouver), and every major university library. As such, data associated with the technology and computer Library of Congress (LOC) Classifications (i.e., the T class and QA75-77 classes) should provide a comprehensive list of the major technology titles available in Canada.[13] To avoid double counting, we de-duplicated the data using information in the **MA**chine **R**eadable **C**atalogue **R**ecords (MARC) for each of the titles.[14]

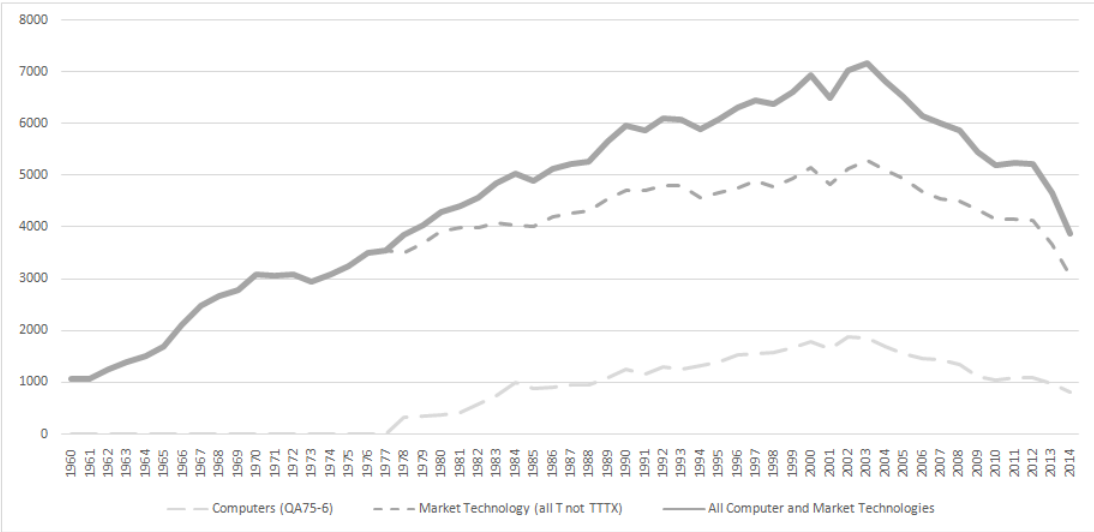
11 Cleansed residuals are Solow-type TFP measures that attempt to control for factors such as increasing returns, imperfect competition, cyclical utilization of capital and labour, and reallocation effects.

12 See, for example, Basu, Fernald, and Kimball (2006) and Christiano, Eichenbaum and Vigfusson (2004).

13 While some libraries use the Dewey decimal system, the MARC records, for the most part, record both the Dewey and LOC classifications. We make use of the later largely because the major university and research libraries, the principal location for much of the technology literature, uses the LOC classification.

14 MARC records contain identifiers such as the Library of Congress Id number, and ISBN numbers which can be used to remove duplicates.

**Chart 4: Unique LOC Classed Technology and Computer Titles Held in Canada by Copyright Date, 1960-2014**




Source: Authors' calculations from OCLC Worldcat Data.

## What Do the Data Tell Us?

Our indices for Canada, presented in Chart 4, cover the years 1960-2014 and show the unique titles held by copyright date.[15] The most notable finding is that we do indeed see a downturn in innovative activity as proxied by technology and computer titles held in Canadian libraries, in the early 2000s, more or less in line with the fall-off in productivity. As can be seen in the chart, this drop occurred in the T class (all marketable technologies, excluding those related to home production in the TT and TX groups), in QA 75-76 (computer science titles) and in the sum of the two.

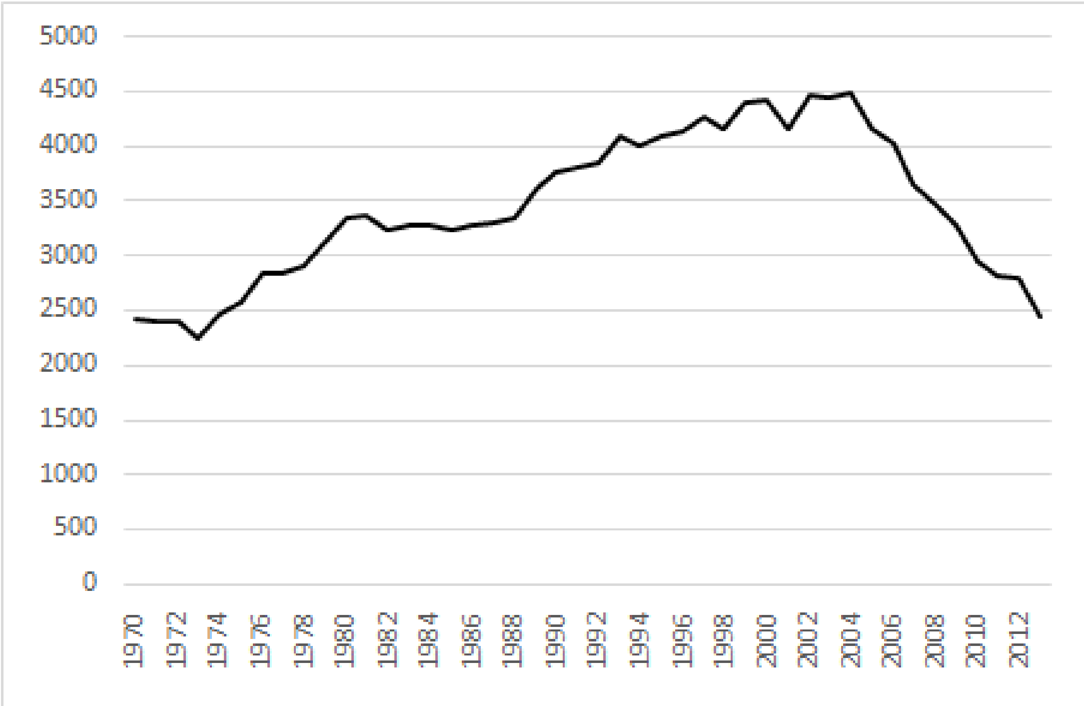
One possible concern about these findings is that the decrease represents not a fall-off in innovative activity but a general decline, for some reason, in the number of all published titles. The data, however, do not support this. On the contrary, they indicate that the number of new titles in other fields (such as literature) rose, not fell, in the early 2000s. Similarly, there is no evidence that acquisitions fell due to budget contractions at Canadian libraries. Indeed, library budgets, for the most part, were unusually robust during these years, bolstered, among other things, by a strong Canadian dollar for much of the period.[16]

Additional support for a technological slowdown comes from south of the border where the well-known decline in innovative activity in the United States (Chart 5) is matched by a drop in the number of new titles in the T class. In short then, the Canadian data, consistent with those in the United States,

15 The decision to omit the last few years of the sample removes biases associated with backlogs in cataloguing activities by libraries.

16 The US-Canadian and UK-Canadian exchange rates matter because the largest number of imported titles come from these two countries.

**Chart 5: Technical Change in the United States: New Titles in LOC T CLass by Copyright Date**



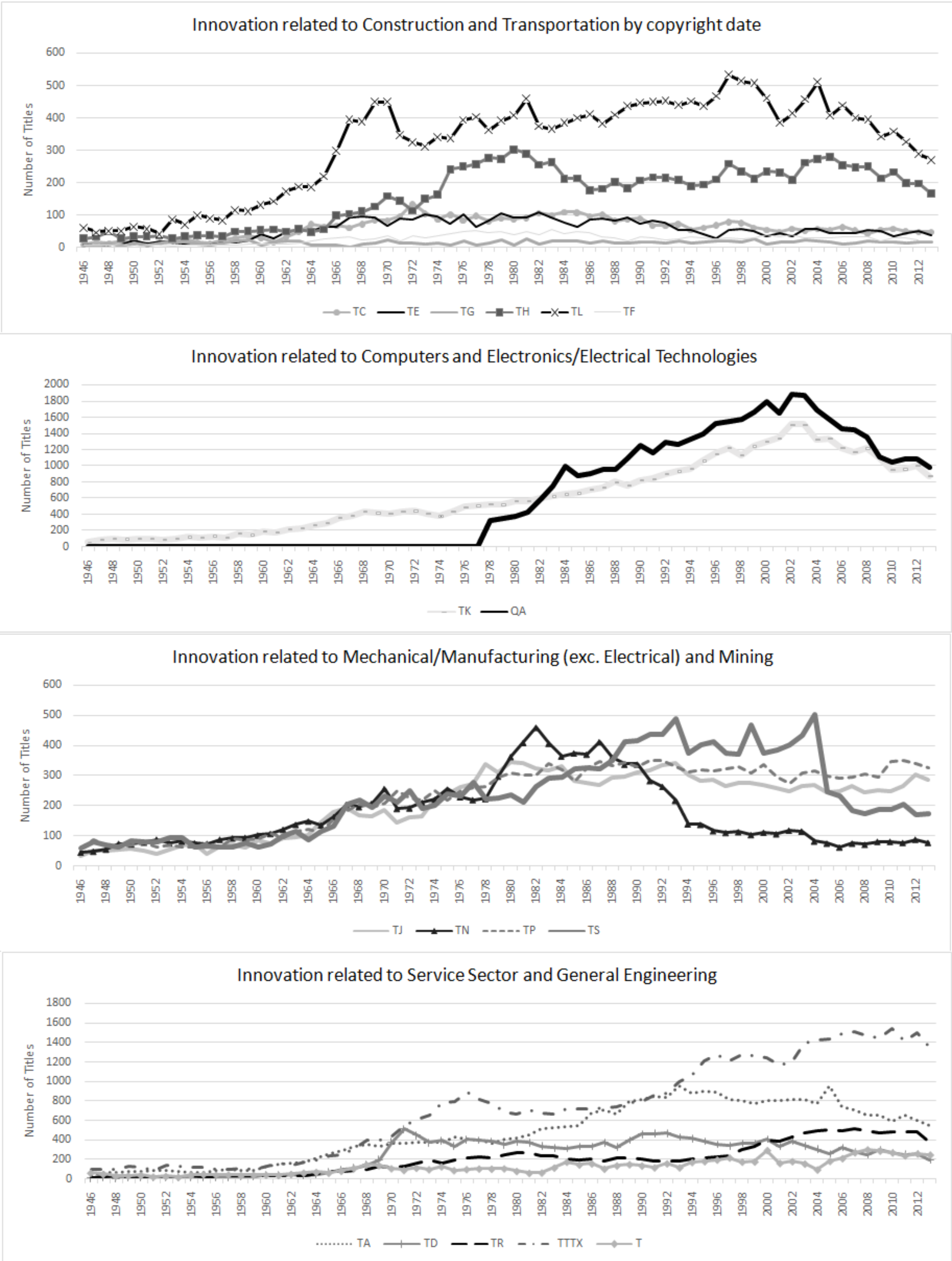

Source: Authors' calculations from OCLC Worldcat Data.

confirm that the fall-off in technical change as captured by library holdings parallels the slowdown in productivity growth.

In an effort to pinpoint the exact sectoral breakdown of these trends, we undertake a more fine-grained analysis. Chart 6 plots the number of titles by copyright date for general technology (T subclass), general engineering (TA), hydraulic and ocean engineering, including the building of dams (TC), environmental and sanitary engineering (TD), highways and roads (TE), railroads (TF), bridge engineering (TG), building construction (TH), mechanical engineering and machinery (TJ), electrical engineering and electronics (TK), transportation technologies (TL), mining and metallurgy (TN), chemical engineering and technologies (TP), photography including uses for digital cameras and medical radiology (TR), manufacturing (TS), home economics/food preparation, handicrafts, cloth manufacturing and design, and management of services such as hotels and restaurants (TTTX), and books in the QA75-77 class (QA) related to computer science.

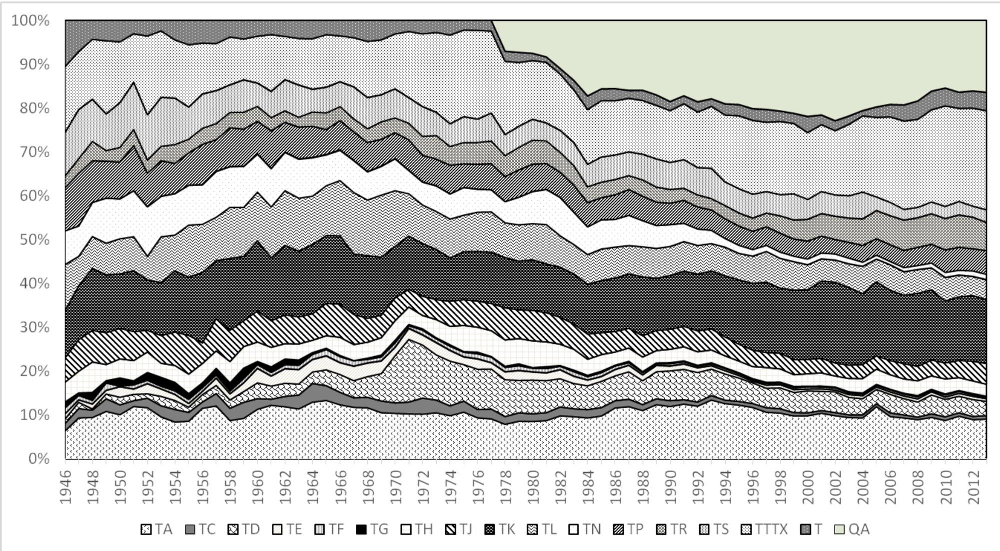
They show that the largest decreases were centered in the QA (computer science and software) and TK (electrical, including telecom, computer hardware, and computer networks). TA (general engineering) and TS (manufacturing technology) display a similar if less dramatic pattern beginning in the 1990s while technical change in mining and natural resources (TN) began its descent, again less pronounced, even earlier. Some sub-sectors, on the other

**Chart 6: Waves of Innovation by Copyright Date – Breakdown of Titles in Technology Classes**




Source: Authors' calculations from OCLC Worldcat Data.

**Chart 7: Distribution of Waves of Innovation in Technology Classes by Copyright Date, 1946 - 2012**




Source: Authors' calculations from OCLC Worldcat Data.

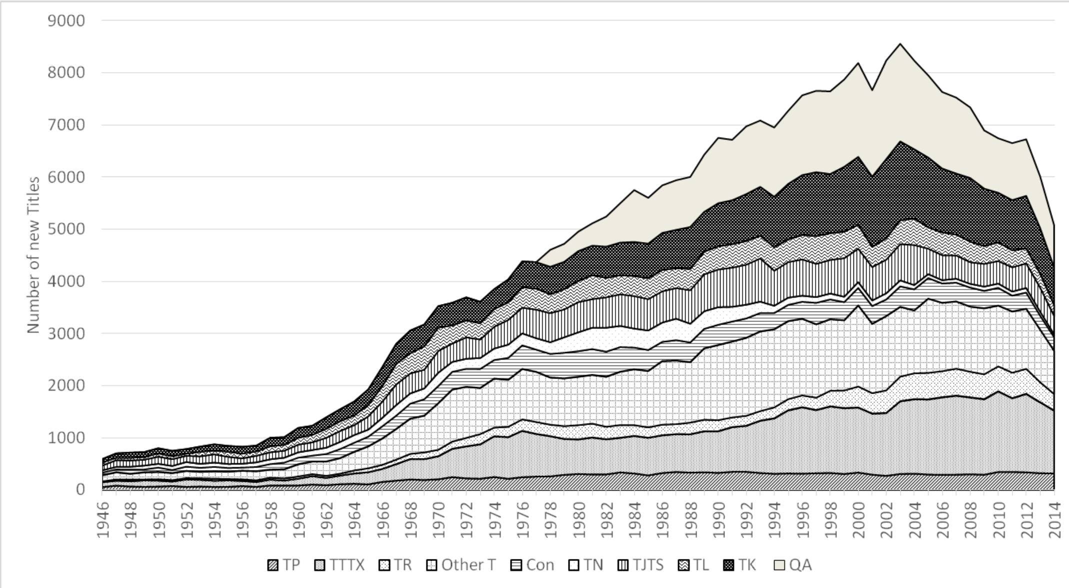
hand, as can be seen in the chart, particularly those linked to services such as TTTX (hotel and restaurants, food prep and related services) and TR (cinematography, photography, radiography) experienced modest growth post 2003. As can be seen by comparing these data with the productivity numbers presented in Chart 2, there is a striking coincidence between the divergent productivity patterns traced by MFP in the service sector and in the goods sectors and innovations in the two sectors.

An examination of the percentage distribution of titles in each of the T categories each year (i.e., the number of new titles in the technology/computer subclass in year j divided by all new titles in the technology and computer subclasses in the same year) provides additional insights into the changing significance of the various technology sub-groups in the country's technological profile. This breakdown is shown in Chart 7.

While TN (mining) was a non-trivial area of innovation in the early post-war period, it now appears to account for a relatively small share of new innovations. On the other hand, TL (automotive), which was approximately the same as mining in terms of its innovative importance in the late 1940s, has declined much less in the ensuing 60 or so years.

The largest changes in shares have been in the Information Technology (IT) related areas. Specifically, the computer class (QA) clearly rose to prominence in the 1980s and 1990s, but has lost ground recently. In contrast, TK (electrical/electronics), a main contributor to innovative activity throughout the period, has, following the introduction of personal computers and the internet, boosted slightly its share in the total. Finally, near the end of the sample period, the share of innovations related to TP (chemical technologies including some biotech innovations), TR,

**Chart 8: Technical Change Over Time by Copyright Date**




Source: Authors' calculations from OCLC Worldcat Data.

and TTTX are all on the rise.[17]

In an effort to synthesize the information contained in the previous area figures, we present in Chart 8 a stacked area graph. To do this we created ten groups out of the initial sixteen and ordered them from bottom to top by average growth rate post-2003. It is clear that if we focus sharply on the period after 2003 the largest decline in the number of new technological titles occurred in construction ("Con defined as TC +TE+TH+TG), mining (TN), mechanical/manufacturing ("TJTS defined as TJ +TS), transportation (TL), electrical/electronics (TK), and computers (QA). Moreover, within this larger grouping, areas linked to computer technologies and electronics were the largest contributors to the fall-off with a lesser but still not insignificant part played by transportation and manufacturing. In contrast, changes in the number of new titles in TP (chemicals), TTTX (hotel and restaurants, food prep and related services) and TR (cinematography, photography, radiography) seem to have played no role in the decline while environmental technologies, general engineering, and railroads (i.e., "Other T" defined as subclass T + TA + TD +TF) experienced at most a minor reduction in new titles. While the coincidence between the sectoral pattern of the slowdown in innovations and the drop in productivity growth would seem to suggest that the former were largely responsible for the latter, we undertake a formal statistical analysis in the next section before presenting concrete conclusions.

17 Interestingly, Gu and Lee (2013) point out that the information and culture sector's labour productivity and multi-factor productivity grew during the 2000-2010 period. This would be consistent with an increase in innovation captured by the TR class.

## A Statistical Analysis of Technical Change's Contribution to the Productivity Slowdown

To determine the impact of variations in technical change on Canadian MFP, we ran a series of bivariate VARs[18] on annual data from 1961 to 2014 of the form:

$$Y_t = \alpha + \sum_{j=i}^{k} \rho_j Y_{t-j} + f(t) + \epsilon_t \qquad (1)$$

where the starting date was determined by the availability of MFP data from Statistics Canada and the end date by the availability of the book holdings data. We estimated cases with $k = 2, 3$ where $Y_t$ = [ln(Productivity$_\mathrm{t}$), ln(tech index$_\mathrm{t}$)], with and without time trends included,[19] as well as a case with both productivity and the technological indices in first differences.[20] We include more than one year of lags because, in our previous work, we found that many of the titles (and innovations) coming from south of the border begin to diffuse with a 1-3 year lag in Canada.

Technology shocks are identified using a Cholesky decomposition. Specifically, our identifying assumption, similar to the one we used in our previous work (and in keeping with Christiansen (2008) and Shea (1998)), is that a technology shock only affects MFP with a lag. Since the different specifications make very similar predictions, we focus on the cases of VARs in levels with 2 lags and a trend and VARs in first differences. Due to space constraints, we limit our discussion to areas where the effects of the technology shocks are significant.

### Aggregate Technology Shocks

Overall, we find that business sector productivity (MFPagg) is Granger-caused by the aggregate technology measures (i.e., "T Class" is defined as all new T titles per year and "T class +QA75-6" are all T class and computer titles) at the 5 per cent and 10 per cent levels with no evidence of reverse causality. When we looked at the relationship between the indicators and MFP in the goods and service sectors, we found the technology measures signif-

18 A vector autoregression (VAR) is a useful time-series application to capture the linear interdependencies among economic variables. The model consists of a system of equations where a linear multivariate relationship is defined for each variable. VARs are a-theoretical as they contain little or no economic theory. They do not have any implication for causality. Thus, researchers often impose a structure or restriction (i.e. determining contemporaneous casual relationships between variables) on VARs to isolate estimates of policy or economic agents' behaviour and its effects on the system or the economy. With this assumption, economic shocks occur from different sources of uncertainty and interact with each other only through their effect on the decisions of the economic agents. Hence, it is clear how the causalities work in the economy.

19 Time trends are included in the base case to account for the rise over time in the number of unique technology titles driven by: (1) increases in potential readership as a result of population growth and a rise in general educational levels, and (2) decreases in publishing and market costs caused by technological advances in the publishing.

20 In the Appendix we run two alternative sets of regressions, one where we substitute labour productivity for MFP the other where we replace ln(tech index) with ln(stock of technology titles). The results illustrate that the main findings reported in the paper are robust to these sensitivity checks. The Appendix is posted at http://www.csls.ca/ipm/35/Alexopoulos_Cohen_Appendix.pdf.

icantly Granger-caused MFP in goods but not MFP in services, again indicating that the slowdown in innovation appears to have had its greatest effect on manufacturing, mining and construction.

The impulse response functions confirm that positive technology shocks during this period increased both aggregate and goods sector productivity significantly over the 10-15 years following the shock with the peak impact occurring after 5 years.[21] In contrast, there was no significant impact on service sector MFP. As the responses displayed in Chart 9 (along with 90 per cent confidence bands)[22] show, while the effects of the shocks are long lasting, the results become significant only after a few years, in keeping with the conventional wisdom that Canada adopts U.S. innovations with a lag.

Table 2 displays the associated variance decompositions for the cases of VAR in levels and VARs in growth rates for both business sector MFP and MFP for the goods sector. The results for the aggregate and goods sectors suggest that technology shocks account for a significant fraction of the fluctuations in Canadian MFP (and its growth rates). The fraction of the variation goes up modestly over time, similar to magnitudes seen for the United States.[23]

### Disaggregated Technology Shocks

As innovations are likely to vary in terms of their impact on productivity, it is useful to break down technical change into a number of sub-categories to determine with greater precision the technology-productivity link for Canada. To do this, we examine separately the effects of technology shocks associated with manufacturing/mechanical (i.e., TJ+TS), Chemical (TP), transportation (TL), mining (TN), construction (TC+TE+TH+TG), and electrical (TK) in a series of bivariate VARs. We find that only the first of these Granger-cause business sector MFP at the 5 per cent level while all the other do so at the 10 per cent level. None of the other shocks were significant at conventional levels. For the goods sector, we find that electrical (TK) and mechanical/manufacturing technologies (TJTS) Granger-cause goods sector MFP at just under a 1 per cent level. None of the technology indicators consistently Granger-cause service sector MFP at conventional levels of significance.

In Panel B of Chart 10 we present cases where we find significant responses to the various technology shocks. Overall, the trajectories are similar to those seen for aggregate technology. In most cases, peak impact occurs 4-5 years following the shock with a limited initial impact. The one exception is mechani-

21 In what follows, only significant responses to shocks are displayed in the charts.

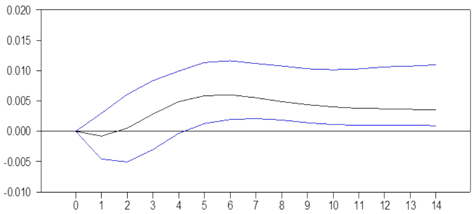
22 All confidence bands are computed using a Monte Carlo procedure.

23 See Alexopoulos and Cohen (2018) and Alexopoulos (2011) for US values.

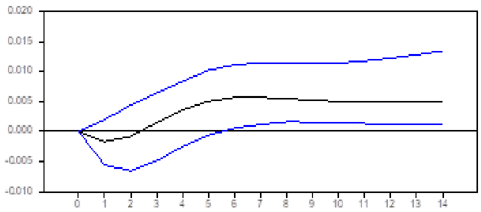
**Chart 9: Responses of Canadian MFP to a Positive One-Standard Deviation Aggregate Technology Shocks.**

Panel A. Business Sector MFP responses (VARs in levels)

T Class

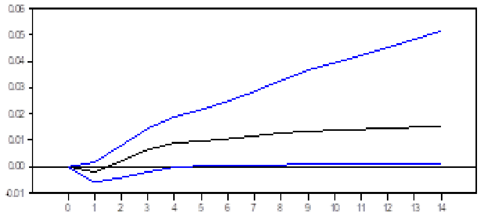



T Class + QA75-6

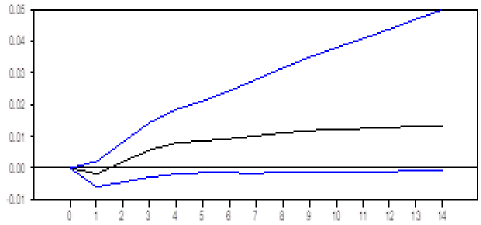



Panel B. Implied Business Sector MFP responses (VARs in first differences)

T Class

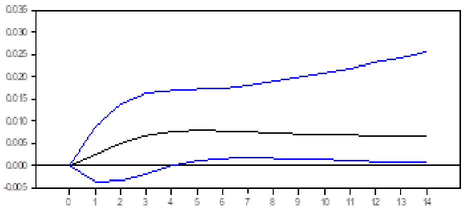


T Class + QA75-6

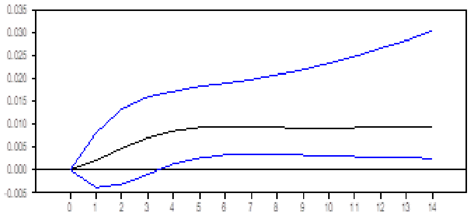


Panel C. Goods sector MFP responses (VARs in levels)

T Class

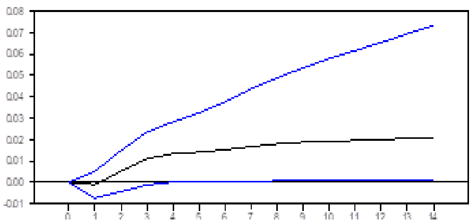


T Class + QA75-6

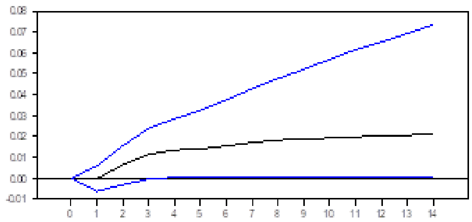


Panel D. Implied Goods sector MFP responses (VARs in first differences)

T Class



T Class + QA75-6

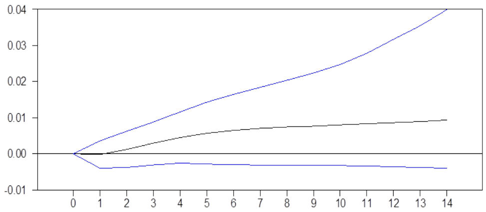


Note: The responses measure percentage deviations of MFP in response to positive one standard deviation technology shocks. Each period is one year. The panels display the estimated responses and the 90 per cent confidence bands. The responses displayed are from the bivariate VARs with two lags. Our indicators are ordered last and shocks are identified using a Cholesky decomposition. Implied MFP responses are the *cumulated* growth responses from the VAR in estimated with differences.

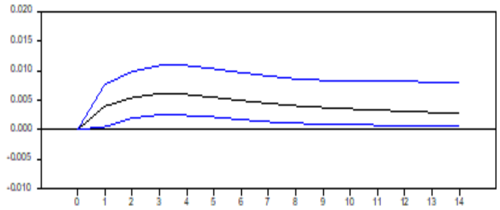
**Chart 10: Selected Responses of Business Sector MFP, and Goods Sector MFP to Positive One Standard Deviation Technology Shocks**

Panel A. Business Sector MFP

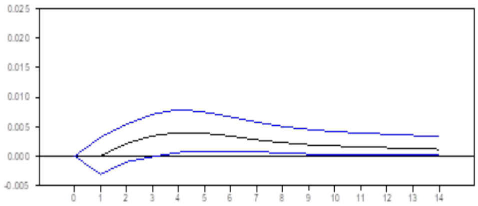
Electrical/Electronics (TK)



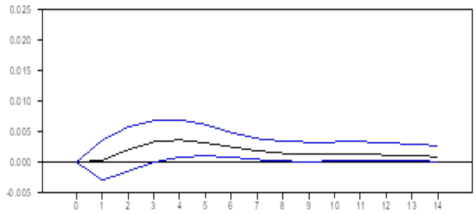
Mechanical/Manufacturing



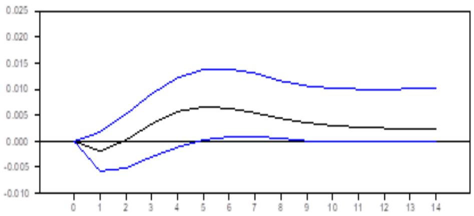
Chemical (TP)



Construction

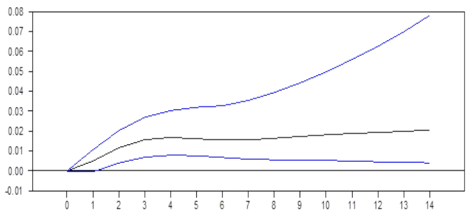


Transportation (TL)

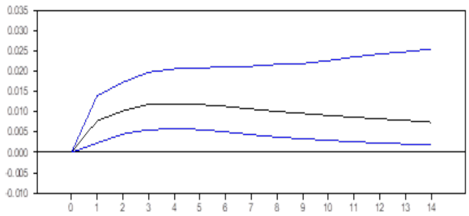


Panel B. Goods Sector MFP

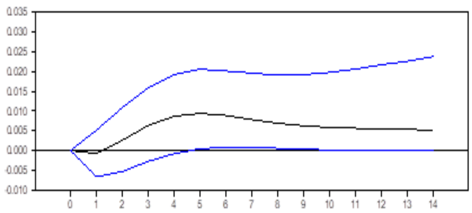
Electrical/Electronics (TK)



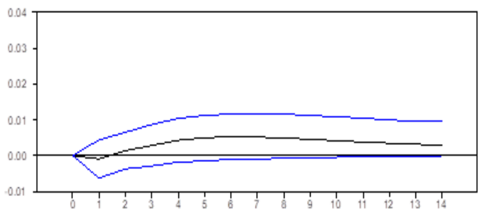
Mechanical/Manufacturing



Chemical (TP)



Transportation (TL)



Note: The responses are percentage deviations of MFP in response to positive one standard deviation technology shocks. Each period is one year. The panels display the estimated responses and the 90 per cent confidence bands. The responses displayed are from the bivariate VARs with two lags and a trend. Indicators are ordered last and shocks are identified using a Cholesky decomposition.

**Table 2: Variance Decompositions of VARs for Business Sector and Goods Sector MFP Levels and Growth Rates**

| Horizon (years) | Level (ln) MFPagg | Level (ln) MFPgoods | Growth MFPagg | Growth MFPgoods |
|---|---|---|---|---|
| | T class technologies | | | |
| 3 | 1.5 | 2.2 | 9.8 | 8.2 |
| | (0.1, 11.2) | (0.1, 14.2) | (2.3, 23.9) | (1.2, 21.4) |
| 6 | 13.8 | 9.0 | 18.1 | 13.6 |
| | (2.1, 37.4) | (0.6, 32.9) | (4.4, 38.8) | (2.1, 32.6) |
| 9 | 25.2 | 14.6 | 19.5 | 14.5 |
| | (5.1, 52.7) | (1.3, 41.5) | (4.6, 42.1) | (2.1, 37.4) |
| 12 | 29.4 | 17.6 | 20.1 | 14.8 |
| | (7.1, 61.5) | (1.8, 47.7) | (4.7, 44.8) | (2.1, 40.3) |
| | T class and QA75-77 technologies | | | |
| 3 | 1.7 | 2.2 | 8.4 | 7.9 |
| | (0.1, 12.2) | (0.1, 13.4) | (1.6, 21.6) | (1.0, 21.6) |
| 6 | 10.4 | 12.3 | 14.7 | 12.2 |
| | (1.7, 30.2) | (1.2, 36.6) | (2.7, 34.9) | (1.6, 30.9) |
| 9 | 22.1 | 21.5 | 15.8 | 13.3 |
| | (4.2, 49.5) | (2.6, 50.3) | (2.8, 39.0) | (1.6, 36.5) |
| 12 | 29.4 | 26.8 | 16.2 | 13.6 |
| | (6.1, 60.9) | (3.9, 59.1) | (2.8, 41.6) | (1.7, 38.8) |

Note: Numbers in brackets represent the 90% confidence bands.

cal/manufacturing, where both MFP in the business sector and in the goods sector increase significantly within the first few years.

To summarize briefly, it appears that innovations influencing manufacturing/mechanical (TJTS) technologies, and the electrical/electronic (TK) technologies play among the largest roles in explaining the variance in productivity.[24] By the 6-year horizon, approximately 21 per cent of the variation in business sector MFP was attributable to the TJTS innovations, with the share growing to over 30 per cent. When examining the case of electrical technologies, the estimated share at the 6-year horizon was about 10 per cent rising to over 35 per cent by year 12. The effects of the transportation technologies (TL) also appear to be in the 15-25 per cent range for the 6-12 year horizon. In contrast, construction (Con) and chemical technologies (TP) account for only about 10 per cent.

We obtain similar results for the relationships with MFP in the goods sector. In these cases, variations attributable to TJTS and TK were about 11 per cent by the 3 year horizon with the shares growing to 41 per cent and 51 per cent respectively by year 12. The fluctuation in goods sector MFP linked to chemical and transportation technologies remain in the range of 8 per cent-15 per cent. For the service sector MFP, TK (electrical, including networks, and telecommunications technologies) and TR (photographic/digital linked to areas such as advertising, medical services, arts and entertainment sectors, surveying services etc.) are, not surprisingly, the

24 The reported results are from the bivariate regressions. To the extent that the disaggregated series capture common underlying technological changes, it is important to note that these shocks will pick up some of the same variation in MFP.

largest contributors to fluctuations in productivity. However, the results are generally found to be insignificant at standard levels.

Predicting the future path of technical change in Canada (as elsewhere) is extremely difficult. However, given that many of our new technologies come from our southern neighbor, it is possible to glean some information about the probable course of new innovations by looking at current advances in the United States in conjunction with other available evidence. We present some of this below, and, for the most part, it would appear to support the notion that there is a quickening pace of innovative activity there, and, given the revolutionary nature of many of the new technologies, *if* Canadian firms embrace them, the future path for productivity here looks promising.

## Is the Productivity Slowdown Over?

Evidence to support our optimism comes from, among other sources, technical titles distributed by Amazon. We make use of Amazon data to examine the most recent trends because cataloguing backlogs at libraries render numbers incomplete and thus severely bias downwards results.[25]

Because Amazon is in the business of selling books, it makes every effort to keep its listings up to date. For this reason, Amazon turns out to be a remarkably valuable source of information on the latest book titles.

This said, there are a number of features of the Amazon data that should be noted. First, because Amazon titles contain significantly less metadata on each book than do library catalogues, our ability to allocate the titles to the Library of Congress classifications is constrained. Second, Amazon data include more e-book and titles published by authors or conference organizers than do the catalogues of most libraries. Third, while library holdings, by definition, represent books that *have been* purchased, those listed on Amazon represent books that *can be* (but may not have been) purchased.

While the first factor limits our ability to use Amazon data for fine grained sectoral analyses and hinders direct comparisons with the holdings-based indices, the two other factors work to extend the time between when increases in the number of technology titles on Amazon are seen and the impact on productivity but does not compromise the value of the indicator.[26]

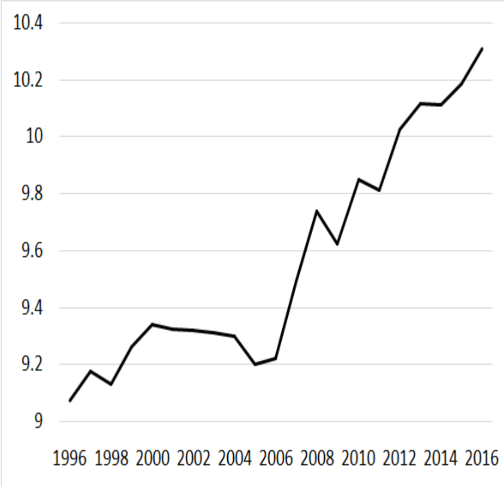
Chart 11 displays the data from Amazon's websites in Canada and the United States. First, we see that the number of US English language computer and

25 It is useful to note that our previous work would suggest that once backlogs are cleared, there is a high correlation between the Amazon.com data and titles listed in the Library of Congress' catalogue.

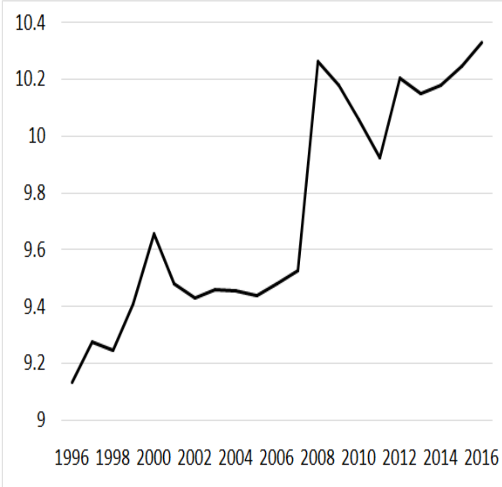
26 Items more akin to journal publications have previously shown longer lags since they tend to capture advances earlier on in the development process. Moreover, the appearance of a listing does not guarantee sales of the title in much the same way that filing a patent application offers no guarantee that technology will be commercialized.

**Chart 11: Book Titles for Amazon**

Panel A. Computer and Technology Titles (ln) in English by release date- Amazon.com




Panel B. Computer and Technology Titles (ln) - all languages by release date- Amazon.ca




Source: Panel A is based on the authors calculations from data on Amazon.com on English language titles. Panel B is based on the authors calculations from book listings (all languages) on the Canadian site Amazon.ca.

technology titles listed on Amazon.com, after roughly flat-lining for a decade following 1996, began to grow rapidly again after 2005 (Panel A of Chart 11). Second, as can be seen in Panel B, computer and technology titles in all languages for sale on Amazon.ca trace a similar pattern, with recovery starting in 2007-08. In short, there is reason to be optimistic.[27]

To uncover the sources of the increase, we look at the break-down in the number of Computer and Technology titles by sub-class. In Panel A of Chart 12, the major categories are represented in the form of word clouds, where font size varies directly with the frequency of titles in each of the categories. In Panel B, change over the five-year period in the relative importance of the top 25 subcategories is presented. Together, these charts indicate that the growth in new titles has occurred mostly in areas related to artificial intelligence, computer security, cloud computing, big data and CAD (related to advanced manufacturing). In particular, 47 per cent of the recent computer science titles are linked to AI and 42 per cent of these relate to robotics.

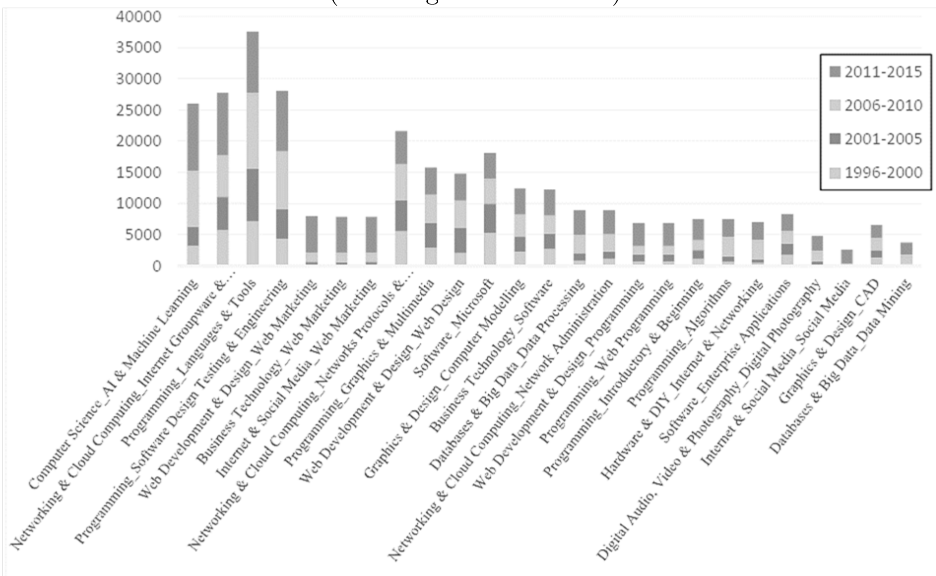
Chart 13 provides additional evidence of a dramatic innovative upswing in these areas. Patents granted by the United States Patent and Trademark Office (USPTO), reported in Panel A, show a jump in both robots and AI. Panel B reveals that the number of newspaper articles published on robots and AI in both America and Canada has soared over the last five or so years while, in Panel C, it can be seen that the number Canadian media articles on AI re-

27 Some of the increase is due to the availability of self-published and e-titles. However, even without these, there is a noticeable increase in the most recent years.

**Chart 12: Top Technology Subgroups in Amazon Data**

Panel A) Word Cloud of Top 10 Technology Subgroups in Last 5 Years


Panel B) Evolution of 5 Year Totals for Top 25 Subgroups for the 2010-15 Period (ranked greatest to least)




Source: Authors' calculations from Amazon.com.

lated employment issues jumped sharply after 2014. Overall, these data would seem to indicate a marked renewal of innovative activity in both the United States and Canada, with the promise that a vast new array of products and processes is likely to hit the market in the near future.

Will these advances reinvigorate productivity growth in Canada? The answer depends largely on how quickly and deeply they spread across the economy. The recent rebound in U.S. productivity growth (Table 1), may be at least partly attributable to gains associated with the adoption of the new technology. The evidence for Canada is, at present, mixed. On the one hand, Canada lags countries such as Japan, Germany and the United States (Chart 14) in the adoption of robots.[28]

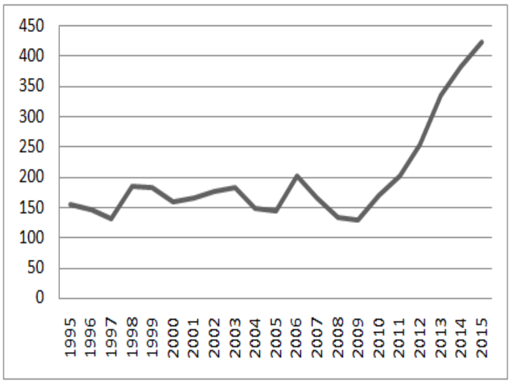
Moreover, while there is some willing-

28 A new survey from Accenture, Intel, Forbes Insight and SAS conducted in the summer of 2018 finds that while Canadian businesses are adopting AI, they lag behind many countries, including the United States, in terms of adoption and full deployment rates. See https://www.accenture.com/ca-en/company-news-release-artificial-intelligence-finds-study.

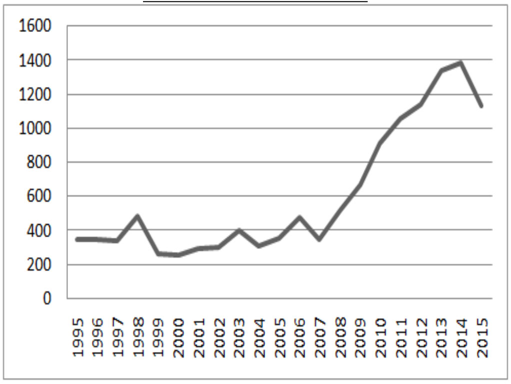
**Chart 13: Indicators of Technical Change**

Panel A. Patents Granted by the US Patent and Trademark Office

Robots

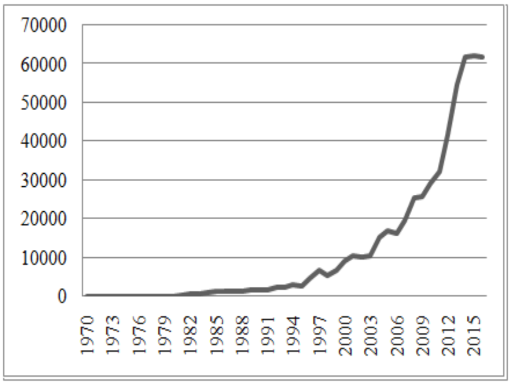



Artificial Intelligence

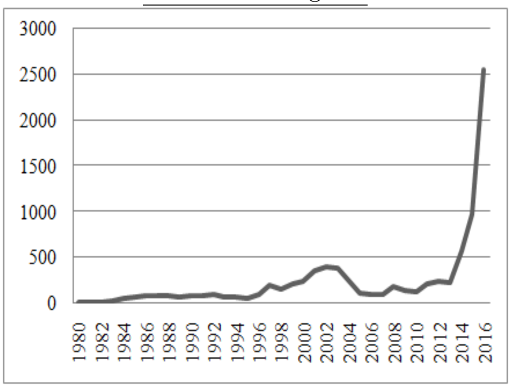



Panel B. Factiva Articles

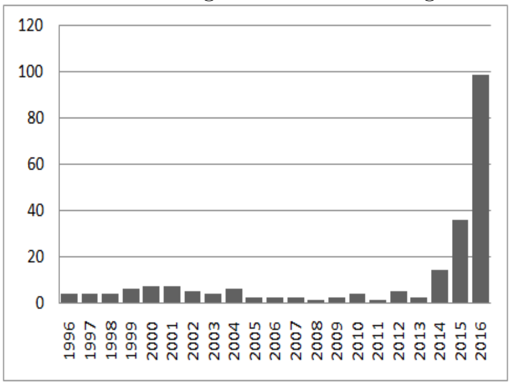
Robots




Artificial Intelligence

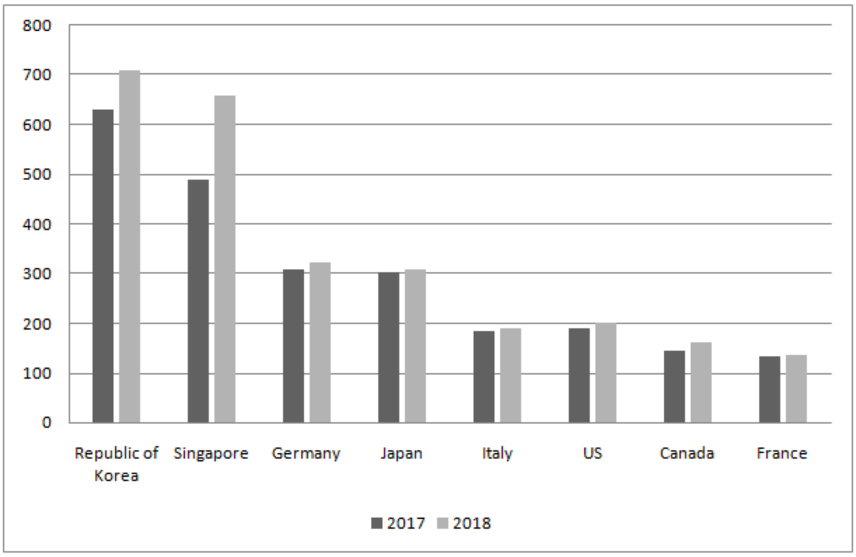



Panel C. Canadian Media Coverage of AI Mentioning Labour Market Issues




Source: Panel A is from the U.S. Patent and Trademark office. The patent counts by classes are based on original and cross-referenced classification with duplicate patents eliminated with classes. Panel B is based on authors calculations of the number of articles in the Factiva database on Robots and Artificial Intelligence. Panel C is based on authors calculation on the number of articles from Canadian sources in Factiva that are related to AI and the labour market.

**Chart 14: Number of Installed Industrial Robots per 10,000 Employees in Manufacturing in Selected Countries, 2017 and 2018**




Source: World Robotics, 2017.

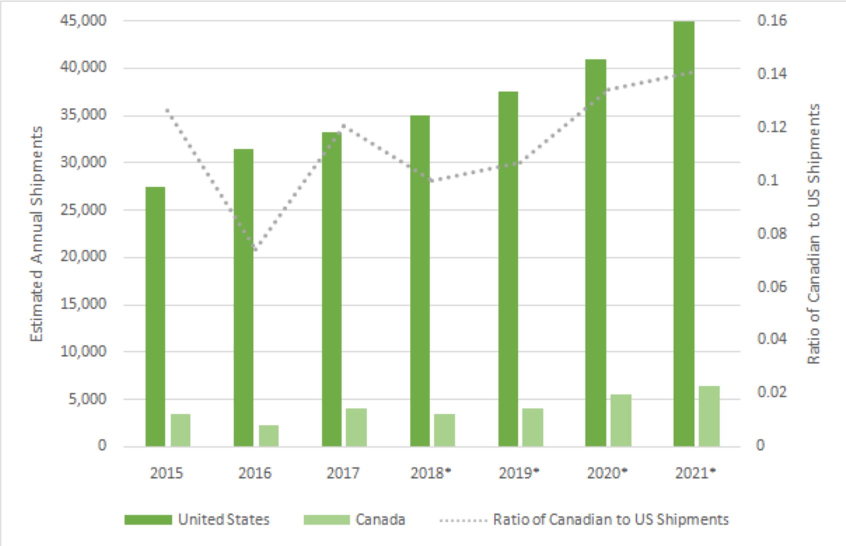
ness in Canada to invest in robotic technology (Chart 15) and AI, a large gap still exists between the pace of adoption in the United States and Canada.

On the other hand, if adopted, the productivity (and profit) payoff to "robotization is substantial. It has been estimated, for example, that the labour productivity gains in 1993-2007 associated with the adoption of industrial robots exceeds that attributable to the use in the United States of the steam engine between 1850 and 1910 (Crafts, 2004; Graetz and Michaels, 2015).

Our results support these findings since both AI and robotics are tied to innovations in electrical engineering and electronics and mechanical/manufacturing – the main drivers of MFP in the 1961-2014 period. Moreover, an analysis of the industry tags associated with articles from Factiva related to Artificial Intelligence and Canada suggests that many industries will benefit from advances in these areas. This is illustrated in the word cloud reported in Chart 16, where once again the size of the font indicates the relative frequency of mention of particular industries in the relevant articles. Major players, not surprisingly, include computers and electronics, telecommunications, machinery, pharmaceuticals, retail, finance, agriculture and biotechnology.[29] In short, then, while Canada currently lags its international competitors in the adoption of these new advances, the pay-off to catching up is large and there is at least some evidence to suggest Canadian entrepreneurs and firms

29 See Alexopoulos and Cohen (2018) for additional evidence on the potential for the use and spread of AI and robotics in the United States, and a comparison of these technologies to major GPT technologies in the past. See, also, Eichengreen (2015) for a discussion of the importance adaptability and adoption in determining the impact of new technologies.

**Chart 15: Shipments of Multipurpose Industrial Robots**




Source: Statistics are from the 2017 IFR World Report, where * represents the IFR's estimates of shipments.

are beginning to seize the opportunity.

## Summary and Conclusion

Our results indicate, first, that there was a slowdown in productivity growth in Canada in the first decade or so of the 21th century, very similar to the one observed in the United States. Second, our VAR analysis reveals that technology shocks both in aggregate and in the areas of manufacturing/mechanical and electrical played an important role in driving the fall-off in productivity growth. We also find that the decline in productivity growth was more sector specific in Canada than is usually realized with the drop most marked among goods producers and least in services. As it happens, these results were echoed in the technical change numbers where the poorest performers were linked to mining and manufacturing.

The concern among a number of prominent economists is that this recent slowdown is just the start of a long period of secular stagnation, powered at least in part by lackluster technological advances. We would maintain that this preoccupation is unjustified. We have seen productivity slowdowns and speedups in the past – our previous work indicates that technical change comes in waves of lesser and greater intensity which suggests that this time is probably not different. As confirmation of this, we note that there are tentative signs, especially, but not only, in the United States, that a technological rebound is already underway. (The last row in Chart 2 provides compelling support for this observation.) Based on our textual analysis and confirmed by Linked-In, Factiva and other sources, the major new areas include, among others, AI, and robotics. As we report in the final section of the article, the recent turnaround in innovative activity in the United States bodes well for the future of productivity and economic growth there. Can the same be said for Canada? Given the usual

**Chart 16: Factiva Industry Tags Associated with AI in Canada**


Source: Authors calculation based on volumes of industry tags associated with AI articles in Canadian sources on Factiva.

adoption lags that typify the uptake of new technologies in Canada, it is difficult to be sure that we will take advantage of the new opportunities presented by these advances but we can, with confidence, make two observations. First, the new technologies are (almost) as accessible in Canada as they are in the United States and, second, there is no reason to believe that this time is different. That is, while we tend to adopt with a lag, we do, on the whole, seize the day. If we are correct, then the issues that Canadian policy makers will have to confront in the near future are not those associated with stagnation but, quite the contrary, are the ones, such employment opportunities, training requirements, and income distribution that the new disruptive technologies are likely to present.

## References


Alexopoulos, M. (2011) "Read All About It! What Happens Following a Technology Shock?," *American Economic Review*, Vol. 101, No. 4, pp. 1144-1179.

Alexopoulos, M. and J. Cohen (2009) "Measuring Our Ignorance, One Book at a Time: New Indicators of Technical Change, 1909-1949," *Journal of Monetary Economics*, Vol. 56, No. 4. pp. 450-470.

Alexopoulos, M. and J. Cohen (2011) "Volumes of Evidence: Examining Technological Change in the Last Century through New Lens" *Canadian Journal of Economics*, Vol. 44, No. 2. pp. 413-450.

Alexopoulos, M. and J. Cohen (2012) "The Effects of Computer Technologies on the Canadian Economy: Evidence from New Direct Measures," *International Productivity Monitor*, No. 23, Spring, pp. 17-30. http://www.csls.ca/ipm/23/IPM-23-Alexopoulos-COhen.pdf.

Alexopoulos, M. and J. Cohen (2018) "Secular Stagnation, Technological Change and its Relationship with Productivity," Working Paper, University of Toronto.

Baldwin, J.R. and W. Gu (2013) "Multifactor Productivity Measurement at Statistics Canada," *Canadian Productivity Review*, Statistics Canada, Catalogue No. 15-206-X, No. 031, pp. 1-27.

Baldwin, J., H. Liu, and M. Tanguay (2015) An Update on Depreciation Rates for the Canadian Productivity Accounts, *Canadian Productivity Review*, Catalogue No. 15-206-X, No. 039, pp. 1-56.

Basu, S., J.G. Fernald, and M. S. Kimball (2006) "Are Technology Improvements Contractionary?" *American Economic Review*, Vol. 96, No. 5, pp. 1418-1448.

Christiano, L., M. Eichenbaum, and R. Vigfusson (2004) "The Response of Hours to a Technology Shock: Evidence Based on Direct Measures of Technology," National Bureau of Economic Research, Working Paper No. 10254.

Christiansen, L. (2008) "Do Technology Shocks Lead to Productivity Slowdowns? Evidence from Patent Data," IMF Working Paper, WP 08/24.

Crafts, N. (2004) "Steam as a GPT: A Growth Accounting Perspective," *Economic Journal*, Vol. 114, No. 495, pp. 338-351.

Eichengreen, B. (2015) "Secular Stagnation: The Long View," *American Economic Review, Papers and Proceedings*, Vol. 105, No. 5, pp.66-70.

Fernald, J. G. (2014) "A Quarterly Utilization-Adjusted Series on Total Factor Productivity," Federal Bank of San Francisco Working Paper Series, 2014-15.

Fernald, J. G. (2016) "Reassessing Longer-Run U.S. Growth: How Low?" Federal Bank of San Francisco Working Paper Series, 2016-18.

Fernald, J. G. (2018) "Is Slow Productivity and Output Growth in Advanced Economies the New Normal?" *International Productivity Monitor*, No. 35, Fall, pp.139-149.

Gordon, R. J. (2015) "Secular Stagnation: A Supply Side View," *American Economic Review, Papers and Proceedings*, Vol. 105, No. 5 pp. 54-59.

Gordon, R. J. (2016) *The Rise and Fall of American Growth: The U.S. Standard of Living Since the Civil War* (Princeton, NJ: Princeton University Press).

Graetz, G. and G. Michaels (2015) "Robots at Work," *CEP Discussion Paper*, No. 1335.

Gu, W. and B. Lee (2013) "Productivity and Economic Growth in the Canadian Provinces, 1997 to 2010," *Canadian Productivity Review*, Statistics Canada, Catalogue No. 15-206-X, no. 030, pp. 1-36.

Gu, W. and M. Willox (2018) "Productivity Growth in Canada and the United States: Recent Trends and Potential Explanation," *Interantional Productivity Monitor*, No. 35, Fall, pp.73-94.

McGoogan, C. (2017) "Moores Law Is Not Dead, Says Intel Boss," Technology Intelligence, *The Telegraph*, Las Vegas, 5 January.

Shea, J. (1999) "What Do Technology Shocks Do?" in B. Bernanke and J. Rotenberg (eds.) *National Bureau of Economic Research Macroeconomics Annual 1998*, (Cambridge, MA: MIT Press), pp. 275-310.

Soloveichik, R. and D. Wasshausen (2013) "Copyright-Protected Assets in the National Accounts," BEA Working Papers 0102, Bureau of Economic Analysis.

U.S. Bureau of Economic Analysis (no date) "Table 3, BEA Rates of Depreciation, Service Lives, Declining-Balance Rates, and Hulten-Wykoff Categories" at https://apps.bea.gov/scb/account_articles/national/0797fr/table3.htm.

## Appendix: VAR Results Based on Labour Productivity and Technology Titles

In this appendix, we present results using labour productivity instead of MFP and technology stocks in place of flows in a selection of VARs to show that the main results reported in the body of the article are robust to using alternate measures of these variables. In both cases, the results are for VARs using two lags with the variables in levels.[1]

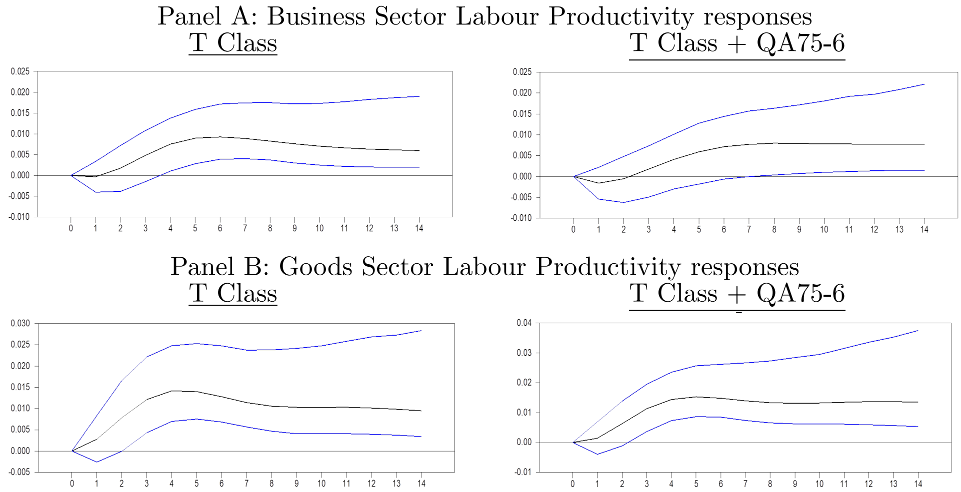
Estimates of labour productivity (both business sector and disaggregated for goods and service sectors) come from Statistics Canada (Table 36-10-0208-01). Similar to the data for MFP, we see evidence of a slowdown in productivity slowing in the early 2000s, with labour productivity falling off much more for the goods sector than for the service sector. Chart A1 displays the response of Canadian business sector labour productivity to a positive one-standard deviation shock to aggregate technology where the technology measures are those used in the article. We again find evidence that a positive aggregate technology shock increases labour productivity across the entire business sector (Panel A) and for goods producers (Panel B) with approximately the same lag as seen for MFP. The variance decompositions suggest that technology shocks account for a slightly larger share of fluctuations in labour productivity than they did for movements in MFP. For example, we find that the share of aggregate labour productivity fluctuations attributable to aggregate technology shocks range from 10-24 per cent in year 6, rising to 38-48 per cent by year 12. For labour productivity in the goods producing industries, the shares rise from 32-36 per cent in year 6 to 43-56 per cent in year 12.

Chart A2 displays labour productivity responses to selected disaggregate technology shocks along with 90 per cent confidence bands. Once again, the results are similar to those obtained for MFP. Panel A shows that aggregate labour productivity rises significantly in response to positive shocks in mechanical/manufacturing (TJTS), transportation (TL), chemicals (TP), construction (Con), and Home economics/food preparation, handicrafts, cloth manufacturing and design, and management of services (TTTX). Panel B displays the significant responses for the Goods sector. As can be seen, labour productivity rises following a positive shock to electrical/electronic technologies (TK), mechanical/manufacturing technologies (TJTS), chemicals (TP) and construction (Con). A similar pattern, reported in Panel C, is traced by labour productivity in services (food prep and service industry (TTTX), photography (TR), including medical photography and cinematography, and Construction (Con)) in response to positive technology shocks.[2]

1 While magnitudes differ somewhat, the main results are similar when additional lags are added to the VARs or we examine cases with first differences.

2 MFP responses in the service sector, while positive, were insignificant and not reported in the paper.

**Chart A1: Responses of Canadian Business Labour Productivity to Positive Aggregate Technology Shocks**




Note: The responses are percentage deviations of labour productivity in response to positive one-standard deviation technology shocks. Each period is one year. The panels display the estimated responses and the 90 per cent confidence bands. The responses displayed are from the bivariate VARs with two lags and a trend. Indicators are ordered last and shocks are identified using a Cholesky decomposition.

Next, we show that our results are, for the most, the same whether we use the stock of existing technologies or the flow of new ones to measure technical change. For this analysis we created stock estimates using the perpetual inventory method on our data. This required us to assign different rates of depreciation to various technology groupings. Since no estimates of depreciation for the knowledge within technology titles currently exist, we began by examining estimates related to the depreciation of general book titles, and the depreciation rates for different types of capital assets.[3] Solovechik and Wasshausens (2013) analysis utilizes an annual 17.3 per cent depreciation rate for books when computing the capital stocks of copyright-protected assets. However, given that the books considered in that study included many titles in fields where knowledge depreciates slowly (e.g. language, literature, history), we decided to adjust the rates for our groups upwards (or in a few cases downwards) based on the depreciation rates for the dominant technologies within each class. These rates are displayed in Table A1 with the resulting technology stocks presented in Charts A3 and A4.

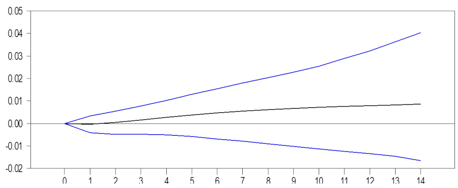
Consistent with the data on the flow of new technology, the patterns in Chart A3 clearly indicate that there was a slowdown in the growth of technology that occurred around 2003. Moreover, as Chart A4 confirms, the slowdown is particularly prominent in the fields of electrical technologies (TK), computer related technologies (Comp) and mechanical/manufacturing technologies

3 See. Baldwin *et al.* (2015) and the depreciation rates posted by the BEA.

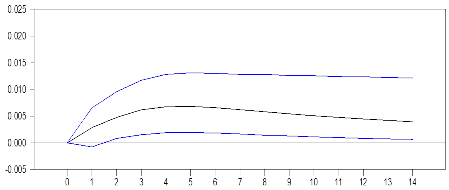
**Chart A2: Selected Responses of Business Sector, Goods Sector and Service Sector Labour Productivity, and Goods Sector Labour Productivity to Positive Technology shocks**

Panel A: Business Sector Labour Productivity responses

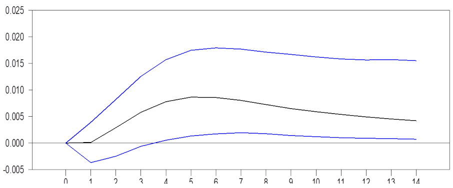
Electrical/Electronics (TK)



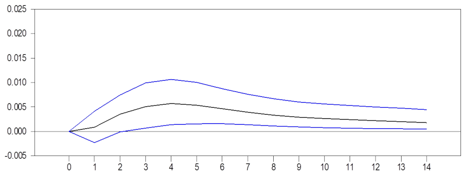
Mechanical/Manufacturing



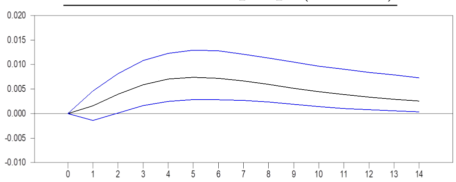
Transportation (TL)



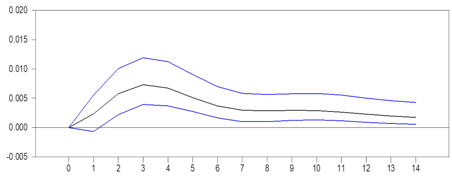
Chemical (TP)



Services, Food prep (TTTX)

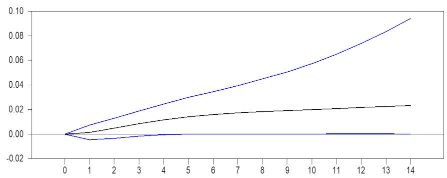


Construction

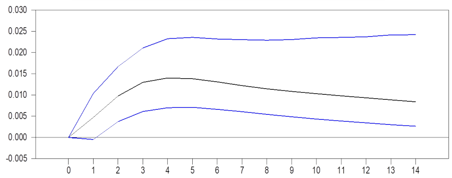


Panel B: Goods Sector Labour Productivity Responses

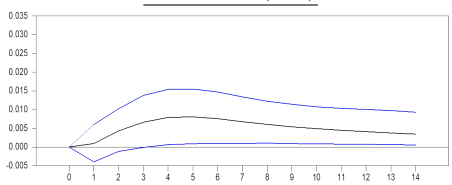
Electrical/Electronics (TK)



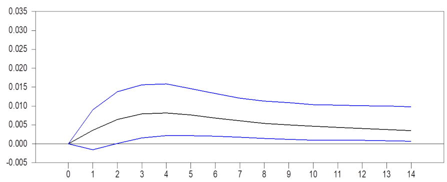
Mechanical/Manufacturing



Chemical (TP)

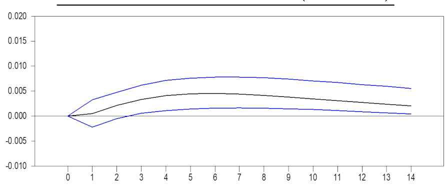


Construction

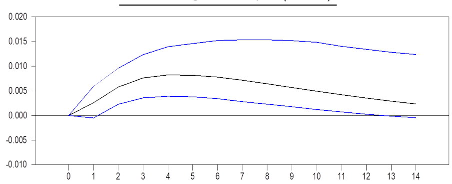


Panel C: Labour Productivity Service Sector Responses

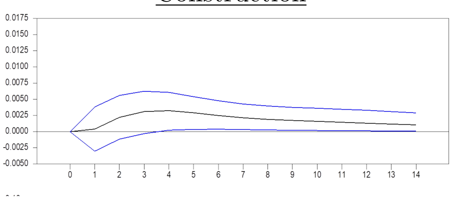
Services, Food Prep (TTTX)



Photography (TR)

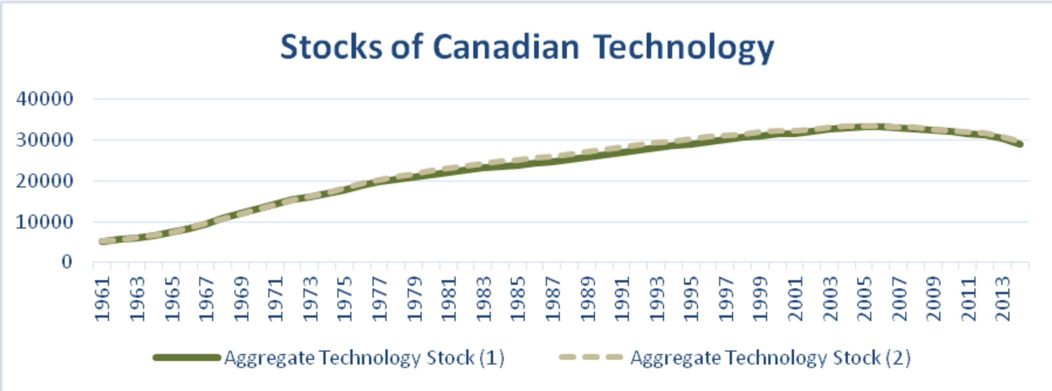


Construction



Note: The responses are percentage deviations of labour productivity in response to positive one-standard deviation technology shocks. Each period is one year. The panels display the estimated responses and the 90 per cent confidence bands. The responses displayed are from the bivariate VARs with two lags and a trend. Indicators are ordered last and shocks are identified using a Cholesky decomposition.

**Chart A3: Estimated Stocks of Technological Knowledge in Canada, 1961-2013**



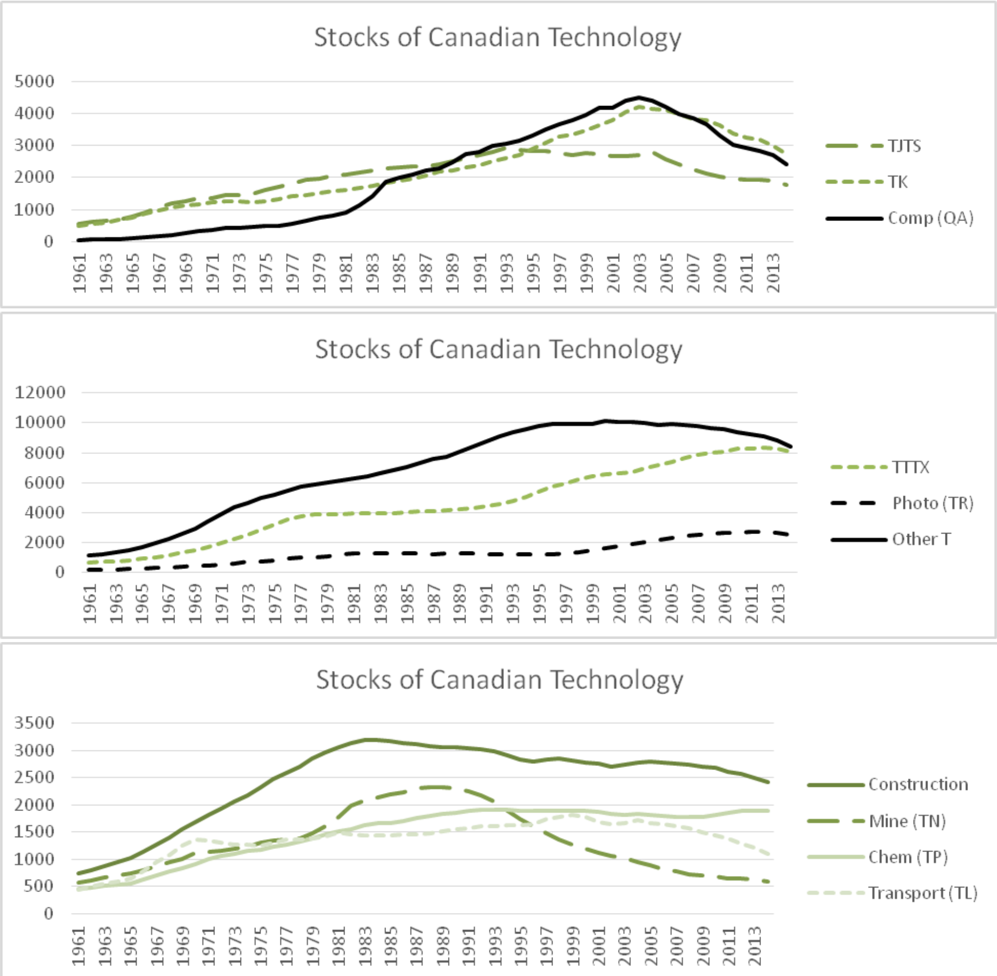

Note: Aggregate Technology Stock (1) computes stock from T Class titles assuming a constant rate of depreciation across all categories of 18.8 per cent. Aggregate Technology Stock (2) computes the stocks assuming depreciation rates from Table 1A for each Technology class.

(TJTS).

Across the various specifications, we find that, in year 6, approximately 7 per cent-15 per cent of the variation in aggregate MFP and in MFP in the goods producing sector is attributable to aggregate technology shocks, with the shares growing to approximately 16-25 per cent by year 12.

Chart A5 displays a selection of the responses to disaggregate technology shocks when we use stocks instead of flows of technology in the VARs. Overall, there is again a positive relationship between these shocks and MFP for the business sector, with the strongest effects in goods production. As in the baseline cases, the electrical/electronic technologies (TK), mechanical/manufacturing technologies (TJTS) and transportation technologies (TL) have the largest impact on aggregate MFP and MFP in the goods producing sector. Moreover, the variance decompositions again confirm that technologies played are large role in driving fluctuations in productivity, with approximately 5 per cent-10 per cent of the variations attributable to the TJTS, TK and TL technologies at year 6 growing to between 25 per cent-35 per cent by year 12.

**Chart A4: Estimated Structure of Technological Knowledge in Canada by Type of Technology, 1961-2013**




Authors' calculations on OCLC WorldCat data using depreciation rates for technology classes in Table 1A.

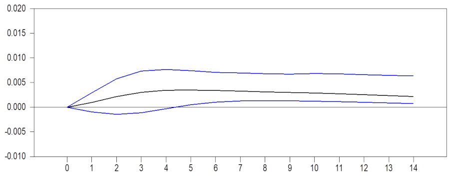
**Table A1: Assumptions for Depreciation rates per class**

| Class | Description of Class | Depreciation rate utilized | Main Technologies/categories used to assign depreciation |
|---|---|---|---|
| QA75-76 | Computer Science and software | 0.4 | Computer software prepackaged and developed |
| Subclass T | General Technology incl. works on management engineering, patents, R&D and technical Education | 0.17 | General Education materials (books) and intellectual property (R&D and patents) |
| TA | Engineering and management of engineering works | 0.17 | Books |
| TC | Hydraulic Engineering (incl. Dams, harbours, canals and irrigation) | 0.1 | hydraulics and machinery associated with construction |
| TD | Environmental Engineering and sanitary Engineering | 0.1 | environmental technologies, sewage treatment construction |
| TE | Engineering and Construction of Highways, roads and pavements | 0.11 | construction machinery for construction of roads |
| TF | Railroad Engineering | 0.06 | Railroads and locomotives |
| TG | Bridge Engineering | 0.08 | Bridges and related construction equipment |
| TH | Building Construction | 0.17 | Technologies for housing construction and repair incl. tools, heavy machinery, electrical heating, security systems |
| TJTS | Mechanical Engineering, Machinery and Manufacturing of textiles, rubber, paper, metals and metal products, wood products and stoneworks. | 0.25 | Tools, industrial machinery and robotics |
| TK | Electrical Engineering and Electronics (including Telecomm, computer hardware and computer networks) | 0.33 | Networks, Telecommunications, Electronics |
| TL | Motor Vehicles, aeronautics and astronautics | 0.27 | Automobiles, Automotive parts, Trucks, Airplanes |
| TN | Mining and Metallurgy | 0.15 | Mining equipment, heavy equipment, industrial machinery |
| TP | Chemical manufacturing, Biotechnology, Production of cement, oils, fats, wax, fuel, clay, ceramics, glass. paints, polymers, explosives, petroleum products. Food manufacturing and refrigeration. | 0.17 | Chemical production, related R&D, and machinery used for production of these goods |
| TR | Photography, Cameras and Cinematography | 0.17 | Photographic Equipment |
| TTTX | Home furnishings, Laundry, Clothing manufacturing, jewelry manufacturing, manual training, hairdressing, cooking, hospitality industry and food preparation | 0.17 | Office Equipment, machinery for food prep, home furnishings, jewelry, books |

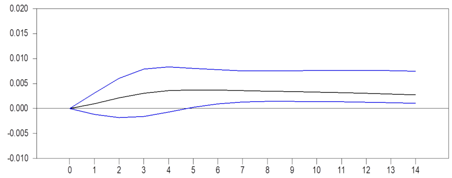
**Chart A5: Responses to Positive Aggregate Technology Shocks**

Panel A: Response of Aggregate MFP

T Class

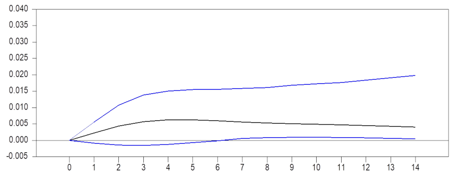



T Class + QA75-6

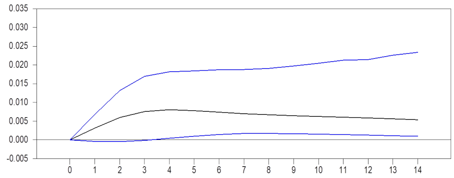



Panel B: Response of MFP in the Goods Producing sector

T Class




T Class + QA75-6




Note: The responses are percentage deviations of MFP in response to positive one-standard deviation technology shocks. Each period is one year. The panels display the estimated responses and the 90 per cent confidence bands. The responses displayed are from the bivariate VARs with two lags. Indicators are ordered last and shocks are identified using a Cholesky decomposition.

# Is Slow Productivity and Output Growth in Advanced Economies the New Normal?

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*INSEAD*

Abstract

Advanced economies have seen a notable slowdown in potential growth in the past decade or so. Demographics look much less favorable to output growth than in the past, and productivity growth has been only modest. The demographic and productivity factors driving this slowdown in potential growth look to be largely independent of the Great Recession. These factors do not at this point look likely to change rapidly, despite considerable uncertainty about the future contribution of artificial intelligence and robots.

Growth since the Great Recession has been disappointing across advanced economies. For example, prior to 2007, U.S. growth in gross domestic product (GDP) of 3 per cent or more seemed normal.[2] But growth from the trough of the Great Recession in mid-2009 has averaged only 2.3 per cent (through the third quarter of 2018).

Moreover, the disappointing U.S. growth figures came in the context of a recovery that was strong enough to bring the unemployment rate down from nearly 10 per cent to under 4 per cent. So even the disappointing pace of growth during the recovery has been much faster than the underlying trend, or potential, pace that would have been consistent with a constant unemployment rate.

Unfortunately, the fundamentals of potential growth do not look much better now than they have in the past decade. Advanced economies face challenging demographics and productivity growth remains only incremental. We can hope for better outcomes (particularly in terms of productivity) but we should not be surprised if we do not obtain them.

## Demographics

Let us start with demographics. Chart 1 shows growth rates by decade of the "prime-age" population (aged 25

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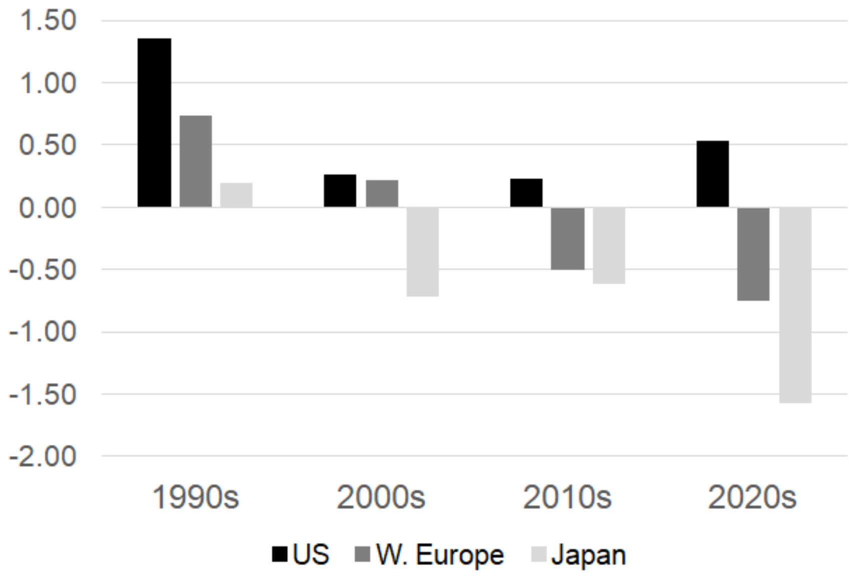
2 For example, the lowest growth rate over any 25 year period from 1929-2007 was 2.97 per cent, reached in 1993.

**Chart 1: "Prime" Working Age Population Aged 25-54 in the United States, Western Europe and Japan, Annual Per Cent Change**




Source: UN Population Projections. Europe excludes Eastern Europe.

to 54), using U.N. data and population projections for the United States, Western Europe and Japan. Most people in this age group are working.

In the 1990s, US prime-age population growth was nearly 1-1.5 per cent per year and Western Europe about 0.7 per cent, while Japan was barely growing. By the 2010s, the prime-aged population in the United States was barely growing, whereas Western Europe and Japan were both shrinking.

Looking ahead to the 2020s, the United States prime-age population will continue to grow, albeit modestly. But Western Europe and Japan will shrink even faster than in the recent past – dramatically so in the case of Japan.

These demographics are the biggest reason why potential GDP growth in the future will be faster in the United States than in Western Europe or Japan. After all, the United States workforce will not be shrinking, whereas it will in many other major advanced economies. But, importantly, across almost all advanced economies including the United States, the demographics look worse for growth than in the past.

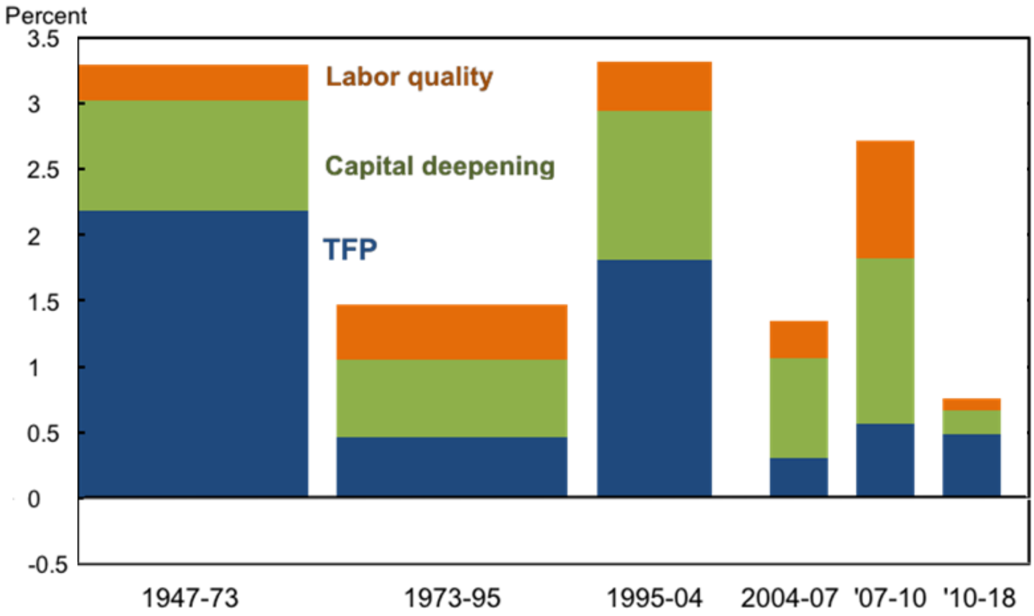
## Understanding Recent Productivity Patterns

Now let us turn to productivity growth. How productive will the people who are working be at producing GDP?

To understand the future, Chart 2 starts by looking to the past. It shows conventional growth accounting results for the United States business sector economy since 1947. The blue bar shows the contribution of total factor productivity (TFP), a broad measure of innovation that captures any output growth that is not explained by growth in measured inputs of capital or labour.

TFP growth was very strong before 1973 and in the period 1995-2004. Apart from that period, it has more typically

**Chart 2: Contributions to Growth in U.S. Business Sector Output per Hour (average annual rate of change)**




Source: Fernald (2014). Quarterly; samples end in Q4 of years shown except 1973 and 2018 (end Q3). Capital deepening is contribution of capital relative to quality-adjusted hours. Total factor productivity measured as a residual.

averaged around 0.5 per cent per year — whether one looks at the 1973-95 period, or at the 2004-2007 run-up to the Great Recession, or during and since the recession.

A considerable body of research examined the pickup in U.S. TFP growth in the mid-1990s. The United States had a decade of rapid and transformative gains associated with the internet and other uses of information technology, including reorganizations of businesses and industries.

But that burst of exceptional TFP growth clearly came to an end before the Great Recession, as shown by the much slower growth rate from 2004-2007. Fernald *et al.* (2017) use a variety of statistical approaches to confirm the pre-recession timing of the slowdown.[3]

The time pattern of labour productivity, or output per hour, looks broadly similar to TFP. But when you look at the final two bars, there are some noticeable differences. Notably, labour productivity growth was strong relative to TFP during Great Recession but has been weak relative to TFP ever since. This post-2007 divergence between TFP and labour productivity reflects cyclical dimensions of labour productivity growth during the recession itself (2007-2010) that subsequently unwound (2010-2018).

First, during the recession, firms disproportionately fired low-skilled workers. That provided a substantial boost to labour quality. During the subse-

3 See also Diaz *et al.* (2017) and Kahn and Rich (2018).

quent recovery, those lower-skilled workers found jobs again, so the average skill level of the labour force has grown much more slowly.

Second, during the recession, the number of workers fell sharply, whereas measured capital input never fell. So the remaining workers had more capital to work with. As a result, capital deepening (in Chart 2, capital per quality-adjusted worker) rose rapidly and contributed exceptionally to labour productivity.[4] Since 2010, firms had plenty of capital. What was missing was demand. As demand returned, they could meet it by hiring workers. More technically, as Fernald *et al.* (2017) argue, capital-output ratios were very high in 2009 and 2010, which muted incentives to invest for some years. As a result, capital deepening contributed much less to growth, and labour productivity growth has been weak relative to TFP.

Looking ahead, even without any change in the TFP trend, labour productivity growth is likely to pick up. Businesses will not be able to continue meeting demand by hiring people given demographics, they are likely to run out of people. Rather, they will return to adding capacity, which should boost capital-labour ratios in a normal way.[5]

Turning to Europe, Chart 3 shows that TFP growth has been slowing since the 1960s. Most of this slowdown is, in fact, a striking indication of success. Europe came out of World War II far behind the United States in terms of productivity levels. Productivity in European economies grew fast and, by the 1990s (if not earlier), had largely caught up.

But, especially since the mid-1990s, productivity growth in Europe has, by and large, fallen short of the U.S. pace.[6] There remains a debate whether some of that further slowing since 2007 reflected the Great Recession itself, but the dominant feature is the pre-recession slowdown (Cette, Fernald and Mojon, 2016).

Forecasting the future of TFP growth is extremely hard. Fernald (2016) argues for a regime-shift model for TFP. In some periods, TFP growth has been fast, in other periods, it has been slow. And in the past 45 years, there was only one decade with high TFP growth (from the mid-1990s to the mid-2000s). Otherwise, the slow regime of about 0.5 per cent TFP growth looks "normal."

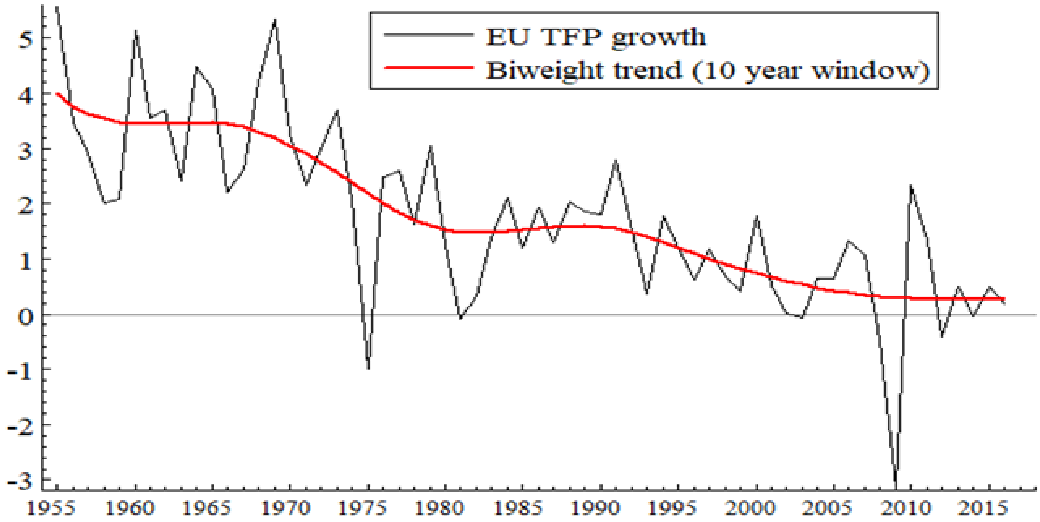
Intuitively, there were important and innovative technological developments taking place in the 1970s and 1980s, just as there are today. But for most of this period, this innovative activity led to business sector TFP growth of about 0.5 per cent per year.

4 Much of this capital could have been idle, of course, and low capital utilization would show up in measured TFP growth. However, Fernald (2015) argues that by the end of 2010, much of the decline in utilization had been unwound.

5 The 2018 cut in U.S. capital taxes is also likely to provide some boost to capital deepening, though it seems hard to detect in the data so far.

6 A large literature from the early 2000s explored this shortfall in growth. For a summary of this debate, see Timmer *et al.* (2010 and 2011).

**Chart 3: Total Factor Productivity Growth, the European Union, Annual Per Cent Change, 1955-2016**




Source: Bergeaud, Cette and Lecat (2017).

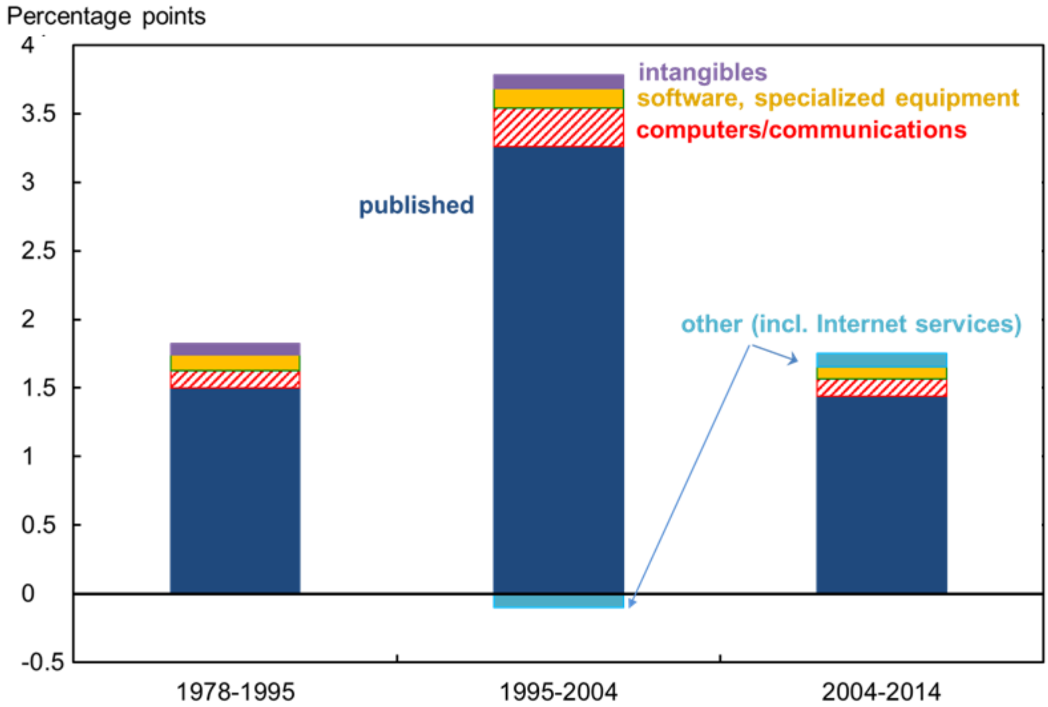
One reason the pace has not been faster is something that even the techno-optimists highlight, which is that there are sizeable adjustment and adoption costs (e.g., Brynjolsson *et al.* 2018). Learning how best to harness artificial intelligence (AI) in, say, health care delivery at a day-to day level is hard. Indeed, whether the future TFP figures look incremental, or extraordinary, is determined not by possibilities that we see, but by the pace through which society is able to overcome the myriad barriers to adoption.

For forecasting, the fact that we have been in a slow-growth regime suggests that slow TFP growth is the most likely outcome for a while. But what we do not know is how long that regime will last. It is certainly possible that we could see another burst in broad-based innovation related to artificial intelligence, robots, and other digital innovations. Until we do, my base case is that TFP growth will remain relatively slow.

Finally, looking at U.S. data, I would note that labour quality is also likely to be a drag on future labour productivity growth. Labour quality, which measures the contribution of education and experience, rose 0.42 per cent per year in 1973-95. Hence, it "explained" a substantial share of productivity growth. In contrast, Bosler *et al.* (2016) estimate that in 2022-2025, labour quality will rise only about 0.1 to 0.2 per cent per year. Jorgenson *et al.* (2016) is qualitatively similar: They estimate that labour quality will rise less than 0.1 per cent per year in 2014-2024.

On its own, then, reduced labour quality growth suggests marking down labour productivity and GDP projections by at least 0.2 of a percentage point and possibly more. (In economic models, the mapping from labour quality growth to labour productivity growth is one-for-one.)

**Chart 4: Adjustments to Growth in Output per Hour, Business Sector, Percentage Points per Year**




Source: BLS, Fernald (2014a), Byrne *et al.* (2016), and author's calculations. Other comprises Internet, free digital services, globalization, and fracking.

## Did Productivity Growth Really Slow?

The above discussion takes the measured TFP and output figures at face value. But an important counterargument is that maybe the 1995-2004 TFP surge never ended, but we just stopped measuring the gains? Maybe the statistics are missing most of the benefits of our smartphones, Google searches, and other IT-related hardware and software?

Byrne, Fernald, and Reinsdorf (2016) and Syverson (2016) dig into that story of growing mismeasurement. The fundamental problem with the story is we have always had mismeasurement. And, while Byrne *et al.* find plenty of evidence of mismeasurement, they find no evidence that mismeasurement has become worse. In fact, their point estimates were that IT-related mismeasurement was even larger in the late 1990s and early 2000s. So adjusting for mismeasurement made the post-2004 productivity slowdown even more severe.

You can see the argument in Chart 4, taken from Byrne *et al.* (their Figure 1). The dark blue portions of the bars show the published data on average growth in business sector labour productivity, that is, real output per hour. Productivity growth was exceptional from 1995 through 2004 but has since slowed by about 1.75 percentage points per year.

The bars also quantify several potential sources of mismeasurement. The main challenge is determining the appropriate quality-adjusted prices used to deflate nominal expenditures. For example, when one buys a new computer it could cost the same as your previous one but might be much more powerful - with a faster processor, better image quality, and more memory. The true price of the computer has dropped to account for your spending the same nominal amount for a better computer. Adjusting for quality change is challenging: If the statistics do not incorporate enough of an adjustment for quality, then we also do not measure the full increase in the inflation-adjusted real quantity produced.

The bars incorporate improved and more consistent deflators for computers/communication equipment and software and specialized equipment. They also incorporate the effect of including additional intangible capital. Finally, there are an assortment of other small adjustments.[7] The important point is that, although there is mismeasurement in all of the time periods, there is no evidence that the mismeasurement has grown.[8]

Of course, even if growing mismeasurement is not the reason for weak measured productivity growth, it is important to acknowledge that there is mismeasurement. There is still much work to be done to improve the estimates. We need to continue to improve the deflators. In addition, statistical agencies can increasingly seek to tap new sources of big data from major retailers, payment processors, and the like. Obviously, there are challenges of whether concepts are the same, and whether samples are representative; and there are privacy concerns by data owners. But there is at least the hope that these data can improve the accuracy, timeliness, and relevance of economic statistics.

Finally, when we think about welfare, one of the major issues we could address is to think hard about the market/nonmarket boundaries. We could work to create satellite accounts to understand those boundaries better, and to assess the benefits, as there has been a blurring of those boundaries.

## Explanations for Slow TFP Growth

So why did U.S. TFP growth slow after 2004? I would highlight three main hypotheses to explain why the 1995-2004 productivity surge did not last.

The first hypothesis, which is my preferred one, is that we have returned to normal after an exceptional information-technology (IT) linked decade after 1995 (Gordon, 2016 and Fernald, 2015). Every story from the early 2000s regarding the productivity surge pointed to IT. And much of that literature acknowledged that the gains were a sequence of one-off improvements. One does not know ex ante how many Walmarts and

7 See Byrne *et al.* (2016) for details.

8 The figure, of course, is in terms of labour productivity. For economy-wide TFP, the effects are much smaller because there is not only missing output but also missing capital input. Byrne *et al.* (2016) note, almost in passing, that this economy-wide effect masks the fact that the corrections raise TFP growth in producing IT-related productsmany of which are capital goodswhile reducing TFP growth in the rest of the economy. Byrne *et al.* (2017) expand on this point, which they interpret as deepening the productivity puzzle.

Costcos will be opened, at the expense of smaller, less efficient retailers. But nearly every job, and every industry, was transformed in some way between the mid-1990s and mid-2000s. For most of us, the changes to our work life have been much more incremental since then.

Of course, over the past decade smartphones and other technologies have had major effects on how we communicate, entertain ourselves, inform ourselves about the world, and much more. Nevertheless, consumer-oriented technologies such as smartphones have plausibly transformed how we live much more than they have transformed how we work.[9]

What this line of argument suggests is that modest productivity growth is the new normal. There are certainly upside surprises possible. We might well experience another wave of IT-linked productivity gains, but we do not know when they will arrive.

A second hypothesis is that it was the Great Recession that slowed investment in innovation or otherwise made the economy less efficient? Adler *et al.*, 2017 discuss a range of channels through which a recession (financial or otherwise) or period of slow growth might endogenously slow innovation. For the United States, the fundamental problem with that story is that, as already noted, the slowdown in productivity growth predated the recession. The bar chart in Chart 2 shows that U.S. productivity growth in the three years preceding the Great Recession (2004-2007) was already far short of its 1995-2004 pace.

More broadly, the Great Recession was unusually traumatic. But the productivity experience of the past decade and a half is not unusual. As Chart 2 showed, TFP growth of around 0.5 per cent per year has been the norm since the early 1970s.

A final hypothesis is declining dynamism, possibly caused by increases in regulation or other causes (e.g., Decker *et al.*, 2016; Barro, 2016). Both dynamism and regulation surely are related to productivity. After all, the dynamic process of productivity growth in part involves reallocating resources from less productive to more productive uses; and innovators need an incentive to innovate. Across countries, regulatory barriers do seem to affect growth rates. For example, many studies have argued that labour and product-market rigidities made it more difficult for European economies to undertake the business reorganizations necessary to benefit from information technology (Cette *et al.*, 2016).

There are a range of frictions that might affect entrepreneurship and reallocation. Starting with regulation, however, it is not clear for the United States that rising regulatory burdens are a first-order cause for why the 1995-2004 productivity surge did not last.

First of all, a common story that post-

9 Of course, there is a counterargument that new technologies are making us less productive. For example, Ward *et al.* (2017) find that even having proximity to a cell phone reduces our cognitive capacity.

2008 increases in regulation somehow caused the slowdown does not fit the timing. As noted already, the slowdown started much earlier – 2004 or 2005, if not 1973. Second, even for longer time periods, it is challenging to find a direct empirical link between fluctuations in industry-specific federal regulations and industry productivity dynamics. Fernald *et al.* (2017) look for such a link but do not find it.

In terms of dynamism more broadly, the relationship with productivity growth is a priori unclear. In some cases, technology may favor large firms so that reduced job and firm turnover is associated with productivity gains. That represents a largely benign decline in dynamism. In other cases, innovation is associated with new establishments and firms, and may require substantial reorganization of jobs. In that case, barriers to dynamism are likely to impede productivity growth. Of course, declining dynamism could in some cases simply be a symptom of declining opportunities for startups. For example, in the late 1990s, the internet caused a gold rush in Silicon Valley – startup activity and other measures of dynamism were very high. The gold rush ended and, while some firms were big winners, many others disappeared.

It is not certainly not clear that the frictions that have reduced reallocation explain the post-2004 slowdown in business sector labour productivity. A challenge is to figure out what the most efficient level of dynamism is, as well as to identify and quantify the importance of specific frictions and barriers that cause deviations from that efficient level. For now, I see declining dynamism as a symptom, but I do not yet know what it is a symptom of.

## Conclusion

With all of the above in mind, let us summarize what has changed in terms of potential output growth relative to the past decade: Not much.

Demographics are not going to change rapidly. Migration can rearrange the global population somewhat, but few advanced countries are pushing to increase immigration these days.

And productivity growth has not yet shown signs of recovery. Corporate tax cuts in the United States could help at the margin. Easing regulation makes some companies more profitable but, as noted, there is limited empirical evidence to suggest it will do all that much for economic growth. (Fernald *et al.*, 2017).

The biggest wild card for productivity growth is the future of technology, and the degree to which the gains from artificial intelligence and robots will spread more broadly across the economy. It could happen. We just do not know when.

In the absence of such a major pick-up in TFP growth, my current view remains roughly consistent with Fernald (2016). U.S. trend labour productivity growth, in particular, is likely to be in the 1.5 to 1.75 per cent range. Indeed, an update of the formal analysis in Fernald (2016) suggests a point estimate for long-run growth (say, 5 to 7 years out) of only 1.6 per cent. This is consistent with the labour productivity growth rates we saw in the 1970s and 1980s. Even that would require a substantial pick-up from the labour productivity growth rates since 2010, and a modest pick-up from the average pace since 2004.

To conclude, there is no question that the recovery has been much slower than we would have liked. Unfortunately, as Fernald *et al.* (2017) argue, the evidence suggests that the Great Recession was a deep recession superimposed on a sharply slowing trend. There is no evidence yet that trend labour productivity and output growth are poised for a substantial pick-up.

## References


Adler, G., R.A Duval, D. Furceri, Sinem Kili elik, Ksenia Koloskova, and Marcos Poplawski-Ribeiro (2017) "Gone with the Headwinds: Global Productivity," IMF Staff Discussion Note, April.

Bloom, Nicholas A., Charles I. Jones, John Van Reenen, and Michael Webb (2017) "Are Ideas Getting Harder to Find?" Research Papers repec, Stanford University, Graduate School of Business.

Barro, Robert J. (2016) "The Reasons behind the Obama Non-Recovery," *The Wall Street Journal*, September 20. http://scholar.harvard.edu/files/barro/files/wsj_published_version_092116.pdf.

Barro, Robert J., and Jason Furman (2018) "The Macroeconomic Effects of the 2017 Tax Reform," *Brookings Papers on Economic Activity*, Spring.

Bergeaud, A., G. Cette, and R. Lecat (2017) "Total Factor Productivity in Advanced Countries: A Long-term Perspective," *International Productivity Monitor*, No. 32, Spring, pp. 6-24. http://www.csls.ca/ipm/32/bergeaud_cette_lecat%20version%202.pdf.

Bosler, Canyon, Mary C. Daly, John G. Fernald, and Bart Hobijn (2016) "The Outlook for U.S. Labor-Quality Growth," Federal Reserve Bank of San Francisco Working Paper 2016-14. http://www.frbsf.org/economic-research/publications/working-papers/wp2016-14.pdf.

Brynjolfsson, Erik, Daniel Rock, and Chad Syverson (2018) "Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics," forthcoming in Agrawal, Gans, and Goldfarb (eds.) *The Economics of Artificial Intelligence: An Agenda* (Cambridge, MA: NBER).

Byrne, David M., John G. Fernald and Marshall B. Reinsdorf (2016) "Does the United States Have a Productivity Slowdown or a Measurement Problem?" Conference paper prepared for *Brookings Papers on Economic Activity*, March.

Byrne, David, Stephen D. Oliner, and Daniel E. Sichel (2017) "Prices of High-Tech Products, Mismeasurement, and the Pace of Innovation," *Business Economics*, Vol. 52, No. 2, pp. 103-113.

Cette, Gilbert, John G. Fernald, and Benot Mojon (2016) "The Pre-Great Recession Slowdown in Productivity," *European Economic Review*, Vol. 88, pp. 3-20.

Decker, Ryan A., John Haltiwanger, Ron S. Jarmin, and Javier Miranda (2016) "Declining Business Dynamism: What We Know and the Way Forward," *American Economic Review*, Vol. 106, No. 5, pp. 2037.

Diaz, Juan-Antolin, Thomas Dreschel, and Ivan Petrella (2017) "Tracking the Slowdown in Long-Run GDP Growth," *Review of Economics and Statistics*, Vol. 99, No. 2, May, pp. 343-256.

Fernald, John G. (2014) "A Quarterly Utilization-Adjusted Series on Total Factor Productivity," Manuscript. Data available at http://www.frbsf.org/economics/economists/jfernald/quarterly_tfp.xls.

Fernald, John G. (2015) "Productivity and Potential Output Before, During, and After the Great Recession," *NBER Macroeconomics Annual.*

Fernald, John G. (2016) "Reassessing Longer-Run U.S. Growth: How Low?" Federal Reserve Bank of San Francisco Working Paper 2016-18. http://www.frbsf.org/economic research/publications/working-papers/wp2016-18.pdf.

Fernald, John G., Robert E. Hall, James Stock, and Mark Watson (2017) "The Disappointing Recovery of Output after 2009," *Brookings Papers on Economic Activity*, Spring, pp. 1-58.

Jorgenson, Dale W., Mun S. Ho, and Jon D. Samuels (2016) "Education, Participation, and the Revival of U.S. Economic Growth," National Bureau of Economic Research Working Paper Series No. 22453.

Kahn, Robert A. and Robert W. Rich (2018) "Kahn-Rich Productivity Model Update," https://www.newyorkfed.org/medialibrary/media/research/national_economy/richkahn_prodmod.pdf.

Syverson, Chad. (2016) "Challenges to Mismeasurement Explanations for the U.S. Productivity Slowdown," Working Paper no. 21974, National Bureau of Economic Research.

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

Timmer, Marcel P., Robert Inklaar, Mary O'Mahony and Bart van Ark (2011) "Productivity and Economic Growth in Europe: A Comparative Industry Perspective," *International Productivity Monitor*, No. 21, Spring, pp. 3-23. http://www.csls.ca/ipm/21/IPM-21-Timmer-et-al.pdf.

Ward, Adrian F., Kristen Duke, Ayelet Gneezy, and Maarten W. Bos (2017) "Brain Drain: The Mere Presence of Ones Own Smartphone Reduces Available Cognitive Capacity," *Journal of the Association for Consumer Research*, No. 2, April, pp. 140-154. https://doi.org/10.1086/691462.

# What Do We Know About the Productivity Slowdown? Evidence from Australian Industry Data

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Abstract

The productivity slowdown across industrialised countries since around 2004 is a topic of much interest to academic researchers and policy makers alike. As we search for explanations for the slowdown, it is useful to consider what the performance has been at the industry level. This article provides some evidence and perspectives from official Australian industry-level data. While industries have experienced different productivity growth profiles since 1989-90, they all experienced a slowdown after 2003-04. A rise in inefficiency may be one source of this slowdown. Some suggestions for future research directions that may provide a deeper understanding of productivity growth are suggested, in the spirit of a slowdown being too valuable to waste.

## Diversity of the Productivity Experience Across Industries

As we puzzle over the productivity slowdown that is afflicting industrialised countries,[2] and contemplate appropriate policy responses, it is worthwhile keeping in mind that performance at the level of specific industries can be very diverse. This is illustrated in Chart 1, for the twelve core industries of the Australian market sector.

The aggregate twelve-industry market sector is represented by the black line with square boxes (Market Sector (12)). The slowdown from the mid-2000s is very noticeable through a flattening out of this line compared to the earlier period. What is also very evident is the diversity of productivity performance across industries.

Agriculture, forestry and fishing is the stand out productivity performer, even with two large downward spikes (in 2002-03 and 2006-07) which repre-

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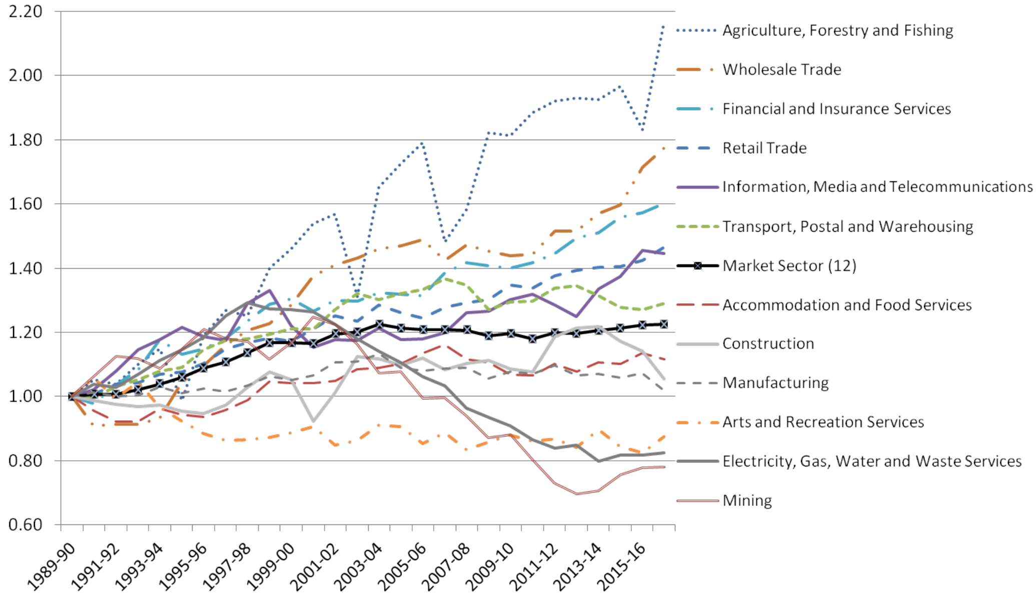
2 For recent aggregate productivity trends across OECD countries, see OECD (2018).

**Chart 1: Multifactor Productivity in Australia, by Industry (1989-90=100)**




Source: Australian Bureau of Statistics (2018). Note that the indicated years are fiscal years, which run from July 1 to 30 June. The plotted series are cumulated indexes, indicating the level of productivity relative to the base year of 1989-90.

sent the effects of drought. Water is a missing input in almost all productivity analyses, as is the case for the official Australian statistics. Hence the disappearance of a non-measured input has no effect on the input index, but it does have an input on output, reducing productivity growth.[3]

Another standout productivity performer is mining, but at the opposite end of the spectrum. High mining commodity prices led to a mining investment boom. There was much additional input (through major investments in mine development), but with lags in producing output. Combined with falling yields, this led to falling mining productivity.[4]

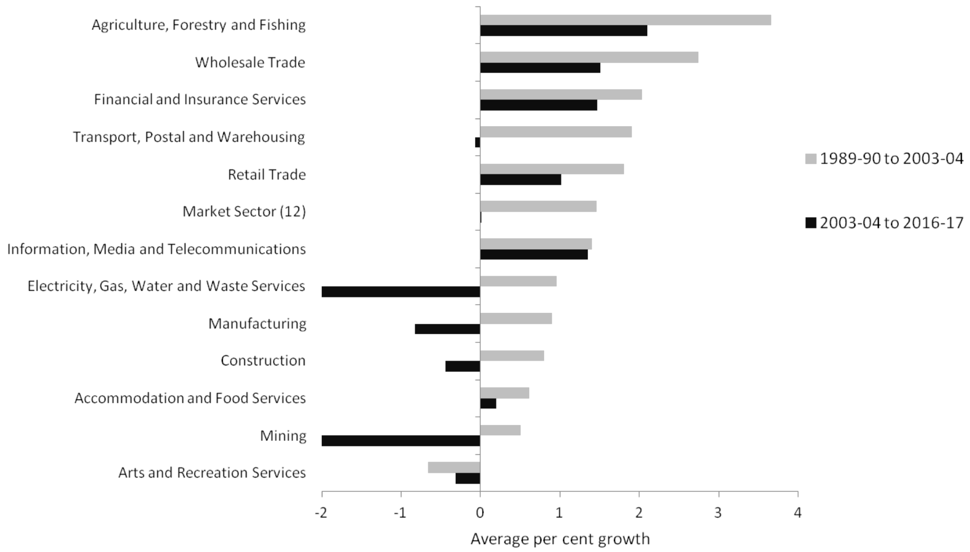
Between these extremes, there are many other industries for which further examination can reveal particular developments which can go some way to explaining their productivity performance over time.[5] Looking at Chart 1, the problem is whether or not there are policies to address the aggregate productivity slowdown when the experiences of the industries seem so diverse. Some commonality of experience across in-

3 Productivity growth, as calculated by national statistical offices, is defined as an output index divided by an input index. That is, it is the growth in output not explained by the growth in input.

4 See Topp, Soames, Parham and Bloch (2008) who found that around a third of the decline in mining multifactor productivity between 2000-01 and 2006-07 was due to long lead times between investment in new capacity in mining and the associated output response. See also Topp and Kulys (2014) on the role of natural resource inputs. For more on industry productivity performance in Australia, see Parham (2012), Connolly and Gustafsson (2013) and Capeluck (2016).

5 For electricity, gas, water and waste services, investment in electricity grid upgrades and the building of idle desalination plants are a major part of the explanation for the performance.

**Chart 2: Industry Multifactor Productivity in Australia, by Industry, by Sub-Period**




Source: Australian Bureau of Statistics (2018). Note that the indicated years are fiscal years, which run from July 1 to 30 June.

dustries would be encouraging for the prospect of a policy, or policies, which may assist in raising the performance of all industries.

## Commonality of the Productivity Experience Across Industries

While Chart 1 suggests diversity, Chart 2 provides some evidence of commonality. It can be seen that all industries had a slower productivity growth in the later period, 2003-04 to 2016-17 with the exception of arts and recreation services.[6] Thus, while overall the productivity experience of these industries is very diverse, there seems to have been something in common which affected their respective productivity, causing it to slow in each case. This may be considered rather surprising. While the strength of the slowdown differs, to have such commonality of experience is somewhat startling and puzzling. It suggests that whatever is driving the slowdown may be mitigated by technological change, but even then no industry has avoided the effect of some seemingly fundamental drag on growth.

The possibility of mismeasurement has been raised to explain productivity slowdowns, past and present.[7] Chart 2 could be interpreted as evidence of increased mismeasurement; perhaps the increasing complexity of the modern economy means that measurement be-

6 The negative productivity growth of -0.6 per cent in arts and recreation services in the earlier period eased to -0.3 per cent in the latter period. This performance hardly suggests this industry as a model for other industries in terms of productivity growth.

7 See, for example, Diewert and Fox (1999) for discussion and references regarding the computer productivity paradox of (particularly) the 1970s and 1980s. See Byrne, Fernald and Reinsdorf (2016) on mismeasurement and the current slowdown.

came more difficult after 2004, resulting in either missing output or an overestimation of input usage, or both. However, given the diverse nature of these industries, in terms of their outputs and inputs, it is hard to see how mismeasurement could have affected all industries to such a sufficient extent as to overwhelm gains from technical change over this period.[8]

## Digging Deeper: Decomposing Productivity Growth

Chart 3 provides a decomposition of aggregate market sector productivity, as measured by the Australian Bureau of Statistics.[9] The method is that of Diewert and Fox (2018), which provides contributions of technical progress, inefficiency and input prices to productivity growth. In Chart 3, as logs have been taken, the three components add up to the solid line, which is the path of officially measured multifactor productivity (MFP) growth.[10]

The relatively high TFP growth in the 1990s is usually attributed to the benefits of microeconomic reforms. In other countries, which did not have microeconomic reforms around this time, similar growth is usually attributed to the finally realized benefits of investments in computers over multiple years.[11] The poor growth performance in the 2000s can then be interpreted as a result of the gains from microeconomic reforms having been exhausted. This has led to recent calls for another round of microeconomic reforms to stimulate another golden age of productivity growth.[12]

What can be seen from Chart 3 is that technical progress (T) was rapid through the 1990s, tapered off in the 2000s, and has started to pick up again from 2012. The slowdown in technical progress obviously affected productivity growth, but as the method excludes the possibility of technical regress, it cannot explain falling productivity levels.[13]

Inefficiency (E) has increased dramatically since 2003-04.[14] Thus this increase in inefficiency corresponds with the pro-

8 Syverson (2017) noted that an aggregate productivity slowdown is observed across many countries with diverse industry structures, making mismeasurement of economic activity an unlikely candidate to explain away the slowdown.

9 Further results of applying this method to Australian productivity data, for individual industries and states, are available in Zeng, Parsons, Diewert and Fox (2018).

10 The series which is decomposed is not exactly the same as the official productivity series, but it is very close. It differs because of the way in which the official data are aggregated to form the market sector results.

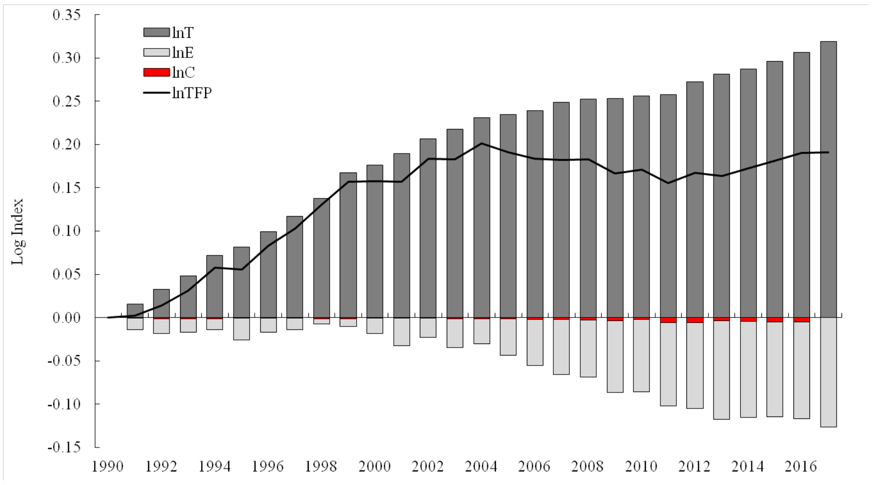
11 A popular argument is that it took a while for firms to re-organise the workplace in order to take advantage of the capabilities of computers.

12 There appears to be no consensus on the nature of any future round of microeconomic reforms, besides perhaps the removal of bureaucratic red tape.

13 It seems reasonable in a modern economy that technological capability is not lost. Puzzling about their empirical results which seemed to show technological degradation for countries with very low capital-labour ratios, Kumar and Russell (2002) asked the following: Does knowledge decay? Were blueprints lost? See also Aiyar, Dalgaard and Moav (2008).

14 The other component is the effect from changes in input prices, C. This is tiny relative to the contributions of technical progress and inefficiency, and hence will not be discussion further.

**Chart 3: Decomposition of Market Sector TFP in Australia into Technical Progress (T), Inefficiency (E) and Input Prices (C), 1990-2017**




Source: Zeng, Parsons, Diewert and Fox (2018), using data from Australian Bureau of Statistics (2018).

ductivity slowdown. It can be argued that this is more reasonable than interpreting the productivity slowdown as a decline in the pace of advancement of technology. The increase in inefficiency can be interpreted as a direct consequence of the technological disruption that leads to the stranding of assets.

For example, if Airbnb leads to hotels having a decline in occupancy rates, it is difficult for an established hotel to downsize; how to sell off a just one corridor of excess rooms? Similar examples can be easily thought of for almost all of the industries within the market sector.

If a firm is underutilizing an asset (through facing excess capacity or technological obsolescence) and cannot dispose of it, it remains on its books. The fact it is underutilized is typically not captured by the national statistical office. At the same time, the firm may be investing in new capital, in order to take advantage of new technologies; old and new technologies may exist in parallel within the same firm, due to stranded capital. This leads to a measured rise in inefficiency, which appears as a decline in productivity. Similarly a national statistical office may not capture asset disposals appropriately, so that even if the firm does dispose of the asset, this may not be reflected in the productivity statistics.

Hence, we return to the possibility that mismeasurement potentially underlies at least some of the measured TFP slowdown. However, this time it is from the mismeasurement of capital input, rather than the mismeasurement of market output, which has been the emphasis in much of the literature to date.

## Research Directions

It seems that we are still lacking the certainty to declare the direction and extent of future productivity growth. We are currently in a period of perhaps unprecedented technological change, yet there exists significant anxiety about the contemporaneous decline in measured productivity growth. Throughout history, technological change, a main driver of productivity, has either been a source of inspiration or despair, either being the driver of higher standards of living or a source of our (employment and social) worries.[15] A better understanding of the performance and measurement of economies during periods of technological disruption can go a long way to easing anxieties, and to the design of effective growth policies. Some research directions in which understanding can be profitably advanced are provided below.

## The treatment of new and disappearing goods.

Statistical agencies are typically unable to appropriately measure the effects of new and disappearing goods on inflation and economic growth. The problem is that prices of the goods are obviously missing when they do not exist, or are not included in the statistical agency survey. This obviously creates problems for the construction of price deflators and the corresponding measures of real economic activity. This is not a new problem statistical agencies have long implemented strategies for replacement sampling[16] but one that may have become more important given a proliferation of new and specialized goods and services, often related to the digital economy.[17] With increasing availability of transaction level data and electronic sourcing of product characteristics, it is possible to explore different choices for handling this problem, and the implicit quality adjustment that alternative methods imply.[18]

## Valuation of new free goods and services.

Free goods and services characterize much of the digital economy, represented by Facebook, YouTube and popular applications such as Whatsapp. With news, entertainment and communication services increasingly moving to such plaforms, they are replacing services which have observed market prices. The result is lower measured economic activity, resulting in lower measured economic growth and hence productivity. Again the problem can be thought of as one of missing prices even free goods have a value to consumers. There have been attempts at eliciting valuations using (laboratory and online) experiments and to examine the impact on economic growth of including these valuations in augmented measures of GDP.[19]

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15 See, for example, Mokyr, Vickers and Ziebarth (2015) for a broad historical perspective.

16 Statistical agencies refresh their sample of products by substituting replacement products for the disappearing products. They may make some quality adjustments to the new products, making replacement products comparable to the disappearing products.

17 This is not limited to services and software design. The cost of designing and producing new and specialized products has likely been significantly reduced through computer aided design and technologies such as 3D printing.

18 See Diewert, Fox and Schreyer (2018) and Adams and Klayman (2018) for more on this problem.

19 See Brynjolfsson, Collis, Diewert, Eggers and Fox (2018).

### Better time-use data

Few countries have detailed and regular data on how time is used.[20] Such data can be used to understanding production in the home. This can help beyond learning about the distribution of household work across gender and age groups, but also about the impact of the digital economy on the production and consumption of entertainment services. The production and consumption of free digital entertainment (such as YouTube videos) has an opportunity cost, and this provides another way to place a value on such goods. It can also aid in the measurement and valuation of the labour that goes into the production of community-developed software, such as the program R, and household innovation (Sichel and von Hippel, 2018).

### Firm-level data

Finally, the increasing availability of firm-level data, and linked longitudinal employer-employee data, provides the opportunity to examine productivity from the firm level. Berlingieri, Blanchenay, Calligaris and Criscuolo (2017) describes the OECD MultiProd project, which provides harmonised micro-aggregated data of paramount importance for investigating the extent to which different policy frameworks can shape firm productivity and examining the way resources are allocated to more productive firms. There is much policy relevant research emerging using firm-level data, and the scope will increase as other (administrative) data sets are linked, such as detailed traded data.[21]

What should be clear is that while there are measurement problems which may be created or exacerbated by the modern economy, there are also opportunities facilitated by new data and research methods becoming available due to the digital economy.

## Conclusion

So what do we know about the productivity slowdown? Clearly not enough, but with the emergence of new data sources and methodologies there are increasing opportunities to understand sources of productivity. Combined with heightened interest from policy makers, the potential for researchers to advance understanding of sources of productivity is great. It could be said that no slowdown should go to waste.

## References


Adams, B. and A. Klayman (2018) "Cross-validation of Quality-adjustment Methods for Price Indexes," *Monthly Labor Review*, June, U.S. Bureau of Labor Statistics, Washington, D.C. Accessed at: https://doi.org/10.21916/mlr.2018.18.

Aiyar, S., C-J. Dalgaard, and O. Moav (2008) "Technological Progress and Regress in Pre-industrial Times," *Journal of Economic Growth*, Vol. 13, pp. 125-144.


20 The last time-use survey in Australian was in 2006. Funding for a new time use survey has been announced recently, by the Minister for Women, for 2020-21; see Craig (2018).

21 In Australia, the Australian Treasurys Firming up Productivity in Australia project is seeking to build capability in microdata analysis and improve the microdata access environment. There is a focus on developing a productivity growth narrative from the firm level to inform structural policy; Australian Treasury (2018).

Australian Bureau of Statistics (2018) "Estimates of Industry Multifactor Productivity, 2016-17," Cat. No. 5260.0.55.002, Canberra, Australia. https://treasury.gov.au/productivity/.

Australian Treasury (2018) "Firming Up Productivity in Australia," presentation to the EMG Workshop 2018, UNSW Sydney 29-30 November. Accessed at: https://treasury.gov.au/productivity/.

Berlingieri, G., P. Blanchenay, S. Calligaris and C. Criscuolo (2017) "The Multiprod Project: A Comprehensive Overview, OECD Science, Technology and Industry Working Papers, 2017/04, OECD Publishing, Paris.

Byrne, D., J. Fernald and M. Reinsdorf (2016) "Does the United States Have a Productivity Slowdown or a Measurement Problem?" in J. Eberly and J. Stock (eds.) *Brookings Papers on Economic Activity*, Spring 2016, (Washington, D.C.: Brookings Institute).

Brynjolfsson, E., W.E. Diewert, F. Eggers, K.J. Fox and A. Gannamaneni (2018) "The Digital Economy, GDP and Consumer Welfare: Theory and Evidence," paper presented at the The Sixth IMF Statistical Forum: Measuring Economic Welfare in the Digital Age, 19-20 November, Washington D.C.

Capeluck, E. (2016) "A Comparison of Productivity Developments in Canada and Australia," *International Productivity Monitor*, No. 30, Spring, pp. 43-63. http://www.csls.ca/ipm/30/capeluck.pdf.

Connolly, E and L. Gustafsson (2013) "Australian Productivity Growth: Trends and Determinants," *Australian Economic Review*, Vol. 46, No. 4, pp. 473-482.

Craig, L. (2018) "A decade after the invention of the smartphone, were about to find out how we use out time," The Conversation, https://theconversation.com/a-decade-after-the-invention-of-the-smartphone-were-about-to-find-out-how-we-use-our-time-107195.

Diewert, W.E. and K.J. Fox (1999) "Can Measurement Error Explain the Productivity Paradox?" *Canadian Journal of Economics*, No. 32, pp. 251-280.

Diewert, W.E. and K.J. Fox (2018) "Decomposing Value Added Growth into Explanatory Factors," in E. Grifell-Tatj, C.A.K. Lovell and R. Sickles (eds.) *The Oxford Handbook of Productivity Analysis*, (New York, NY: Oxford University Press), Chapter 19, pp. 625-662.

Diewert, W.E., K.J. Fox and P. Schreyer (2018) "The Digital Economy, New Products and Consumer Welfare," ESCoE Discussion Paper 2018-16.

Kumar, S. and R.R. Russell (2002) "Technological Change, Technological Catch-up, and Capital Deepening: Relative Contributions to Growth and Convergence," *American Economic Review*, Vol. 92, pp. 527-548.

Mokyr, J., C. Vickers and N.L. Ziebarth (2015) "The History of Technological Anxiety and the Future of Economic Growth: Is This Time Different?" *Journal of Economic Perspectives*, Vol.29, No. 3, pp. 31-50.

OECD (2018) *Compendium of Productivity Indicators 2018*, (Paris, France: OECD Publishing).

Parham, D. (2012) "Australias Productivity Growth Slump: Signs of Crisis, Adjustment or Both?" Visiting Researcher Paper, Productivity Commission, Commonwealth of Australia.

Sichel, D. and E. von Hippel (2018) "Household Innovation, R&D, and New Measures of Intangible Capital," November, unpublished manuscript.

Syverson, C. (2017) "Challenges to Mismeasurement Explanations for the U.S. Productivity Slowdown," *Journal of Economic Perspectives*, Vol. 31, pp. 165-186.

Topp, V. and T. Kulys (2014) "On Productivity: The Influence of Natural Resource Inputs," *International Productivity Monitor*, No. 27, Fall, pp. 64-78. http://www.csls.ca/ipm/27/27-vttk.pdf.

Topp, V., L. Soames, D. Parham and H. Bloch (2008) "Productivity in the Mining Industry: Measurement and interpretation," Productivity Commission Staff Working Paper, Canberra, Australia.

Zeng, S., S. Parsons, W.E. Diewert and K.J. Fox (2018) "Industry and State Level Value Added and Productivity Decompositions," presented at the EMG Workshop 2018, UNSW Sydney 29-30 November.