The Centre for the Study of Living Standards

THE CENTRE FOR THE STUDY OF LIVING STANDARDS (CSLS) is a national, independent, not-for-profit research organization which began operations in August 1995. Its objectives are twofold. First, to contribute to a better under- standing of trends and determinants of productivity, living standards, and eco- nomic well-being in Canada through research. Second, to contribute to public debate by developing and advocating specific policies to improve the standard of living of Canadians.

The activities of the CSLS are motivated by the following general principles:

1) in the long run, productivity growth is the key to improved living standards;
2) in the short to medium term, elimination of any output gap is the most effective way to raise living standards;
3) the equitable sharing of productivity gains among all groups in society is an essential element of the economic growth process;
4) increased cooperation among the various groups which make up our society can contribute significantly to better living standards; and
5) reliable data are crucial to the monitoring and analysis of living standards and to the development of effective policies to increase living standards.

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Editors' Overview

The 45th issue of the *International Productivity Monitor* contains eight articles. The first part of the issue features five articles in a symposium on Canada's productivity performance which includes contributions from Finance Canada, Innovation, Science and Economic Development Canada, Statistics Canada, and the Centre for the Study of Living Standards. The second part of the issue has three articles on measurement issues related to capital, capacity utilization, and productivity.

It is well-known that Canada's productivity performance is recent years has been weak. To understand the reasons for this situation, it is important to have a full understanding of the nature of this performance. In the introductory article for the symposium, **Chris Haun** and **Timothy Sargent** from the Centre for the Study of Living Standards provide a detailed analysis of both the post-2000 productivity growth slowdown as well as the more recent slowdown during the pandemic. They find that Canada's productivity growth since 2000 is similar to other advanced OECD countries. However, Canada's productivity levels are at the bottom of the ranking of advanced countries. This is particularly apparent in comparison with Canada's neighbour, the United States. Canada's business sector now has only 70 per cent the productivity levels of the U.S. business sector. The authors also look at industry sectors: they find that weak productivity growth since 2000 is largely a result of within sector productivity changes, rather than reallocation of labour to sectors with lower productivity levels or weaker productivity growth. Finally, the authors find that while lower growth in the 2000-2019 period overall is largely attributable to much weaker multifactor productivity growth, there was a pronounced slowdown in capital accumulation, particularly of ICT capital, that put downward pressure on productivity growth after the financial crisis.

The United States has experienced a much smaller fall-off in productivity growth than Canada after 2000, resulting in an increased divergence in labour productivity growth rates between the two countries, up from 0.5 points in 1987-2000 to 0.9 points in 2000-2019. The second article by **Wulong Gu** and **Michael Willox** from Statistics Canada examines the reasons for this situation, with a focus on the information and cultural services industry. They point out that labour productivity growth in this industry in the United States jumped to 7.8 per cent per year in 2000-2019, compared to only 1.5 per cent in Canada. Despite the small size of this sector, this difference in productivity growth increased the Canada-U.S. productivity growth gap by 0.45 percentage points. In addition, they argue that the information and cultural services sector, especially the important telecom component, is an important input into other industries and that Canada's poorer productivity performance in the sector led to greater price increases than in the United States, with a negative effect on the productivity of the industries using the output of the information and cultural services industry as inputs. The authors make the case that lower productivity growth and greater price increases in the sector in Canada reflects a lower level of competition in this country than in the United States.

While there is no consensus on the reasons for slower productivity growth in Canada, it is widely recognized that Canada's productivity performance is negatively affected by weak investment in R&D, machinery and equipment investment, and information and communications technologies (ICT). In the third article, **Carlos Rosell**, **Kaleigh Dowsett** and **Nelson Paterson** from Finance Canada provide an assessment of Canada's mediocre investment and productivity performance and the factors behind it. They identify and discuss a number of factors, including small and dispersed markets, the regulatory framework, the large presence of small firms, an increase in zombie firms, a growing productivity gap between frontier and non-frontier firms, skills mismatch, and management education. While all those factors have somewhat contributed to the shortfall in Canada's productivity performance, there is no silver bullet to solve the productivity problem. Going forward, the authors identify and discuss what they see as four structural transformations affecting productivity growth, namely population aging, the green transition, the realignment of global trade, and increasing digitization and use of AI.

The Canadian economy is currently undergoing movement toward net zero emissions, the green transition, and the adoption of information technologies such as AI, the digital transition. These twin transitions represent significant challenges and opportunities for productivity growth. In the fourth article in the symposium, **Jonathan Barr, Peter Foltin and Jianmin Tang** from Innovation, Science and Economic Development Canada explore the implications of these transitions for productivity. They recognize that a reduction in the size of the high-productivity level oil and gas sector can have a negative impact on aggregate productivity through a composition effect. But they argue that the environmental and clean technology (ECT) sector is performing well in terms of output and productivity. They also note that environmental regulation can in some instances spur innovation, as documented in the literature on the Porter hypothesis. In contrast to the uncertain implications of the green transition for productivity, the digital transition is expected to have positive effects on productivity. ICT services productivity growth has been very rapid since 2000. Artificial Intelligence has great potential to boost productivity, but Canadian firms appear to be laggards in their use of this technology.

In contrast to slow productivity growth, the number of patents granted to Canadian researchers has increased rapidly in recent years. This is paradoxical as patents are an important measure of innovation and technological progress, the driver of productivity growth. In the fifth article in the symposium **Iain Cockburn**, **Megan MacGarvie** and **John McKeon** from Boston University document and then undertake a detailed econometric analysis to explain what they call Canada's patent/productivity paradox. The authors find that neither a low quality of Canadian inventions nor a lower invention rate in the ICT area can explain the paradox. They find suggestive evidence that foreign ownership of patents and inventor migration may play important roles in explaining the paradox. They conclude that simply increasing the number of patents is not a path to prosperity. To avoid a 'patents without growth' route the article recommends to look at ways to stem the net-outmigration of inventors, to encourage the location of immigrant inventors and R&D workers within Canada, and to review the role of tax policy for innovation.

Reliable estimates of multifactor productivity (MFP) require accurate and consistent estimates of capital stocks and capital services. In the sixth article, **Pierre-Alain Pionnier, Belén Zinni and Kéa Baret** from the OECD examine the sensitivity of MFP estimates to the different assumptions related to asset depreciation and retirement patterns and initial capital stocks made by national statistical offices in their construction of the capital stock. They use the U.S. national accounts as a laboratory and calculate what would happen in the United States if the assumptions of other countries were used. They find that most other G7 countries have faster rates of depreciation for buildings and that, under these assumptions, the net capital stock would be smaller and, U.S. GDP would be up to 0.5 per cent higher, with important implications for MFP measurement. The authors conclude with a call for more frequent review of the methods national statistical offices use for asset depreciation. The purpose of the review is not t standardize assumptions, but to ensure that differences reflect country-specific factors.

Over the course of a business cycle, the rate of capacity utilization influences productivity. This means to understand and explain short-to-medium-term fluctuations in productivity, accurate measures of capacity are needed. Capacity utilization measures have traditionally been calculated at the industry level. In the seventh article on the issue, **Jianmin Tang** from Innovation, Science and Economic Development Canada and **Weimin Wang** from Statistics Canada develop a methodology to measure capacity utilization at the firm or micro-level. The much greater availability of micro data has made such firm-level estimates of capacity utilization possible. The methodology is based on the theory of the firm in terms of profit maximizing and price taking and is exogenous to productivity shocks. The authors conclude that controlling for capital utilization is essential for evaluating the economic impact of economic policies and programs such as support for ICT adoption and that this firm-level capacity utilization measures can potentially play an important role in this regard.

In 2001, the OECD published the manual *Measuring Productivity - Productivity Manual: Measurement of Aggregate and Industry Level Productivity Growth* followed in 2009 by the publication of *Measuring Capital: OECD Manual 2009*. These two publications provided a detailed guide for national statistical offices on how to incorporate the KLEMS production account framework into national accounts, with particular implications for the measurement of productivity. In the eighth and last article in the issue, **Nicholas Oulton** from the London School of Economics provides a detailed discussion of how national statistical offices in the United Kingdom, the United States, and Canada responded to the OECD guidelines. Oulton concludes that within the OECD, the level of support and take-up of the KLEMS approach taken up by national statistical offices has been variable. National statistical offices in both Canada and the United States follow the OECD guidelines for the production of their productivity statistics. In the EU and the United Kingdom there is still some way to go as productivity statistics are still not fully integrated into the national accounts.

Decomposing Canada's Post-2000 Productivity Performance and Pandemic-Era Productivity Slowdown

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Abstract

Labour productivity growth in Canada has been significantly lower since 2000, and has fallen further since 2019. In this article we examine why this has occurred. We approach the question from three angles: first we look at how Canada's performance compares to other OECD countries, particularly the United States; second, we decompose Canadian productivity growth by sector, and look to see to what extent slower productivity growth is due to lower growth within sectors, or reallocations across sectors; and finally we perform a growth accounting exercise in order to understand the relative contributions of multifactor productivity, capital intensity and labour quality. We find that Canada's productivity growth since 2000 has been similar to peer countries, but that the level of productivity is lower than for almost all other peer countries. Weak productivity growth after 2000 is largely attributable to weak productivity within sectors rather than sectoral reallocation. We also find that the slowdown in productivity growth post-2000 relative to 1981-2000 is largely a result of declines in multifactor productivity. However, during the latter part of the post-2000 period there was a pronounced slowdown in capital growth, particularly in ICT, that put downward pressure on productivity growth. More recently, productivity growth over the 2019-2022 period has been very weak. As a result, returning even to the pre-pandemic levels of productivity growth in the near term will be challenging.

Labour productivity growth in Canada has diminished considerably relative to the pre-2000 period, with business sector productivity dropping from an average of 1.74 per cent per year in the 1973-2000 period to an average of 0.96 per cent per year in the 2000-2019 period. Work by many productivity researchers finds a second step-

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1 Chris Haun is an economist at the Centre for the Study of Living Standards (CSLS). Timothy Sargent is Deputy Executive Director at the CSLS. The authors thank Andrew Sharpe, Bart Van Ark and one anonymous referee for comments. This article is a revised and abridged version of Haun (2023). Emails: chrisghaun@gmail.com; tim.sargent@csls.ca

wise reduction in the annual growth rate of labour productivity following the year 2000, resembling the substantial slowdown observed in the 1970s (Sharpe and Tsang, 2018).[2] This second productivity slowdown seems to be global, though it has been most pronounced in developed economies (Dieppe, 2020). This article aims to enhance and update understanding of Canadian productivity developments post-2000 by analyzing Canada's productivity performance from an international and historical perspective.[3] The first section of this article uses recent OECD data to present a more detailed assessment of Canada's productivity performance relative to other economies. We compare Canada to a cohort of peer countries within the OECD, before moving to analyze the gap between the United States and Canada. In the second section, we perform the Sharpe and Thompson (2010) decomposition across sectors at the NAICS two-digit level, analyzing the within-sector and re-allocation effects on productivity in the post-2000 period. In the third section, we analyze productivity growth from 1961-2021 using official Statistics Canada estimates for the sources of productivity growth — i.e., capital intensity and labour quality. Multifactor productivity — and their contributions to growth pre- and post-2000. A final section concludes.

The Global Productivity Slowdown: Canada's Productivity Performance in International Context

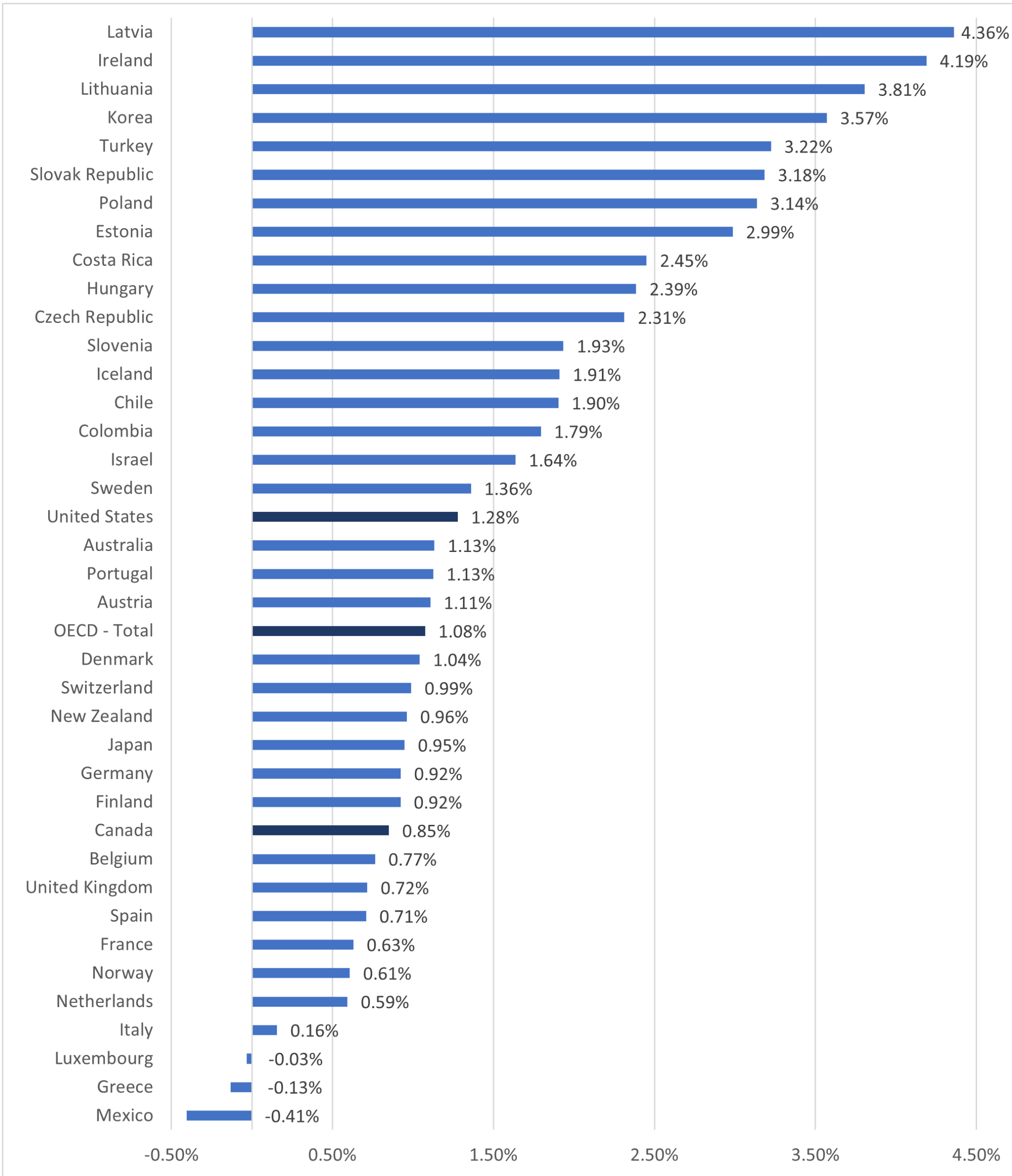
We begin our examination of Canadian productivity trends with an international overview of the post-2000 productivity slowdown. Chart 1 below shows the productivity growth rate for 38 OECD economies for the 2000-2022 period, as well as the average across all OECD countries. Note that the data in this chart are for labour productivity, measured as output per hour, and are for the total economy, not just the business sector.

Canada's relative productivity growth performance is weak but not unusual. As Chart 1 shows, the growth rate in productivity for the Canadian economy averaged 0.85 per cent annually between 2000 and 2022, placing it 28th out of 38 countries. Economies with slower average rates of labour productivity growth include the United Kingdom at 0.72 per cent per year, France at 0.63 per cent per year, Norway at 0.61 per cent per year, and the Netherlands at 0.59 per cent per year and Italy at 0.16 per cent per year among others. Several countries just slightly outperformed Canada, including Germany and Finland at 0.92 per cent per year, New Zealand at 0.96 per cent per year, and Australia at 1.13 per cent per year. The United States

2 The first major slowdown in productivity growth was observed in the 1970s, with 1973 as the pivotal year. In an effort to align data with cyclical peaks (subject to data availability constraints), this article at times decomposes the pre-2000 period into the period spanning from 1961 to 1981 and the period spanning from 1981 to 2000. Readers should note that the use of such time periods masks the magnitude of the 1970s slowdown. That is to say, the slowdown between periods would be meaningfully larger if the periods were aligned with the turning point in 1973.

3 See Sharpe and Sargent (2024) for a general overview of the productivity landscape in Canada.

Chart 1: Total Economy Output per Hour Growth in OECD Countries, Average (Compound) Growth Rates, 2000-2022



Source: https://stats.oecd.org/Index.aspx?DataSetCode=PDB$_G R$
Note: Some country series feature data breaks and estimated or provisional values instead of official statistics for some observations. For full detail on the countries and observations affected, please see the linked database.

and Sweden, meanwhile, performed significantly better than Canada, at 1.28 per cent per year and Sweden at 1.36 per cent per year, respectively.

Countries with rates of annual productivity growth above 1.5 per cent per year tended to be significantly less advanced than Canada at the start of the period, and so one would expect faster growth than Canada as they catch up to advanced economy levels of productivity. This would be true for post-Soviet and Eastern Bloc countries like Lithuania, Latvia, Estonia, Poland, Hungary, as well as Latin American economies like Chile and Colombia.[4] One could also argue that Korea falls into this camp. Ireland, a consistent leader in productivity growth, is something of an anomaly due to its high-tech sector and the fact that many multinational firms book their profits in the country to take advantage of low tax rates (OECD, 2018; Papa, 2019).

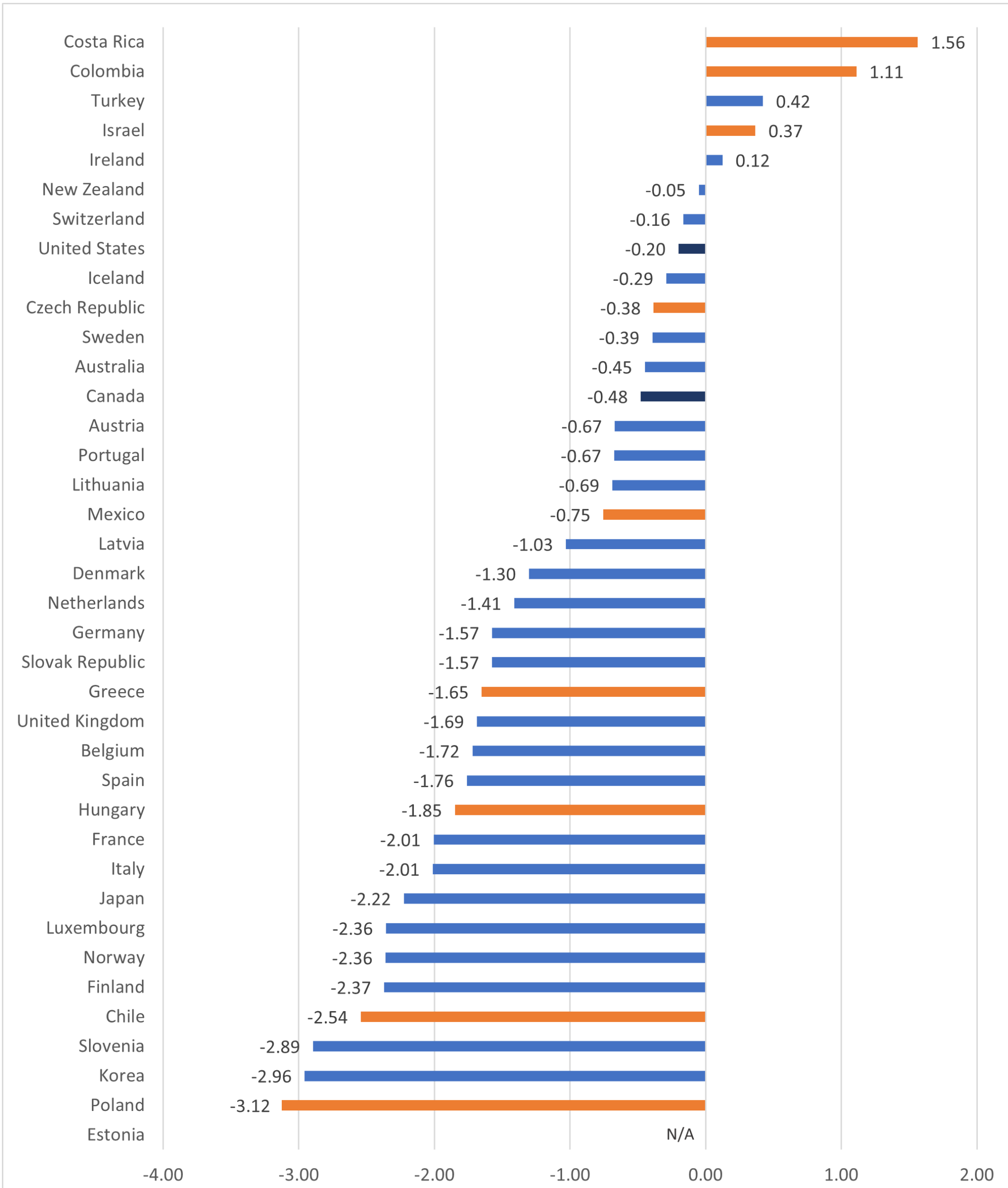
As noted in the introduction, Canada's productivity growth slowed considerably after 2000. We now look at whether the post-2000 slowdown in productivity in Canada was unusual in the OECD. Chart 2 displays the period-to-period changes between the 1973-2000 period and the 2000-2022 period.

This chart shows that compared to other OECD economies, Canada's slowdown in productivity growth was not particularly severe: between the 1973-2000 period and the 2000-2022 period, the average annual rate of productivity growth in Canada fell 0.48 points, from 1.33 per cent per year to 0.85 per cent per year. Expressed differently, out of the 32 OECD economies for which a slowdown occurred, Canada experienced the 8th lowest slowdown. This relatively minor slowdown in productivity growth between periods reflects the fact that Canada's productivity growth was already relatively weak from 1973 onwards. With the exception of Mexico, all of the countries which experienced lower rates of productivity growth than Canada in the pre-2000 period saw less severe slowdowns, suggesting that there is indeed a positive relationship between pre-2000 rates of productivity growth and the magnitude of the post-2000 slowdown as less advanced countries approached advanced country level of productivity. Beyond this, there was no consistent pattern in the size of the productivity slowdown among countries.

We now turn to an examination of what these trends in productivity growth rates have meant for productivity levels. Chart 3 below shows that in in 2022, Canada's total economy labour productivity stood at $53.3 per hour USD (using 2015 PPPs), putting it in 18th place among the 38 OECD countries and on par with the OECD average of $53.4 per hour. However, this average includes developing countries such as Mexico and Colombia. If we restrict our comparison to the 19 advanced countries that could be thought of as peers to Canada—the G7 countries, northwestern European countries such as Belgium, the Netherlands, Luxembourg, Switzer-

4 Mexico is an exception with a very bad productivity performance at -0.41 per cent per year on average between 2000 and 2022.

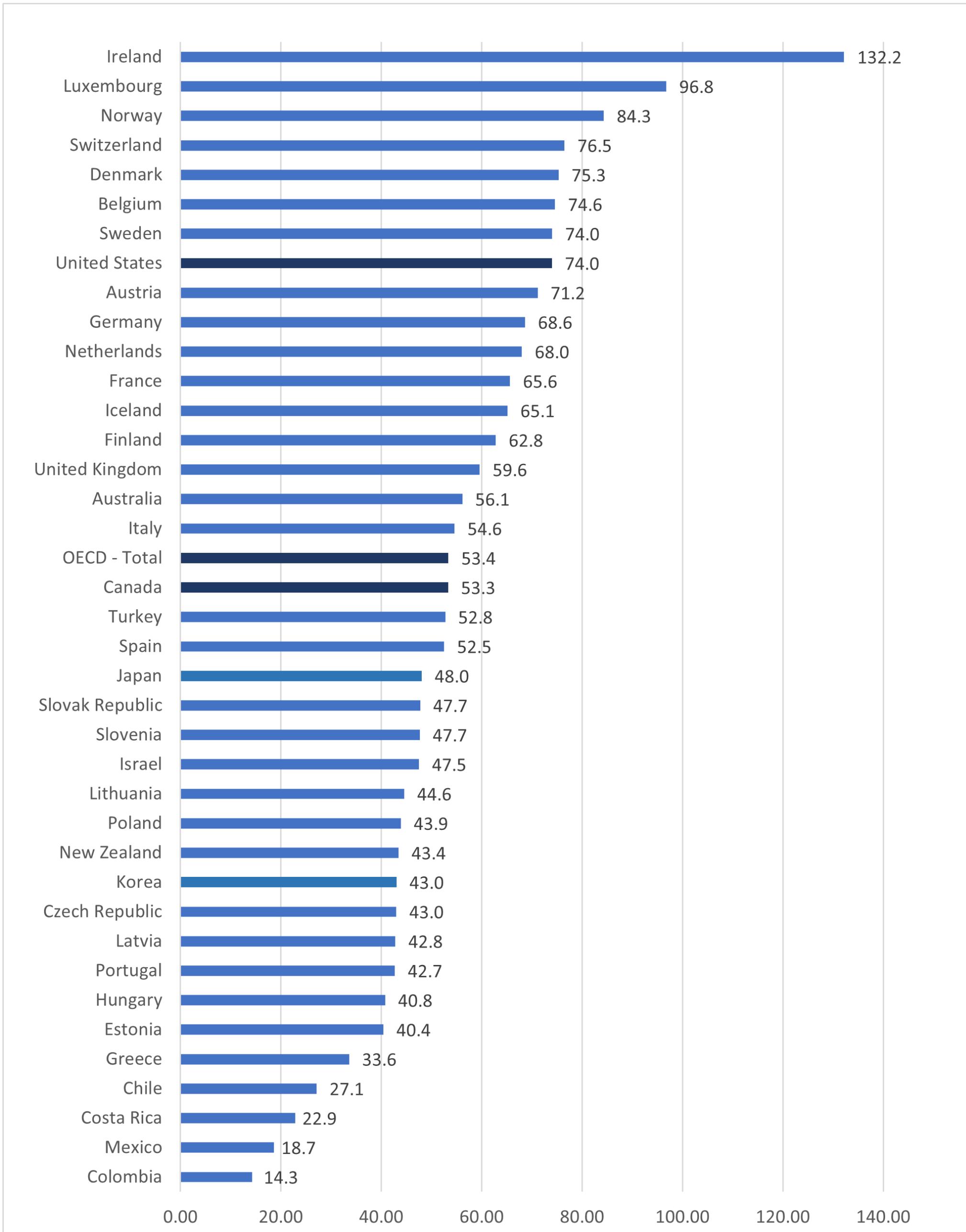
Chart 2: Period-to-Period Change in Average Annual Labour Productivity Growth Rate from 1973-2000 to 2000-2022 (percentage points)



Source: https://stats.oecd.org/Index.aspx?DataSetCode=PDB$_{G}R$

Note: Orange highlights indicate countries for which data is not available for the entire 1973-2000 period. Data before 2000 is unavailable for Estonia. Some country series feature data breaks and estimated or provisional values instead of official statistics for some observations. For full detail on the countries and observations affected, please see the linked database.

Chart 3: Total Economy Output per Hour Levels in OECD Countries, 2022 (USD, constant prices, 2015 PPPs)



Source: https://stats.oecd.org/Index.aspx?DataSetCode=PDB$_G R$
Note: Some country series feature data breaks and estimated or provisional values instead of official statistics for some observations. For full detail on the countries and observations affected, please see the linked database.

land, Ireland, Austria and the Nordic countries, and Australia and New Zealand — Canada is 17th, above only New Zealand and Japan. Canada's relatively weak productivity levels compared to its peers means that we can not blame weaker productivity growth in Canada on the country having relatively higher productivity levels. On the contrary, we would expect Canada's productivity growth to be a little higher than that of its peers, as it caught up to their higher levels of productivity.

Comparisons of Productivity with the United States

Among Canada's peer countries, the United States is perhaps the most natural point of comparison for assessing Canada's productivity performance, given the close geographic, economic, and social ties between the two countries. Chart 4 below provides the growth rates of business sector and total economy labour productivity for the United States and Canada for selected periods. Panel A shows the average (compound) growth rates for business sector productivity for three periods, 1947-1973, 1973-2000, and 2000-2022. Panel B focuses in on business sector productivity trends post-2000, providing rates of growth for the periods spanning 2000-2008, 2008-2019, and 2019-2022. Panels C and D offer rates of growth for the same periods but for the total economy rather than the business sector. However, due to lack of available data, the 1947-1973 period is omitted from Panel C.

The data show that business sector productivity growth in Canada has, on average, lagged that in the United States since 1973 and this phenomenon has become more severe after 2000. In the post-war period of 1947-1973 period Canadian business sector productivity growth over the period actually exceeded growth in the United States by 0.71 percentage points. However, during the 1973-2000 period, productivity growth in both countries fell sharply, although productivity growth was relatively less affected in the United States, falling 1.41 points period-to-period compared to a 2.19 points fall in Canada. This brought productivity growth of the two countries more-or-less in line with each other (1.74 per cent in Canada vs. 1.81 per cent in United States).

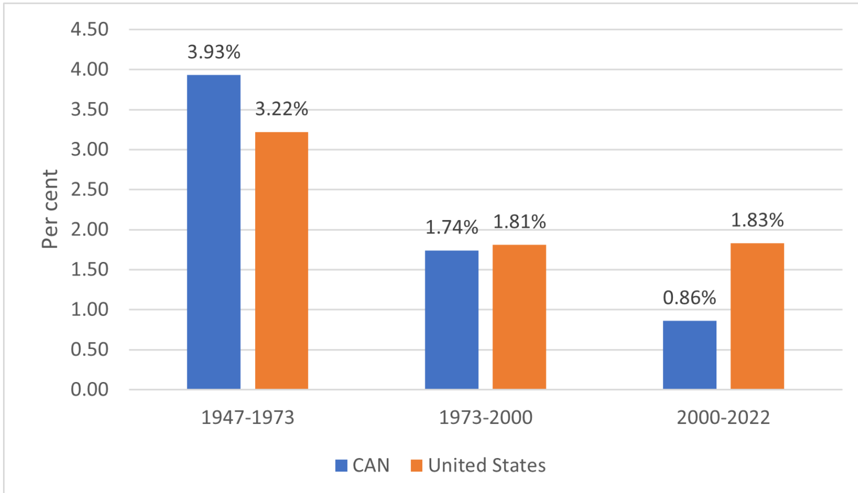
During the 2000-2022 period, Canadian business sector productivity fell once again, with average productivity growth falling 0.88 points from the 1973-2000 period. However, this drop was not mirrored by the American figures.

Comparing growth trends across Canada and the United States for shorter subperiods after 2000 we see that the largest discrepancy between the productivity growth rates of the two countries occurred in the 2000-2008 period, when productivity growth in the United States averaged an impressive 2.50 per cent annually while growth in Canada was quite low at 0.86 per cent annually: a differential of 1.64 percentage points.

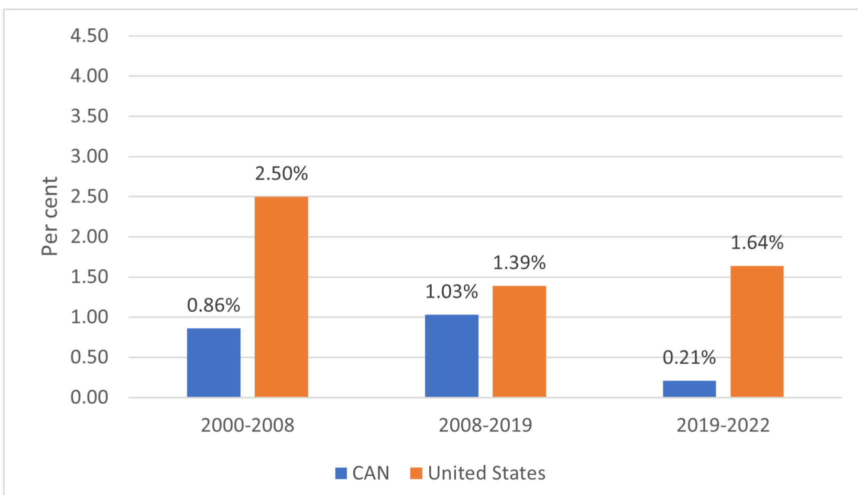
This discrepancy moderated significantly over the 2008-2019 period, as Canadian productivity growth rose 0.17 points to 1.03 per cent and productivity growth in the United States experienced a sharp decline of 1.11 points, down to 1.39 per cent. Altogether, this reduced average productivity growth in the United States to just

Chart 4: Labour Productivity Growth in Canada and the United States

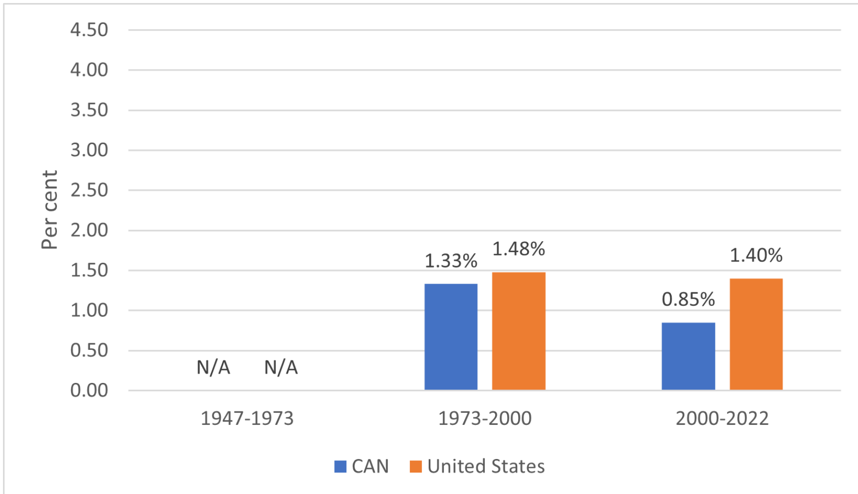
Panel A: Business Sector Output per Hour, Average (Compound) Growth Rates, 1947-2022



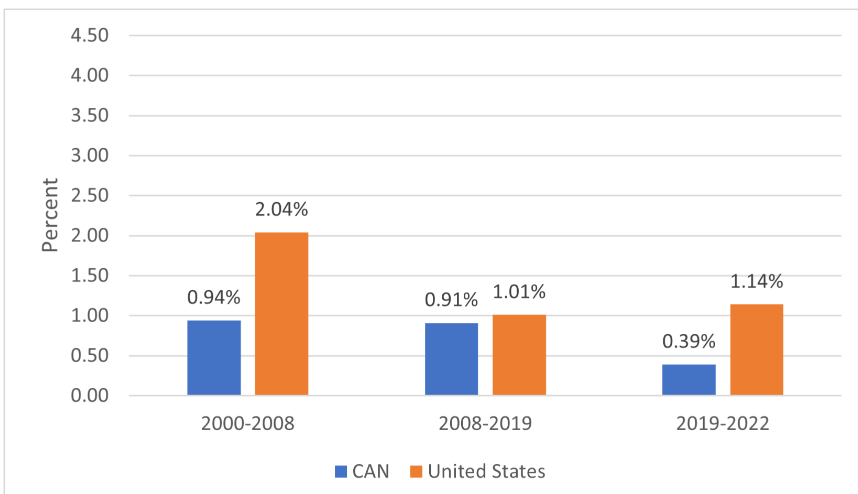
Panel B: Business Sector Output per Hour, Average (Compound) Growth Rates, 2000-2022



Panel C: Total Economy Output per Hour, Average (Compound) Growth Rates, 1973-2022



Panel D: Total Economy Output per Hour, Average (Compound) Growth Rates, 2000-2022



Sources: Canada business sector labour productivity data from Statistics Canada: Table 36-10-0305-01 for 1947-1960, Table 36-10-0208-01 for 1961-2021, Table 36-10-040-01 for 2022. United States business sector labour productivity data from BLS Labour Productivity and Cost Measures – Major Sectors – August 3, 2023 (XLSX sheet). Total Economy labour productivity data from OECD – Productivity and ULC – Annual, Total Economy: https://stats.oecd.org/Index.aspx?DataSetCode=PDB$_GR$.

35 per cent above Canadian average productivity growth, likely reflecting the enduring, asymmetric effects of the 2008 financial crisis.

However, during the 2019-2022 period, any prospect of a return to parity in productivity growth trends between the two economies grew more remote; Canadian business sector productivity growth fell significantly in this period, dropping 0.82 points between 2008-2019 and 2019-2022 to just 0.21 per cent annually. This dramatic decline was not reflected in the United States; rather, American productivity growth actually rebounded somewhat, rising 0.25 points from an average of 1.39 per cent annually in the previous period to 1.64 per cent.[5] These divergent trends resulted in a substantial widening of the cross-country disparity in growth. Average productivity growth in the United States in the 2019-2022 period exceeded that in Canada by 1.43 percentage points. This is slightly smaller than the absolute gap observed in the 2000-2008 subperiod; however, the gap in relative terms is by far the largest between 2019 and 2022, with average productivity growth in the United States nearly 8 times higher than that in Canada. These estimates for the 2019-2022 period should be interpreted with extreme caution however, given the extraordinary nature of the period and the fact that estimates for 2022 productivity growth may still be subject to significant revision.

For comparison, Panels C and D in chart 4 show rates of labour productivity for the total economy. With the exception of the 1973-2000 period, the gap between the rates of growth in United States and Canada is smaller in every period when using total economy measures rather business sector measures. This is particularly visible in 2000-2022 period, where the total economy gap is 0.55 points compared to 0.97 points in the business sector, and the 2019-2022 period, where the gap was 0.75 points in the total economy and 1.43 points in the business sector.

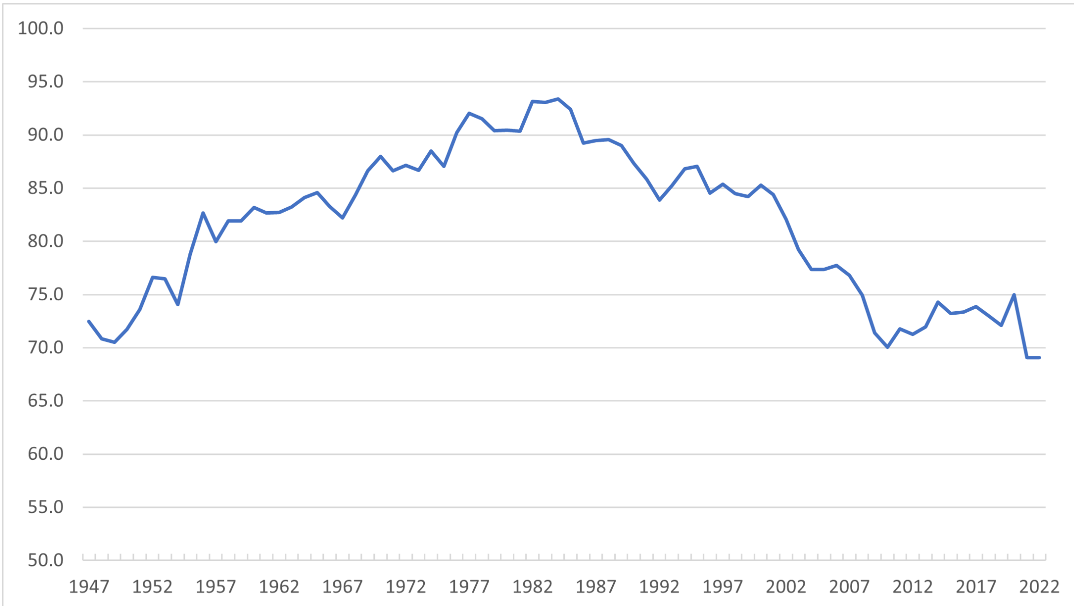
This discrepancy for the 2000-2022 period between estimates of the U.S.-Canada productivity growth gap that use business sector measures and those that use total economy measures is due to productivity growth rates in the non-business sector that are markedly lower than the non-business sector in the United States, but not in Canada. Why non-business sector productivity growth should be significantly lower in the United States than in Canada is puzzling and a topic for further research; for now we tend to place more reliance on business sector rather than total economy measures of productivity given the well-known problems in measuring output in the non-business sector.[6]

Chart 5 shows the implication of United States-Canada differences in growth rates for business sector productivity levels over the 1947-2022 period. The Chart shows

5 For a discussion of productivity level paths in Canada and the United States during the Pandemic see Blit *et al.*, (2020) and Stewart(2020).

6 See CSLS (2004) for a more detailed discussion of differences in the measurement of the non-business sector between the United States and Canada. It should be noted that an important part of the non-business sector for which there is real output growth is the imputed rents for owner-occupied housing.

Chart 5: Relative Labour Productivity Levels (GDP per Hour in the Business Sector in Canada), 1947-2022 (Canada as a per cent of the United States)



Source: Canada labour productivity data from Statistics Canada: Table 36-10-0305-01 for 1947-1960, Table 36-10-0208-01 for 1961-2021, Table 36-10-0480-01 for 2022. US labour productivity from BLS Labour Productivity and Cost Measures – Major Sectors – August 3, 2023 (XLSX sheet). 1999 benchmark of Canada's output per hour at 84.2 per cent of US output per hour from Statistics Canada (2008) "Relative Multifactor Productivity Levels in Canada and the United States: A Sectoral Analysis" Catalogue no. 15-206-X, no. 019, July, p.32.
Note: US-Canada purchasing power parity estimate based on Statistics Canada benchmark of Canadian business sector output per hour at 84.2 per cent of US business sector output per hour in 1999 (Statistics Canada, 2008).

Canadian labour productivity levels (business sector output per hour) as a proportion of labour productivity levels in the United States, using a purchasing power parity (PPP) measure based on a 1999 benchmark developed by Statistics Canada (2008).[7] We can see a narrowing of the productivity gap in the first half of the period, with Canadian productivity reaching 93.4 per cent of the U.S. level in 1984. However, the productivity gap began to widen after 1984, so that by 2007 Canadian business sector productivity had fallen to around 70 per cent of U.S. business sector productivity.

From 2007 to 2019, there was no deterioration in the gap. Rather, a small rebound began to materialize, as Canadian business sector productivity growth slightly outpaced that in the United States and pandemic-related re-allocation effects boosted Canadian productivity levels relative to the United States in 2020. However, economic disruption and further compositional shifts associated with the continuation of the pandemic quickly reversed these initial productivity gains, so that by 2021 Canadian productivity had fallen to below

7 This benchmark calculated Canadian business sector output per hour in 1999 as 84.2 per cent of United States business sector output per labour hour. Relative price indices were calculated using final or market prices in the two countries and then adjusted based on relative producer tax rates.

Table 1: Business Sector Output, Hours Worked and Annual Labour Productivity Growth Rates, United States and Canada, 2019-2022

	2019	2020	2021	2022	2019-2022
Canada					
output (2012 = 100)	117.3	109.5	115.0	119.6	-
hours worked (2012 = 100)	107.4	92.3	103.0	108.5	-
compound annual growth rate of labour productivity	0.62%	8.57%	-5.80%	-1.54%	0.21%
United States					
output (2012 = 100)	121.2	117.0	126.0	128.8	-
hours worked (2012 = 100)	112.3	103.8	109.4	113.6	-
compound annual growth rate of labour productivity	1.88%	4.42%	2.18%	-1.60%	1.64%

Sources: Canada labour productivity data from Statistics Canada: Table 36-10-0208-01 for 2019-2021, Table 36-10-0480-01 for 2022. United States labour productivity from BLS Labour Productivity and Cost Measures – Major Sectors – August 3, 2023 (XLSX sheet).

70 per cent of U.S. levels, the first time it has done so since 1947.

We now turn to an examination of the effect of the pandemic on the Canada-United States productivity gap, and in particular, the asymmetrical manner in which it affected labour productivity in the two economies, Table 1 shows the annual productivity growth rates for Canada and the United States for each year in the 2019-2022 period as well as indexes of output and hours worked. While both economies experienced a boost in aggregate productivity with the onset of the pandemic in 2020, this increase was larger in Canada where year-over-year productivity growth was 8.60 per cent compared to just 4.42 per cent in the United States. This seems to suggest that the initial re-allocation effects seen as workers in low-productivity industries worked fewer hours and left the workforce were stronger in Canada than the United States, likely owing to stricter public health measures and a more forceful pandemic response.[8]

As one might expect, this lack of a strong re-allocation-driven boost to productivity in the United States in 2020 seems to have manifested in a quicker return to normal when compared to Canada. Whereas Canada saw deeply negative productivity growth of 5.90 per cent in 2021 as these workers began to return to the workplace or increase their hours. United States productivity remained at an impressive 2.18 per cent. As these trends continued to play out, both economies saw negative productivity growth of a similar magnitude in 2022. Altogether, these asymmetric effects resulted in a reduction of Canadian business sector productivity relative to the United States, reducing the Canadian level to 69 per cent of the United States level. It is extremely challenging to decouple pandemic effects from non-pandemic related developments in productivity, and hence, readers must exercise caution in making projections for future productivity developments based on these most recent figures. Effects of both the pandemic and supply-shock driven in-

8 It is imperative to note that the re-allocation effect described here need not refer to the actual flow of workers between different industries. Rather, "re-allocation" refers to changes in the share of total economy labour input which individual industries account for. As such, asymmetric job losses, as occurred during the pandemic, are re-allocative to the extent that the input shares of the affected industries fall and, conversely, the input shares of other industries rise. In contrast, widespread job losses which affect all industries more or less the same, would have negligible or null re-allocation effects.

flation are still playing out, and so the 2019-2022 period is not a full cycle that can be easily be compared to earlier periods.

Decomposing Canada's Labour Productivity Growth by Sector

We now turn to a closer look at the performance of Canadian productivity growth by industrial sector.[9] To identify the sources of slowing productivity growth, we use a decomposition formula that breaks down aggregate productivity growth into within-sector effects and re-allocation effects (Sharpe and Thompson, 2010). The decomposition can be expressed as follows:

$$\Delta P = \sum h_i^0 \Delta P_i + \sum \left(P_i^0 - P^0 \right) \Delta h_i + \sum \left(\Delta P_i - \overline{\Delta P} \right) \Delta h_i$$

where P is the overall business sector labour productivity level, P_i is the labour productivity level in sector i, h_i is the share of total economy-wide labour hours which is employed in sector i, the subscript 0 indicates a variable in time 0 (the beginning of the period), Δ indicates change over the period, and $\overline{\Delta P}$ is the average change in business sector productivity across sectors over the period.

The first term in the decomposition captures what we call **within-sector effects**. Within-sector effects refer to aggregate productivity growth attributable to productivity growth within sectors. The latter two terms, meanwhile, capture two distinct re-allocation effects. Re-allocation effects stem from changes in the share of labour input associated with a sector. All else equal, an increase in the share of total labour input which is employed by a sector with above-average productivity will increase the aggregate labour productivity growth in the economy. Conversely, an increase in the labour input share of a sector with below-average productivity will reduce aggregate labour productivity growth in the economy.

These re-allocation effects can be further decomposed into the level effect and the growth effect: the second and third term in the decomposition equation, respectively. The **level effect** captures changes in the productivity level resulting from the movement of inputs across sectors with different productivity levels. Conversely, the **growth effect** captures changes which result from the movement across sectors which experience different degrees of productivity growth over the relevant period. It is important to note that this calculation is performed using absolute changes in labour productivity, and not rates of productivity growth. We apply this decomposition framework to the 2000-2022 period to identify what changes in Canadian labour productivity growth are due to slowdowns or losses in within-sector productivity and which changes are due to compositional changes in the Canadian economy.

Table 2 shows the results of this decomposition for aggregate business sector labour productivity growth for the post-

9 We also decomposed labour productivity growth by province and territory: the results are given in Haun (2023). In general we found that patterns in productivity growth are largely attributable to changes within provinces and territories, rather than reallocation of labour across provinces and territories.

Table 2: CSLS Decomposition by Industry, Within-Sector and Re-allocation Effects on Canadian Business Sector Labour Productivity Growth, 2000-2022

	2000-2008	2008-2019	2019-2022	2000-2022
Within-Sector Effect	0.73	1.15	0.18	0.86
Re-allocation Level Effect	0.52	-0.03	0.20	0.20
Re-allocation Growth Effect	-0.25	-0.06	-0.10	-0.13
Net Re-allocation Effect	**0.27**	**-0.09**	**0.11**	**0.07**
Summed Effects	**1.00**	**1.06**	**0.29**	**0.93**
Actual Business Sector Productivity CAGR	1.00	**1.05**	**0.23**	**0.92**
discrepancy (summed effects minus actual rate of growth)	0.00	0.01	0.05	0.01

Source: Authors' calculations based on Statistics Canada Table: 36-10-0480-01.
Note: For the underlying two-digit NAICS industry-level data on labour productivity levels and labour input for key years in the 1997-2022 period, as well as measures of productivity growth subperiods for each of the periods of interest, see Haun (2023)

Table 3: CSLS Decomposition by Industry, Contributions to Business Sector Canadian Labour Productivity Growth, 2000-2022 (percentage points per year)

	2000-2008	2008-2019	2019-2022	2000-2022
Business sector industries (actual)	**1.00**	**1.05**	**0.23**	**0.92**
Business sector industries (sum of contributions)	**1.00**	**1.06**	**0.29**	**0.93**
Agriculture, forestry, fishing and hunting	0.11	0.11	0.11	0.12
Mining and oil and gas extraction	-0.07	0.15	0.02	- 0.05
Utilities	0.03	0.01	-0.01	0.02
Construction	-0.02	0.03	-0.03	-0.01
Manufacturing	0.15	0.12	-0.05	0.13
Wholesale trade	0.21	0.14	0.04	0.15
Retail trade	0.14	0.10	0.24	0.13
Transportation and warehousing	0.08	0.01	-0.07	0.02
Information and cultural industries	0.10	0.05	-0.04	0.06
Finance and insurance	0.13	0.20	0.29	0.19
Real estate, rental and leasing	0.07	0.06	0.06	0.06
Professional, scientific and technical services	0.02	0.06	-0.34	-0.02
Holding Companies	0.01	0.04	-0.06	0.01
ASWMRS	-0.02	0.03	-0.17	-0.03
Educational services	0.00	-0.01	0.01	0.00
Health care and social assistance	0.00	-0.03	0.03	-0.01
Arts, entertainment and recreation	-0.02	0.01	-0.01	-0.01
Accommodation and food services	0.06	-0.04	0.18	0.03
Other Private Services	0.03	0.03	0.10	0.04

Source: Authors' calculations based on Statistics Canada Table: 36-10-0480-01.
Note: ASWMRS is administrative and support, waste management and remediation services.

2000 period alongside three subperiods: 2000-2008, 2008-2019 and 2019-2022, along with a breakdown of the within sector and re-allocation effects.

Across the post-2000 period, Table 2 shows that the bulk of business sector productivity growth —- 0.86 percentage points out of 0.93 percentage points— was accounted for by within-sector productivity growth. Re-allocation level effects also contribute positively to labour productivity growth; although the growth effect was negative (-0.13), it was slightly outweighed by the level effect (0.20). As a result, productivity growth was increased by 0.07 percentage points, by the net movement of labour into sectors with above-average productivity. Table 3 presents the contribution to business sector labour productivity growth by NAICS two-digit industry for each of the periods in Table 2. These contributions represent the combination of within-sector and re-allocation effects. Table 4 shows the compound annual growth

Table 4: Labour Productivity Growth Rate by Business Sector Industry, Compound Annual Growth Rate, 2000-2022

	2000-2008	2008-2019	2019-2022	2000-2022
Business sector industries	**1.00**	**1.05**	**0.23**	**0.92**
Agriculture, forestry, fishing and hunting	1.85	3.73	4.05	3.09
Mining and oil and gas extraction	-4.57	1.52	0.54	-0.87
Utilities	1.05	0.93	0.24	0.88
Construction	-0.03	0.43	-0.13	0.19
Manufacturing	1.09	0.87	-0.31	0.79
Wholesale trade	3.23	2.05	0.51	2.27
Retail trade	2.89	1.28	2.62	2.04
Transportation and warehousing	1.37	0.46	-1.59	0.51
Information and cultural industries	2.74	1.00	-2.72	1.11
Finance and insurance	1.73	2.41	2.96	2.23
Real estate, rental and leasing	0.24	0.71	2.99	0.85
Professional, scientific and technical services	0.31	0.83	-3.19	0.08
Holding Companies	2.30	2.84	-24.45	-1.58
ASWMRS	0.69	0.58	-3.87	0.00
Educational services	1.24	-0.23	2.42	0.66
Health care and social assistance	0.08	-0.44	0.83	-0.08
Arts, entertainment and recreation	-1.46	0.52	-4.34	-0.88
Accommodation and food services	0.88	0.56	-0.46	0.54
Other private services	1.41	1.03	2.57	1.38

Source: Authors' calculations based on Statistics Canada Table: 36-10-0480-01.
Note: ASWMRS is Administrative and support, waste management and remediation services.

rate for each business sector industry in each period post-2000.

From Table 3 and Table 4 we can see that growth was driven mainly by within-sector productivity gains in five key sectors: finance and insurance (contribution of 0.19 points; growth rate of 2.23 per cent), wholesale trade (0.15 points; growth rate of 2.27 per cent), retail trade (0.13 points; 2.04 per cent), manufacturing (0.13 points; 0.79 per cent), and agriculture, forestry, fishing, and hunting (0.12 points; 3.09 per cent). Apart from the manufacturing sector, these were also the sectors with the highest rates of within-sector productivity growth. The weak performance of manufacturing is notable here. Although this industry is often thought of being the key driver of productivity in the economy, partly because the greater scope for automation than in some other sectors of the economy, the average productivity growth of 0.79 per cent is actually below the business sector average of 0.92 per cent. This relatively poor performance is important because manufacturing is still an important part of the economy accounting for 1.8 per cent of total labour hours in 2022.

Between 2000 and 2008, within-sector productivity growth averaged 0.73 per cent, contributing about three-quarters of the aggregate productivity growth rate observed over the subperiod (Table 2). The reallocation level effect in this case was considerable, with a contribution equal to 0.52 points, The reallocation growth effect (-0.25 points) was smaller and negative, leading to a net re-allocation effect of 0.27 points. Much of this was driven by labour moving to the mining, oil and gas extraction industry which has high productivity levels but low productivity growth.

Looking at individual sectors, we see that productivity growth in 2000-2008 was driven by six key sectors: were wholesale trade (0.21 points; annual growth rate of 3.23 per cent), manufacturing (0.15 points; 1.09 per cent), retail trade (0.14 points;

2.89 per cent), and finance and insurance (0.13 points; 1.73 per cent), agriculture, forestry, fishing and hunting (0.11 points; 1.85 per cent), and information and cultural industries (0.10 points, 2.74 per cent). Altogether, these contributions overwhelmingly reflected within-sector productivity growth.

The 2008-2019 subperiod was different from the preceding subperiod; within-sector productivity exceeded the aggregate rate of business sector productivity growth, as business sector productivity growth averaged 1.05 per cent annually, while annual within-sector growth averaged 1.15 per cent. This dynamic arises because both re-allocation effects were negative, indicating that, on net, labour moved towards sectors with below-average productivity levels (level effect of -0.03 points) and below-average productivity growth (growth effect of -0.09 points). Still, these re-allocation effects were small in magnitude. Six sectors in particular drove productivity growth over the subperiod, contributing about 77 per cent of the business sector growth rate. These sectors were: finance and insurance (0.20 points; growth rate of 2.41 per cent), mining and oil and gas exploration (0.15 points; 1.52 per cent), wholesale trade (0.14 points; 2.05 per cent), manufacturing (0.12 points; 0.87 per cent), agriculture forestry, fishing, and hunting (0.11 points; 3.73 per cent) and retail trade (0.10 points; 1.28 per cent). Contributions from these industries almost exclusively reflected within-sector productivity growth. In general, re-allocation effects were extremely small across all industries in this subperiod.

Comparing the sectors that drove growth in the 2008-2019 period with the 2000-2008 period, we see that five industries made significant contributions in both periods—manufacturing, wholesale trade, retail trade, finance and insurance, and agriculture, forestry, fishing and hunting. Mining, oil and gas contributed negatively in the first period, as its productivity growth was negative, but contributed strongly to productivity growth in the second period. Information and cultural industries, on the other hand, contributed strongly to growth in the first period but not the second, as productivity growth in this sector fell significantly.

The dramatic fall in labour productivity in the mining, oil and gas sector in the 2000-2008 period (productivity fell by 4.57 per cent annually, on average) was a result of a significant expansion in the industry, as high resource prices encouraged the exploitation of lower quality resources. Thus while the sector's share of total labour hours in the economy rose from 1.4 per cent in 2000 to 2.1 per cent in 2008, its productivity fell from \$356 per hour to \$245 per hour over the same period (See the Data tables in Haun, 2023). However, this massive expansion did not continue in the 2008-2019 period—its share of labour hours in the economy remained largely constant—and so productivity growth was positive, 1.52 per cent, on average, allowing the sector to make a significant contribution to productivity growth, instead of being a drag on growth.

As Table 2 above shows, the 2019-2022 period saw a substantial fall in the rate of business sector productivity growth, down from 1.05 per cent annually over 2008-2019 to just 0.23 per cent annually. Within-sector productivity growth was very low over the period, with an average growth rate across the business sector of just 0.18 per cent annually. Labour input shifted towards industries with above-average levels of labour productivity, adding an additional 0.20 points to business sector productivity growth. However, because these industries also tended to have lower productivity growth, a negative reallocation growth effect (-0.10 points) offset about half of this increase.

The most substantial positive industry contributions stemmed from finance and insurance (0.29 points; growth rate of 2.96 per cent), retail trade (0.24 points; 2.62 per cent), accommodation and food services (0.18 points; -0.46 per cent), agriculture, forestry, hunting and fishing (0.11 points, 4.05 per cent) and other private services (0.10, 2.57 per cent). Retail trade, accommodation and food services and other private services, which have significantly lower productivity levels than the economy-wide average, generated significant positive reallocation effects, as their share of labour hours fell owing to the COVID-19 pandemic lockdowns. Indeed, even though accommodation and food services saw negative productivity growth, the fact that so much labour flowed out of this sector, and because its productivity are so low (in 2019 its productivity levels were $22 per hour compared to the business sector average of $57 per hour) meant that it nonetheless made a significant contribution to overall productivity growth in the economy.

Two industries exerted a significant drag on productivity growth during the 2019-2022 period: professional, scientific and technical services (-0.34 points; growth rate of -4.02), and administrative and support, waste management and remediation services (-0.17 points; -3.87). In both cases within industry productivity growth was strongly negative, and there was also a negative reallocation effect as the share of hours in these industries rose. This reallocation effect came both from a level effect, as both these industries have below average productivity levels, and a growth effect, given the aforementioned declines in productivity growth.

Of the other industries which had contributed significantly to Canada's productivity growth over the 2000-2019 period, manufacturing productivity fell slightly (-0.31 per cent), wholesale trade saw only a slight productivity increase (0.51 per cent), and mining, oil and gas saw a productivity increase (0.54 per cent) that was mostly offset by a slight decline in hours worked in the sector. As a result, each of these three industries contributed little to productivity growth.

Given that, as mentioned above, 2019-2022 does not represent a whole business cycle, it remains to be seen whether these patterns of productivity growth by industry will persist. For finance and insurance, and retail trade, which had above average productivity growth over the 2008-2019 period, it seems likely that the pandemic has accelerated existing shifts to e-banking and e-commerce, allowing companies in these areas to shed or re-allocate employees in low-productivity positions, particularly in brick-and-mortar operations. For accommodation and food, which has less opportunity for using technology to increase output and shed labour, and which saw its productivity fall during the pandemic, it is likely that it will once again be a drag on overall productivity growth as labour flows back to this low productivity sector with increased demand for in-person activities such as restaurant meals.

Sources of Canadian Labour Productivity Growth: A Growth Accounting Perspective

Another way of understanding labour productivity growth is to look at the underlying drivers of productivity using a growth accounting framework. Table 5 below presents Statistics Canada growth accounting estimates for business sector Canadian labour productivity growth from 1961 to 2021. 2022 data were not available at the time of writing, which limits our ability to make conclusions about the post-2019 period. Contributions to labour productivity growth are calculated for three sources of growth. The first is multifactor productivity (MFP also referred to as total factor productivity), which is the part of an increase in output which remains after accounting for changes in capital and labour input. MFP is usually thought of as depending on the pace of underlying technological progress, as well as economies of scale, changes in organizational structure, improvements in infrastructure and institutions, and spillover and network effects (OECD, 2023).

The second is capital intensity, the increased productivity which arises as each unit of labour becomes equipped with more capital. The third source of growth is changes in the quality of labour input. In the case of the latter two sources, the contribution is calculated as the growth rate of the component weighted by the share of income which accrues to the relevant factor of production (capital or labour) and is expressed in percentage points.

Panel A of Table 5 provides the estimated contributions to labour productivity growth in absolute terms, while Panel B expresses contributions in relative terms, as a proportion of the total labour productivity growth rate.[10] Panel C, furthermore, provides compound annual growth rates for the variables underlying the contributions, namely labour quality, capital input, and labour input in the form of hours worked. Finally, Panel D shows the share of input costs associated with capital and labour inputs, respectively.

As Table 5 shows, prior to 2000 productivity growth was strong in Canada, business sector labour productivity grew on average at 2.85 per cent over the 1961-1981 period and 1.72 per cent over the 1981-2000 period. Roughly half of this growth was attributable to capital intensity, with ICT capital intensity more important than non-ICT capital intensity after 1981. Multifactor productivity contributed a quarter (26.6 per cent) of productivity growth in the 1961-81 period and a third (34.4 per cent) in the 1981-2000 period. Labour quality contributed about a fifth of growth

10 The sources of growth decomposition performed here using official Statistics Canada data is not perfectly additive. As such, the relative contributions in Panel B, which are calculated using the contributions and the observed rates of labour productivity growth presented for each period in Panel A, do not add to 100 per cent. Still, the discrepancy is small.

Table 5: Sources of Canadian Business Sector Labour Productivity Growth, 1961-2021

Panel A: Absolute Contributions (percentage points)

	1961-1981	1981-2000	2000-2019	2000-2008	2008-2019	2019-2021
Labour Productivity Growth	2.85	1.72	0.96	0.86	1.03	1.09
Multifactor Productivity	0.97	0.46	-0.09	-0.54	0.24	-0.71
Capital Intensity	1.33	0.87	0.79	1.13	0.54	1.29
ICT Capital Intensity	0.18	0.56	0.22	0.43	0.07	0.14
Non-ICT Capital Intensity	1.20	0.35	0.56	0.70	0.48	1.15
Labour Quality	0.53	0.38	0.26	0.28	0.25	0.52
Total Contributions	2.82	1.71	0.96	0.87	1.03	1.10

Panel B: Relative Contributions (%)

	1961-1981	1981-2000	2000-2019	2000-2008	2008-2019	2019-2021
Labour Productivity Growth	100.0	100.0	100.0	100.0	100.0	100.0
Multifactor Productivity	34.0	26.6	-9.2	-63.3	23.7	-65.4
Capital Intensity	46.6	50.6	82.1	131.5	52.2	117.9
ICT Capital Intensity	6.2	32.4	22.4	49.5	6.8	12.6
Non-ICT Capital Intensity	42.3	20.3	58.8	81.0	46.3	105.4
Labour Quality	18.5	22.3	27.0	32.3	23.8	48.0
Total Contributions	99.1	99.5	99.9	100.5	99.7	100.6

Panel C: Compound Annual Growth Rates for Sources of Growth, Factor Costs, and Hours Worked

	1961-1981	1981-2000	2000-2019	2000-2008	2008-2019	2019-2021
Labour Quality	0.85	0.63	0.44	0.48	0.42	0.90
Capital Input	5.68	3.73	2.89	3.96	2.12	1.04
ICT Capital Input	8.17	13.51	5.18	9.23	2.33	1.15
Non-ICT Capital Input	5.46	2.43	2.54	3.15	2.09	1.03
Hours Worked	2.03	1.42	0.97	1.22	0.79	-2.06

Panel D: Labour and Capital Share of Input Costs

	1961-1981	1981-2000	2000-2019	2000-2008	2008-2019	2019-2021
Labour Share of Costs	62.0	60.5	58.9	58.7	58.8	58.5
Capital Share of Costs	38.0	39.5	41.1	41.3	41.2	41.5
ICT Capital Share	2.9	4.6	5.1	5.3	4.6	4.3
Non-ICT Capital Share	35.1	34.9	36.0	36.0	36.6	37.2

Source: Authors' calculations based on Statistics Canada Table 36-10-0208-01
Note: Contributions from growth in multifactor productivity, capital intensity, and labour quality are official Statistics Canada estimates. Contributions from growth in ICT and non-ICT capital intensity are calculated using Statistics Canada data on hours worked and ICT/non-ICT capital inputs and costs for each period. Labour and capital cost shares are calculated by taking the arithmetic average of the share of costs for labour and capital at the start and end of each period.

in both periods.

As we have seen, average productivity growth was significantly lower in the 2000-2019 period: only 0.96 per cent, a decline of 0.76 percentage points from the 1981-2000 period. This decline is largely driven by a collapse in MFP growth, which fell from 0.46 per cent in 1981-2000 to -0.09 per cent in 2000-2019. The contribution of capital intensity fell only marginally (from 0.87 percentage points to 0.79 percentage points), as did that of labour quality (0.38 percentage points to 0.26 percentage points). Part of the decline in MFP is driven by the boom in the resource sector: as noted above, high commodity prices incent companies to develop lower quality and harder to exploit resources.

However, these averages for the 2000-2019 period mask considerable variation if we break the period down in to its two component business cycles. In the 2000-2008 period MFP growth is strongly negative (-0.54 per cent on average); however, the contribution of capital intensity grew quite fast (1.13 percentage points on average) due to strong growth in both ICT capital (which grew 9.23 per cent on average, contributing 0.43 percentage points to productivity growth) and non-ICT capital (3.15 per cent growth, contributing 0.70 percentage points). These fast growth rates in capital input were driven by the rapid adoption of ICT early in the 2000s, and the rise in commodity prices that incented investment in the resource sector.

The 2008-2019 period looks very different. MFP grew, albeit it at a historically low average rate of 0.24 per cent; however, the growth of capital slowed significantly, so that capital intensity contributed an average of only 0.54 percentage points, higher than that of MFP, but only around half of the 2000-2008 period. This slowing in capital input growth was greatest in the ICT sector, where growth declined dramatically to only 2.33 per cent; growth in non-ICT capital also slowed to 2.09 per cent. Part of the latter slowdown can be attributed to weaker commodity prices, especially after 2015, which reduced investment in the resource sector. The deep recession of 2008-2009 in the wake of the financial crisis will also have likely played a role in discouraging investment during this period.

Explaining the decline in multifactor productivity growth post-2000 is challenging, given that multifactor productivity is essentially a residual: the part of growth that we can not explain through changes in capital intensity and labour quality. Changes in the growth of this measure are often attributed to changes in the adoption of new technologies, which is in turn linked to the underlying rate of scientific discovery. The fact that, as we have seen, productivity growth has declined across almost all OECD countries post-2000[11] suggests a common explanation. One possibility might be a slowing of the rate of technological change due to a slowing of the underlying rate of scientific discovery;[12] another is a general slowdown in the rate of adoption of new technologies. This is not to say that there would not be room for Canada to improve its adoption of new technologies—Canada's low levels of labour productivity relative to other countries suggests considerable room for improvement—but simply that the decline relative to 2000 may not be the result of factors specific to Canada.

Conclusions

In this article we have examined Canada's post-2000 productivity slowdown, and its 2020-2022 pandemic experience, from three different standpoints. The first was a comparison with other OECD countries, particularly the United States. The second was a decomposition by industry sector. The third was to use growth

11 While it is true that the United States, generally at the forefront of scientific innovation in many sectors, has not seen much of a decline in productivity growth in 2000-2022 compared to 1981-2000, this is because of very strong productivity growth in the United States in the early 2000s. Subsequent to 2008 there was a significant decline in business sector productivity growth, as Panel B of Chart 4 makes clear.

12 This explanation is supported by a recent paper by Park *et al.* (2023) in the prestigious scientific journal *Nature*, in which the authors find that "papers and patents are increasingly less likely to break with the past in ways that push science and technology in new directions."

accounting to look at the contributions of factors of production.

We found that:

- Canada's post-2000 productivity growth has been similar to peer OECD countries; however, Canada's productivity levels are below almost all these countries.
- While Canada's productivity growth did not slow down as much after 2000 as it did in most other OECD countries, this was because pre-2000 growth was already relatively weak.
- While Canada's productivity growth was faster than that of the United States up until the early 1980s, it has generally been lower since then, so that by 2022 business sector labour productivity was less than 70 per cent of U.S. levels, lower than in any year since 1947.
- While productivity rose significantly in Canada in the first year of the pandemic, these gains have largely been eliminated; on the other hand, the United States has managed to retain most of its pandemic-era productivity increases.
- Productivity growth over the entire 2000-2022 period has largely been driven by growth within industries, rather than reallocation of resources across sectors.
- Key sectors driving growth were finance and insurance, retail and wholesale trade, manufacturing, and agriculture.
- Productivity growth in mining and oil and gas as well as flows of resources in and out of the sector were important for explaining trends in subperiods but did not explain much of productivity growth over the whole 2000-2022 period.
- The productivity slowdown since 2019 was largely a result of reductions in productivity within sectors such as manufacturing, professional scientific and technical services, and wholesale trade; these reductions offset productivity gains coming from sectors such as accommodation and food and retail trade.
- From a growth accounting perspective, most of the post-2000 slowdown in productivity growth can be explained by a collapse in multifactor productivity growth. However, breaking this period down into subperiods, we see a very significant slowdown in capital growth over 2008-2019 period, following a very significant boom in capital investment in the 2000-2008 period. In contrast, MFP Growth picked up a little over 2008-2019, although it remains weak.

In sum then, Canada's productivity growth since 2000 has been disappointing compared to previous decades, and while growth has been similar to many other OECD countries, it has been significantly lower than the United States, despite the close economic ties between the two countries. Furthermore, Canada's productivity level is lower than almost all its advanced country peers. The problem does not seem to be concentrated in one or two sectors, nor is it that labour is moving to sectors with lower productivity levels or growth rates. Rather, it is weak multifactor productivity growth that seems to be playing the biggest role in explaining the post-2000 slowdown, with declining capital intensity, especially in ICT, playing a key role in the last complete business cycle, 2008-2019.

Disappointing though productivity growth has been in Canada, the question for the Canadian economy at the current moment, given that productivity has barely increased since 2019, is less whether it can attain 1.74 per cent—the level it enjoyed from 1981-2000, and close to the U.S. average since 2000—but whether it can even attain the roughly 1 per cent rate of annual productivity growth it enjoyed over the 2000-2019 period. While the United States seems to have hung on to some of the productivity gains that occurred during the pandemic, this has not been the case in Canada.

A return to even 1 per cent productivity growth will depend on the performance of the main drivers of growth. For capital inputs recent trends are not favourable: there has been a significant slowdown in both ICT and non-ICT investment in recent years, partly driven by lower resource prices. Looking forward, higher resource prices could change this picture; however, the commodity prices boom in the early 2000s was driven by industrialisation in developing countries, particularly China, on a scale that does not seem likely to be repeated in the near term. Furthermore, the resource sector, and the broader economy, are facing stricter environmental rules and regulations, which is likely to further reduce the pace of investment.

Another potential headwind to restoring pre-pandemic productivity growth is the historically high levels of immigration that Canada is currently experiencing in recent years. According to Statistics Canada's Labour Force Survey the foreign-born share of Canada's total employment increased by around 4 percentage points between 2017 and 2022, and based on recent trends this pace seems likely to accelerate. To the extent that immigrants, especially recent immigrants, have lower productivity than the Canadian-born, this trend could put downward pressure on the growth of labour quality going forward, which in turn would put downward pressure on productivity growth.

What about MFP growth? As discussed above, there does seem to be evidence for a decline in productivity growth across advanced countries that might be consistent with a fall in the rate of technological progress or with a decline in the rate of adoption of new technologies. This situation might change if technologies such as artificial intelligence are sufficiently productivity-enhancing; however, they would need to be introduced at a scale across the economy to make a meaningful impact on overall productivity growth.

One reason for optimism about the prospects for stronger MFP growth in Canada is, somewhat paradoxically, its comparatively low levels of productivity compared to peer countries, which would seem to indicate that there should be considerable room for Canada to increase productivity by advancing towards the technological frontier. In principle, an open economy like Canada, with high levels of foreign direct investment, and with very close geographic, cultural and economic links to the relatively advanced U.S. economy, should find it relatively easier to import new innovations than many other countries. In practice though, as we have seen, Canada's productivity levels have not been catching up to other countries' levels over many decades, and Canada's historically weak investment in R&D also does not bode well for MFP growth. Overall then, the outlook for Canadian productivity growth does not seem particularly favourable, and rather than reverting to the higher growth rates in the past, it may be that productivity growth will remain low for some time.

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The Post-2001 Productivity Growth Divergence between Canada and the United States

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Abstract

The high degree of integration between the Canadian and the U.S. economies promotes sharing of technologies and innovation spillovers that are conducive to long-term productivity growth convergence. However, since 2001 labour productivity growth rates have diverged in sharp contrast to the previous four decades. A comparison of labour productivity growth decomposed into contributions by industry for both countries reveals that the information and cultural services industry has played an outsized role in the divergence, the start of which coincides with the dot-com recession of the early 2000s. Limits on foreign investment, most notably but not exclusively related to telecommunications, and strong output price growth relative to the United States are key factors for undertaking a simple counterfactual analysis to evaluate the role of competitive intensity in the information and cultural services industry. Estimates of markups and their impact on labour productivity growth suggest that limited competition has significantly reduced the productivity performance of that industry as well as the performances of others that are dependent on its services as intermediate inputs.

The economies of Canada and the United States have been intertwined throughout their history. The two countries' economic bond intensified as relations with their predominantly European roots diminished during the twentieth century and Canada-United States trade grew to be the largest merchandise trading relationship in the world[2] worth over CDN $963 billion in 2022, or about $3.4 bil-

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2 IMF Direction of Trade (DOT) Statistics was accessed Aug. 4, 2023. In 2022, Canada-United States total trade (imports plus exports) was USD 794 billion (imports from Canada = USD 438 billion and exports to Canada = USD 356 billion) compared to China-United States total imports and exports which was USD 691 billion (imports from China = USD 154 billion and exports to China = USD 154 billion).

3 Statistics Canada Table: 12-10-0119-01.

lion each day, representing nearly two thirds of Canada's total global merchandise trade.[3] Beyond sheer volume, this relationship has fostered intricate bi-national supply chains supported by elaborate telecommunications, transportation and energy infrastructure networks.

Despite their strong economic ties, the two economies have experienced episodes of economic divergence. Such episodes, however, tend to be brief. For example, as the 2009 global recession gained momentum and the U.S. economy slowed for several months before Canada's eventually followed suit. Substantive shifts in global commodity price cycles, migration patterns in labour markets, financial system shocks and other factors often lead to periods of divergence in broad-based indicators of economic performance, but they are typically brief enough to be measured in months rather than years. Divergence may be sustained for longer periods in specific markets, such as housing, which are more insulated from international trade cycles. Policies or regulations, related to immigration or agricultural production, for example, may also create sustained wedges between the two countries when they affect specific regions or industries. Nevertheless, broad indicators of national economic health, like real GDP and employment, typically show that the economic fortunes of Canada and the United States move in tandem over the long term.[4]

Yet, one fundamental measure of economic performance stands out as an exception: labour productivity growth. From 1961 to 2001, both nations experienced nearly identical annual business sector labour productivity annual growth rates of 2.3 per cent. However, the countries' labour productivity did not move in lock step with each other over that time. Business sector labour productivity growth rates in Canada were higher than in the United States from the mid-1970s to the mid-1980s. Then, starting from the mid-1980s, U.S. labour productivity growth exceeded Canada's growth until the early 1990s. The difference in the countries' average annual growth disappear over the remainder of the 1990s. While the labour productivity growth gap favouring the United States from the mid-1980s to the early 1990s was substantial enough to merit concerns that Canada's living standards were improving at a pace below its potential, its persistence was small compared to the labour productivity growth gap that appeared after the turn of the century. From 2001 to 2021, the United States observed a moderate deceleration in labour productivity growth to 2.0 per cent,

4 Using OECD data, the Pearson correlation coefficients for real GDP, employment, hours worked and real GDP per capita annual growth rates from 1970 to 2000 suggest that Canada's economy is more positively correlated with the U.S. economy than any other G7 economy on average. However, from 2001 to 2019, the United States became the second or third most correlated with Canada, with marginal differences between the top three, for the same variables. On the other hand, The United States had the second most highly correlated labour productivity growth with Canada in the pre-2001 period, nearly tied with Germany for the most correlated. In the post-2001 period (2001-2019), Canada had the lowest correlation coefficient with the United States for labour productivity growth, which was also the only coefficient that was negative. Source: OECD Dataset: Growth in GDP per capita, productivity and ULC. Note that the OECD data are for the total economy, which includes business and non-business sectors.

5 Growth rates are expressed as compound annual growth rates.

while Canada's growth rate, fell to 0.9 per cent.[5] This enduring divergence, both in magnitude and persistence, poses an intriguing question: What factors after 2001 have driven this significant and sustained gap between two otherwise closely aligned economies?

Krugman (1994) contended that while it was interesting to compare countries' economic performances, lagging productivity was not an indication of a country's failure to compete. He asserted, for example, that there was no empirical basis to claim Japanese productivity growth diminished productivity growth or living standards in the United States.[6] This argument, taken at face value, implies that Canada's lagging productivity performance could be regarded as unimportant. However, that conclusion overlooks what one might expect with two heavily integrated economies. High levels of trade and investment flows, complemented by well-established supply chains and policy coordination, facilitate technology spillovers and shared learning experiences, should push the two countries' economic performances to converge over time. In sharp contrast, Chart 1 suggests that the widening labour productivity growth gap remains on track to continue its two-decade-long trend.[7]

In addition to its longevity and severity, this economic phenomenon is also distinct because of its clear delineation with the previous four decades of productivity growth. The year 2001 is a distinct pivot point that implores the question, what changed at or near that point in time to cause such a distinct break from the past?[8] The growing gap in Canada-United States labour productivity growth since 2001 has been the subject of numerous studies examining the divergence from various perspectives.

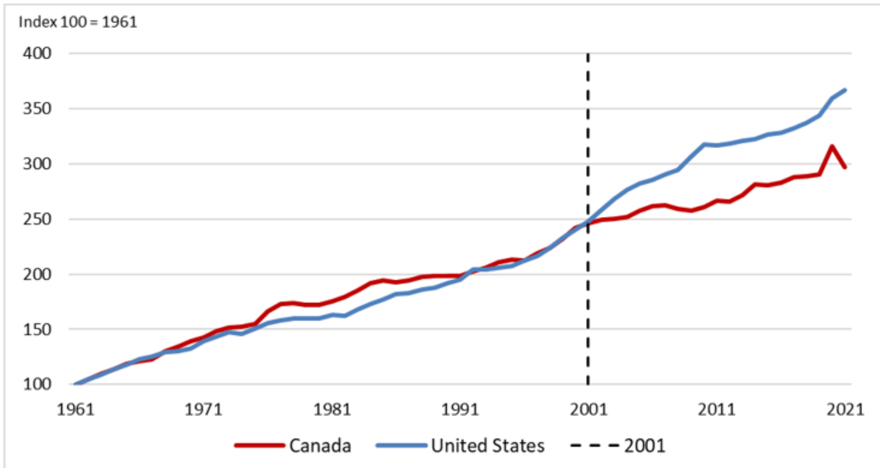
For example, Almon and Tang (2011) focus on the post-2000 output and productivity growth slowdown, attributing differences between the two countries to industrial structural changes, suggesting that shifts in industrial sectors have distinctly impacted productivity. Li *et al.* (2013) emphasize the role of differing methodologies in estimating multifactor productivity growth, highlighting that the variations in approach between Canada and the United States that may lead to contrasting interpretations of productivity trends. Gu and Willox (2018) delve into recent industry trends and potential explanations for the divergence in productivity growth, exploring factors such as technological advancements and labour market dynamics. Lastly, Tang and Wang (2020) expand the scope to include a comparison of industry productivity performance in G7 countries, offering a broader context for understanding Canada's productivity in relation to both the United States and other major

6 Dunn (1994) disputes Krugman's point, arguing that countries compete economically because they compete politically to gain power and influence, which in turn, influences countries' economic policy objectives.

7 Deviations from the longer-term trend in the productivity divergence were attributed to stronger demand in Canada relative to the United States from 2010 to 2014 in Gu and Willox (2018).

8 Structural breakpoint tests following Bai-Perron (2003) identify 2001 or 2002 as the breakpoint that signals the start of the divergence in Canada-U.S. productivity growth rate. Results are available from the authors upon request.

Chart 1: Canada and United States Business Sector Labour Productivity Growth, 1961-2021



Sources: Authors' calculations using Statistics Canada and Bureau of Labor Statistics data.
Note: Labour productivity is measured as real value added per hour worked.

economies.

In contrast to these studies, this article describes how a decline in competitive intensity that is exacerbated by a lack of international competition in a single industry (information and cultural services industry) can limit investment, innovation and technical change that negatively impact other industries.

The remainder of this article is organized as follows. Section 1 describes the data sources, Section 2 discusses the sources of labour productivity growth for the Canadian and U.S. business sectors. Section 3 illustrates which industries make the largest contributions to business sector labour productivity growth. The focus is primarily on how the information and cultural services industry stands out from other industries since 2001. Sections 4 and 5 review international indicators that affect competitive intensity and how trade liberalization influences productivity growth. A counterfactual method to evaluate what productivity growth in Canada would have looked had output price growth for the information and cultural services industry been as low as they were in the United States from 2001 to 2019 is presented in Section 6. Section 7 presents results of the analysis, which is followed by concluding remarks in Section 8.

Data Sources

Productivity measures in Canada and the United States follow the framework established by Jorgenson (1966), Diewert (1976), Jorgenson *et al.* (1987), Jorgenson *et al.* (2005), Schreyer (2001) and Oulton (2023). 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.

At both the industry and aggregate level, total factor productivity (TFP) 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 TFP is often associated with technological change, organizational change, or economies of scale. National productivity data sets consistent with the system of national accounts framework are often referred to as KLEMS, representing the five factor inputs to production, capital, labour, energy, material, and business services, where capital and labour are considered primary inputs and the remaining three are called intermediate inputs.

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 uses 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 post-reference years after 2019 (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 Accounts Division at Statistics Canada.

Hours worked represents the total number of hours that a person devotes to work, whether paid or unpaid. 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. Note that labour input differs from hours worked since labour input incorporates changes in labour composition as well as hours worked. Labour composition accounts for the effects of changes in age (as proxy for experience), education, and class of workers (paid versus self-employed and unpaid family workers), (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; and Gu, 2018).

United States Data

Productivity data for the business sector and individual industries in the United States is from the U.S. Bureau of Labor Statistics (BLS) and the Bureau of Economic Analysis (BEA). Output for the business sector is real 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 TFP and related variables for the private business sector and the BLS and BEA jointly produce the BEA-BLS Integrated Industry-Level Production Accounts (KLEMS), which provide the industry detail used in this analysis. Historical private business sector data are available from 1948 to 2021. The industry-level data from the integrated KLEMS database are available from 1987 to 2020. For this article, the focus is on the productivity performance of the Canadian business sector relative to the U.S. private business sector. The methods for constructing TFP in the U.S. private business sector are documented in Fleck *et al.* (2014) and Garner *et al.* (2021).

The comparability of Canadian and U.S. data is an important concern since different data collection and estimation methods may cause the labour productivity growth gap to be over or underestimated. Issues of data comparability are described in Li *et al.* (2013) though their overall conclusion is that TFP growth estimates for both countries are robust to alternative methodologies and assumptions. Since then, data comparability between the two countries has generally improved particularly with respect to measurement of capital input as noted in Gu and Willox (2018). [9]

Canada-United States Labour Productivity Growth Decompositions

Table 1 shows a decomposition of labour productivity growth into contributions from capital intensity,[10] labour composition and TFP for Canada and the United States. Capital intensity is further decomposed into contributions from information and communications (ICT) capital inputs and non-ICT capital inputs.[11] Canada experienced a discernible slowdown in labour productivity growth, with rates declining from 1.71 per cent per year during 1987-2001 to 0.92 per cent in 2001-2019, a reduction of 0.79 percentage points. Concurrently, the United States saw a more moderate decrease of 0.32 percentage points, from 2.17 per cent to 1.84 per cent over the same periods. The comparative decline in Canada is significantly attributed to a sharp drop in ICT capital intensity, which fell from 0.63 percentage point to 0.20 percentage point, a 0.42 percentage point reduction, while the United States experienced a lesser decline of 0.21 percentage points.

Additionally, Canada's TFP growth shifted from a positive 0.32 per cent growth during 1987-2001 to a negative 0.09 per cent in the subsequent period, marking a 0.41 percentage point decrease. In contrast, the United States maintained positive growth, albeit at a reduced rate, dropping by just 0.09 percentage points from 0.87 per cent to 0.78 per cent. Labour composition in Canada also diminished, contributing 0.25 per cent to productivity growth, down from 0.40 per cent (a 0.15 percentage point reduction), while the United States experienced a slight 0.05 percentage point reduction.

The 0.92 percentage point difference

9 More detailed descriptions of how each country's statistical systems have tended to converge are available in Baldwin *et al.* (2014), Gu (2018), Statistics Canada (2019), Garner *et al.* (2021) and Garner *et al.* (2018a and 2018b).

10 The terms capital intensity and capital deepening are regarded are interchangeable.

11 ICT capital inputs include computer hardware, telecommunications equipment, and computer software and databases.

Table 1: Contributions to Business Sector Labour Productivity Growth in Canada and United States

		1987-2001	2001-2019	2001-2019 less 1987-2001
		Percentage point, compound annual growth rates		
Canada	Labour productivity	1.71	0.92	-0.79
	Capital intensity	0.98	0.76	-0.22
	ICT capital intensity	0.63	0.20	-0.42
	Non-ICT capital intensity	0.35	0.56	0.21
	Labour composition	0.40	0.25	-0.16
	Total factor productivity	0.32	-0.09	-0.41
United States	Labour productivity	2.17	1.84	-0.32
	Capital intensity	1.00	0.82	-0.18
	ICT capital intensity	0.51	0.30	-0.21
	Non-ICT capital intensity	0.49	0.52	0.03
	Labour composition	0.30	0.25	-0.05
	Total factor productivity	0.87	0.78	-0.09
Canada minus the United States	Labour productivity	-0.46	-0.92	-0.46
	Capital intensity	-0.02	-0.06	-0.04
	ICT capital intensity	0.11	-0.10	-0.21
	Non-ICT capital intensity	-0.13	0.04	0.18
	Labour composition	0.10	0.00	-0.10
	Total factor productivity	-0.55	-0.87	-0.32

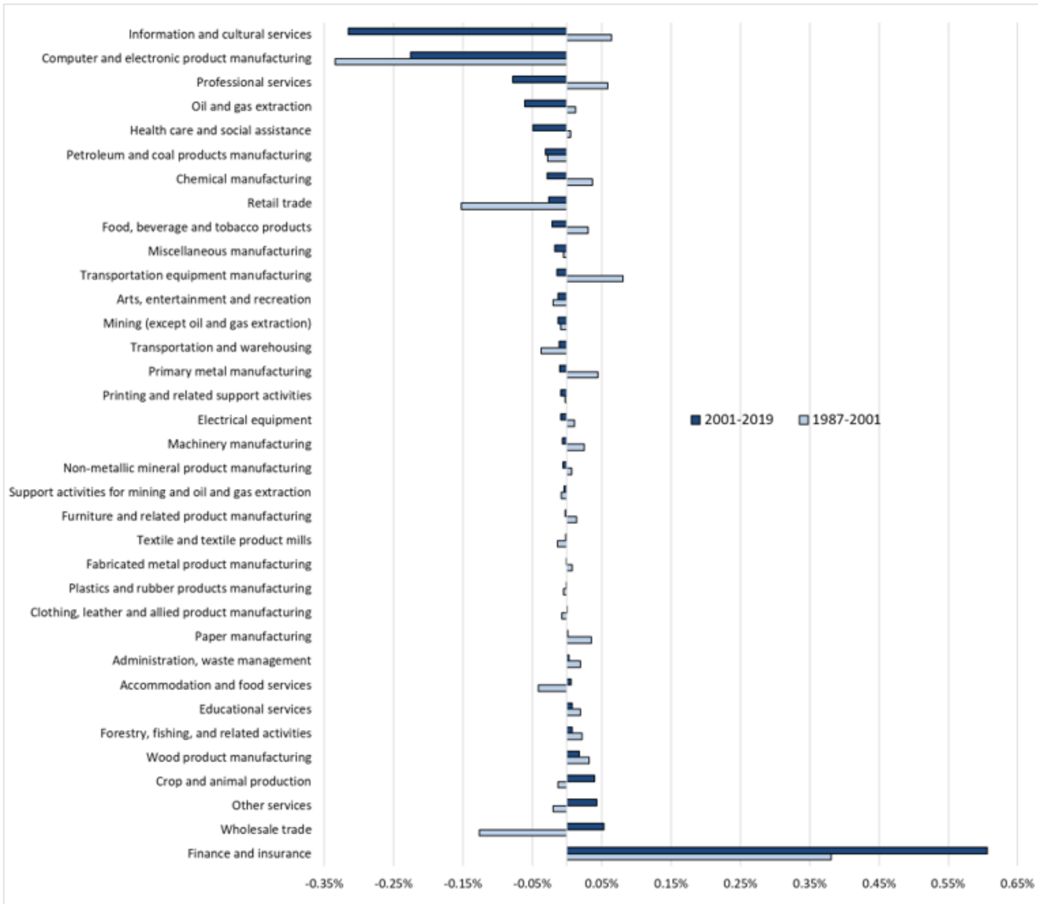
Sources: Statistics Canada, the Bureau of Economic Analysis, the Bureau of Labor Statistics, and authors' calculations.
Note: Percentage point changes represent compound annual growth rates.

in labour productivity growth between Canada and the United States for the period 2001 to 2019 was almost exclusively due to the relatively lower contributions from TFP growth in Canada and, to a lesser extent, lower capital intensity from the ICT capital. The relatively lower TFP growth in Canada accounted for 0.87 percentage points of the 0.92 percentage point difference in labour productivity growth. The relatively lower contribution of ICT capital intensity accounted for 0.10 percentage points of the difference. There was little difference in the productivity effect of labour compositional shifts towards more skilled workers in the two countries. The higher contribution from non-ICT capital intensity can be attributed to relative higher investment in engineering and building construction in Canada

For an industry perspective on the sources of the productivity divergence, detailed tables for individual industries showing annual changes in labour productivity growth for Canada and the United States over the two periods are provided in Appendix B. Additional tables in Appendix B also show each industry's contribution to business sector productivity growth. Canada's labour productivity growth gap with the United States expanded from 0.46 to 0.92 percentage points from the 1987-2001 period to the 2001 to 2019 period, an exact doubling of Canada's gap with the United States. The contributions by industry to the difference in business sector labour productivity growth between Canada and the United States for both periods are presented in Chart 2.

Several features stand out in Chart 2. First, the industries are ordered to show the industries with the largest contribution to the labour productivity growth gap after 2001 at the top. Therefore, the information and cultural services industry and computer and electronic products manu-

Chart 2: Contributions by Industry to the Pre-and Post-2001 Canada-U.S. Business Sector Labour Productivity Growth Gaps



Sources: Appendix tables 1 and 3 based on Statistics Canada, the Bureau of Economic Analysis, the Bureau of Labor Statistics, and based on authors' calculations in Appendix Tables 1 and 3.
Note: Percentage point changes represent compound annual growth rates.

facturing, with the most pronounced negative values appear in dark blue bars at the top. Those two industries contributed 0.60 percentage points of the 0.92 percentage point difference in business sector labour productivity growth between Canada and the United States (0.45 percentage points from the information and cultural services industry and 0.15 percentage points from computer and electronic products manufacturing). This comparison should be taken with a grain of salt since the sum of the industry contributions do not equal the change of 0.92 for the business sector because compound annual growth rates are not strictly additive since they are derived using a nonlinear formula. In addition, compositional or reallocation effects that represent changes in the relative sizes on industries change over time. Compositional effects for the financial and insurance industries were particularly pronounced and asymmetric across countries during the global financial crisis. This helps to account for the second outstanding feature of Chart 2, the relatively strong performance of Canada's finance and insurance industry.

Table 2: Contributions to Labour Productivity Growth, Information and Cultural Services Industry in Canada and United States

		1987-2001	2001-2019	2001-2019 less 1987-2001
		Percentage point, compound annual growth rates		
Canada	Labour productivity	2.50	1.52	-0.98
	Capital intensity	2.44	0.83	-1.61
	ICT capital intensity	2.15	0.48	-1.68
	Non-ICT capital intensity	0.28	0.35	0.07
	Labour composition	0.15	0.16	0.01
	Total factor productivity	-0.10	0.52	0.61
United States	Labour productivity	1.42	7.79	6.37
	Capital intensity	2.07	4.49	2.42
	ICT capital intensity	2.19	3.06	0.87
	Non-ICT capital intensity	-0.11	1.39	1.50
	Labour composition	0.17	0.49	0.32
	Total factor productivity	-0.83	2.81	3.64
Canada minus the United States	Labour productivity	1.08	-6.27	-7.35
	Capital intensity	0.37	-3.66	-4.03
	ICT capital intensity	-0.04	-2.58	-2.55
	Non-ICT capital intensity	0.39	-1.04	-1.43
	Labour composition	-0.02	-0.32	-0.30
	Total factor productivity	0.74	-2.29	-3.03

Sources: Statistics Canada, the Bureau of Economic Analysis, the Bureau of Labor Statistics, and authors' calculations.
Note: Percentage point changes represent compound annual growth rates.

A third noteworthy aspect of Chart 2 is related to why the information and cultural services industry is distinct from computer and electronic products. Although both industries' productivity performance after 2001 was poor, the performance of computer and electronic manufacturing was not only better than that of the information and cultural services industry, but it also marked a notable improvement from the pre-2001 period. In contrast, the information and cultural services industry's performance represents a reversal of fortunes, going from Canada's second-best performer relative its U.S. counterpart to being its biggest laggard.

Table 2 provides a decomposition of labour productivity growth for the information and cultural services industry similar to Table 1. The data reveal a more distinct divergence in the trajectories of the Canadian and U.S. information and cultural services industry's labour productivity. Canada's labour productivity growth per year contracted by 0.98 percentage points, from 2.50 per cent during 1987-2001 to 1.52 per cent in the period of 2001-2019. In stark contrast, the United States witnessed an exceptional gain of 6.37 percentage points, increasing from 1.42 per cent to 7.79 per cent over the same periods.[12]

A critical element of this divergence

12 A further break down of information and cultural services industries into subindustries is not available in the Canadian KLEMS. However, the integrated BEA-BLS KLEMS data provide information for four subindustries of information and cultural services industries, including publishing; motion picture and sound recording; broadcasting and telecommunications and data processing; internet publishing, and other information services. From 2001 to 2019, annual value added labour productivity growth was 7.3 per cent, 2.3 per cent, 8.5 per cent and 9.9 per cent, respectively. The three industries excluding motion picture and sound recording accounted for over 95 per cent of the information and cultural services industries' annual labour productivity growth over the same period. Note that the integrated labour productivity information in the BEA-BLS KLEMS represents gross output labour productivity.

is evident in the ICT capital intensity. Canada's growth in this area declined by 1.68 percentage points, from 2.15 per cent in the first period to 0.48 per cent in the second. In contrast, the United States increased from 2.19 per cent to 3.06 per cent, a rise of 0.87 percentage points, indicating a more substantial investment and utilization of ICT in the latter country.

In terms of TFP, the information and cultural services industry in both countries experienced growth, but at different magnitudes. Canada's TFP improved from -0.10 per cent to 0.52 per cent, marking a positive shift of 0.61 percentage points. The United States, however, registered a more substantial increase from 0.83 per cent to 2.81 per cent, a shift of 3.64 percentage points. These charts point towards a more significant enhancement in efficiency and innovation in the United States information and cultural services industry. Labour composition saw minor changes in both countries, with Canada experiencing a slight increase from 0.15 percentage point to 0.16 percentage point (0.01 percentage point), and the United States recording a more considerable growth from 0.17 percentage point to 0.49 percentage point (0.32 percentage points). This suggests a more substantial evolution in the skills and composition of the U.S. labour force within this sector.

The large divergence in labour productivity growth between Canada and the United States in the information and cultural services industry for the period 2001 to 2019 was due to lower contribution from capital intensity, TFP growth, and slower shifts towards more skilled workers in Canada. For the period 2001 to 2019, the growth in labour productivity in Canada's information sector was 6.27 percentage points lower than that in the United States; the lower capital intensity contribution, mostly from ICT capital in the industry in Canada accounted for 3.66 percentage points of this difference; the lower TFP growth in the sector in Canada accounted for 2.29 percentage points; and the slower shifts towards more skilled workers in Canada accounted for 0.32 percentage points of this difference.

The comparative analysis shows that Canada's lagging business sector labour productivity growth after 2001 is mostly due to weaker growth in ICT capital intensity and TFP. Moreover, the information and cultural services industry, which represents about 4.1 per cent of the business sector by nominal value added on average from 2001 to 2019, had an outsized role in expanding the productivity growth gap due to its weak ICT capital intensity and TFP growth. The industry's role in Canada's productivity divergence with the United States is made more pronounced by its shift from leading its U.S. counterpart by the widest margin (reducing the business sector labour productivity growth gap by 0.04 percentage points) of any industry before 2001 to lagging by the largest margin (increasing the business sector labour productivity growth gap by 0.45 percentage points) primarily due to weak ICT capital intensity and TFP growth.

The information and cultural services industry was not alone in experiencing weaker labour productivity growth after 2001, suggesting that a general lack of innovation and technical change and weak investment may be more pervasive dilemma across the Canadian economy in general that is most serious in the information and cultural services industry. For example, in the computer and electronic product manufacturing industry, Canada witnessed a notable decline in both ICT capital intensity and total factor productivity (TFP) over the years. Specifically, ICT capital intensity experienced a decrement of 0.73 percentage points, from 0.96 per cent in the period 1987-2001 to 0.23 per cent in 2001-2019. Concurrently, TFP descended by 4.13 percentage points, unraveling the gains made in the earlier period.

The mining, oil, and gas extraction industry is also often noted for its weak productivity growth. Though ICT capital intensity in Canada fell only slightly by 0.02 percentage points, TFP recorded a more pronounced downturn of 2.07 percentage points. The decrease in TFP is especially significant, marking a transition from a positive growth rate to a decline over the two periods. Similar trends were posted for the transportation equipment manufacturing industry, where Canada's ICT capital intensity decreased by 0.14 percentage points, accompanied by a 2.46 percentage points decline in TFP. The United States, in contrast, saw improvements, amplifying the productivity gap between the two nations.

In contrast the finance and insurance industry in Canada experienced a decline in ICT capital intensity by 0.42 percentage points but an uptick of 0.82 percentage points in TFP. Similarly, the professional services industry in Canada also faced a reduced ICT capital intensity growth by 0.80 percentage points but marked a rebound in TFP, increasing by 0.50 percentage points. For these last two industries efficiency and innovation associated with TFP growth partly mitigated the impacts of reduced ICT capital investments.

2001: A Pivotal Year for Information and Cultural Services Industry in Canada

The information and cultural services industry outsized role in Canada's poor productivity performance extends beyond its own performance because information and cultural services (distinct from physical ICT equipment) play an important role in supporting innovation and technological change in other industries.

This hypothesis is partly supported by evidence represented in Chart 3, where it is clear to see that the price of information and cultural services industry in Canada has risen in sharp contrast to the price in the United States (an increase of 1.11 per cent per year for Canada and a decline of 0.07 per cent per year for the United States), which coincidentally begins in 2001, the starting point of productivity divergence. The sharply rising relative price of accessing and using information and cultural services represents a substantial increase in real costs to businesses that rely on those services as intermediate inputs.[13]

13 Telecommunications accounted for roughly 60 per cent of the information and cultural services industry's nominal GDP on average from 2001 to 2019.

Given the growing importance for businesses to incorporating data into production processes to monitor and reduce production costs, manage suppliers and value chains, respond to customers needs and identify opportunities to innovate and adopt new technologies, it stands to reason that the higher cost of information and cultural services would have a broad-based negative impact on most industries' total factor productivity as well as their returns on investing in ICT capital inputs. Even if the cost of ICT capital inputs were identical in Canada and the United States, the higher cost of using ICT capital inputs to transform data into actionable information for Canadian firms could reduce the rate of return on investing in ICT.

One might argue that the difference in output prices of the information and cultural services industry is not relevant if the same price trends occurred across all sectors. In that case, singling out the information and cultural services industry from the rest of the economy in Canada may not be justified. However, Chart 4 shows that since 2001, the price of the business sector output in the United States rose at a pace more than 40 per cent faster than in Canada (the dashed lines). In addition, removing the influence of the information and cultural services industry from the business sector for the US has the opposite effect as it does in Canada. In other words, the information and cultural services industry contributed to lowering price growth in the United States, while in Canada, it contributed to a negligible increase in business sector gross output prices.

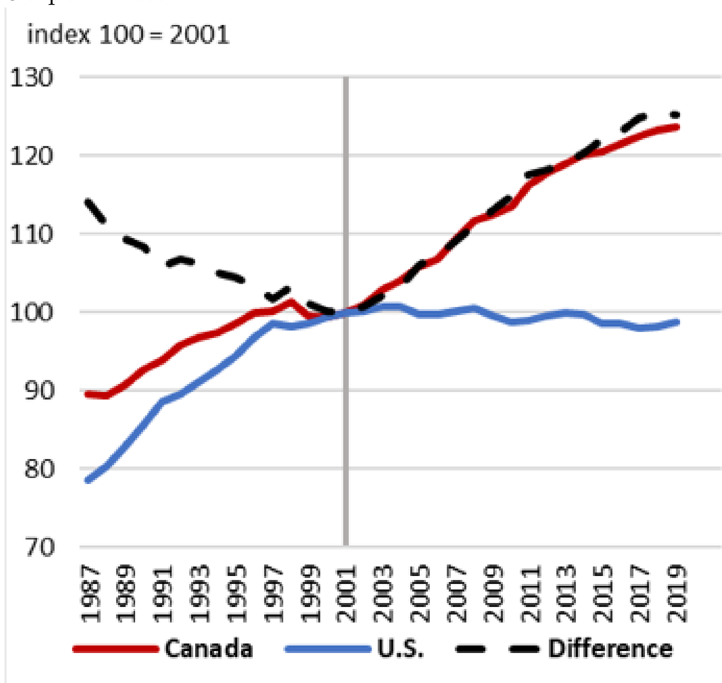
One reason the difference in prices may persist for so many years beyond the 2001 dot-com recession is because of differences in competitive intensity and the decline in competitive intensity in Canada. A lack of competitive intensity allows dominant firms to gain market power, which enables them to set higher prices without the threat of being undercut by competitors, leading to higher prices for consumers, all businesses and governments. Canadian firms in the information and cultural services industry may be more insulated from competitive pressures due to the lack of foreign rivals, which acts as a barrier to entry. A second factor that may contribute to market power is economies of scale, which represents another type of barrier to entry.

A recent report from Competition Bureau (2023) found that Canada's competitive intensity has fallen over the years, a finding that was reflected across all the indicators measured that include concentration, business dynamism and markup. Particularly, the report found that profits and markups have both risen overall since 2000, and these increases were generally greater for firms already earning higher profits and markups.

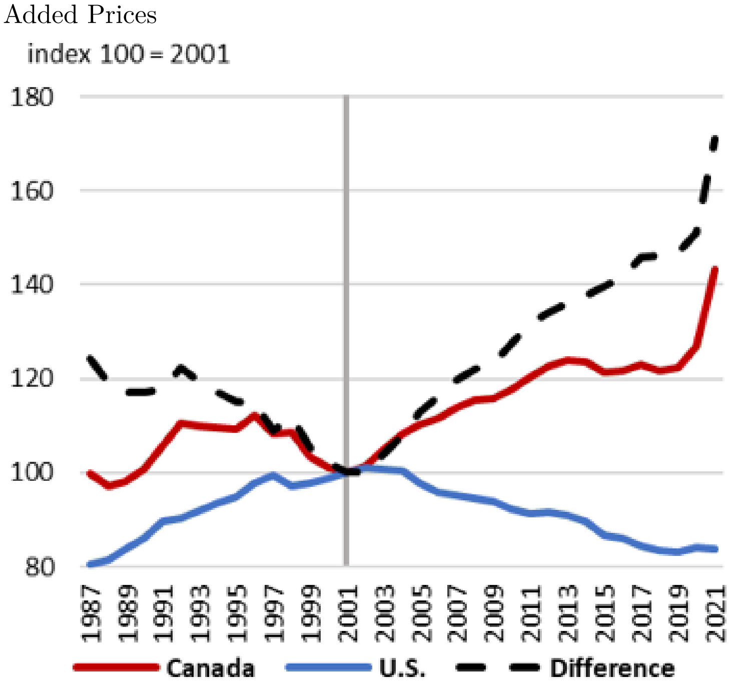
A third is related to government policies and regulations where the federal government, for example, auctions licenses for broadband spectrum to internet service providers. Auctions designed to spur competition by setting aside broadband spectrum for smaller or newer competitors may be less effective if large incumbents are able to acquire their smaller rivals. In describing the nature of broadband spectrum auctions, Middleton (2017) notes the market share of the three largest telecommunications service providers fell from 94 per cent in 2007 to 89 per cent in 2016, but also that

Chart 3: Information and Cultural Services Industry Prices in Canada and the United States

Panel A: Gross Output Prices



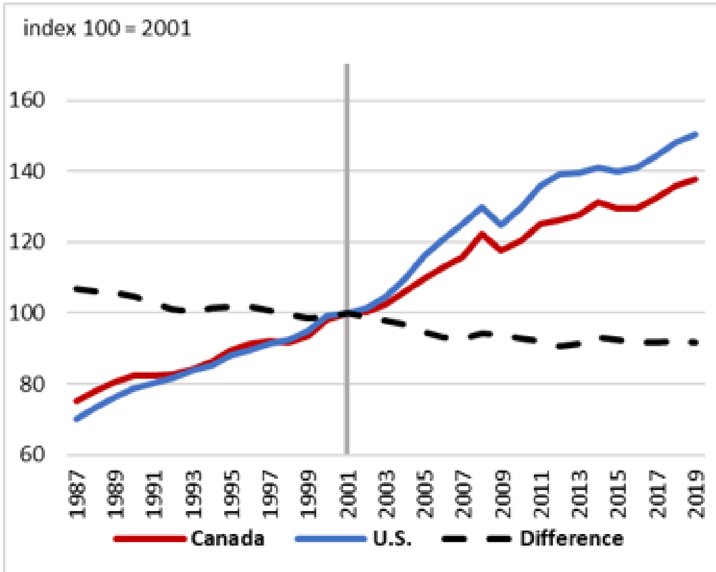
Panel B: Value Added Prices



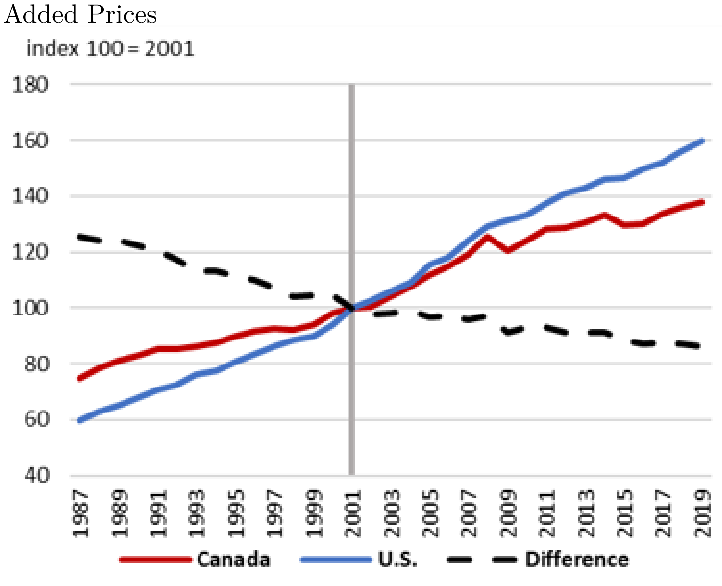
Sources: Statistics Canada, the Bureau of Economic Analysis, the Bureau of Labor Statistics, and authors' calculations.

Chart 4: Business Sector Price Developments in the Business Sector in Canada and the United States

Panel A: Gross Output Prices



Panel B: Value Added Prices



Sources: Statistics Canada, the Bureau of Economic Analysis, the Bureau of Labor Statistics, and authors' calculations.

three entrants during that period not affiliated with incumbents struggled to compete and that two of the three entrants were acquired by the three largest telecommunications service providers.

International Indicators of Market Power

The differences between output prices (levels and growth) in the Canadian and United States information and cultural services industries may be explained by a higher degree of market power in Canada compared to the United States. The OECD Services Trade Restrictiveness Index (STRI) measures obstacles to global services trade which point to Canada's telecommunication industry as an important outlier among its peers. The STRI benchmarks relative to global best practices to facilitate trade. The STRIs for each country and sector quantify restrictions on foreign entry, the movement of people, barriers to competition, regulatory transparency and other discriminatory measures that impact the ease of doing business (Grosso *et al.*, 2015).

The scoring and weighting methodology for calculation of the STRIs covers 18 sectors, five of which correspond closely as sub-industries within the information and cultural services industry. The STRIs take values between zero and one, zero representing an open market and one representing a market completely closed to foreign services providers.

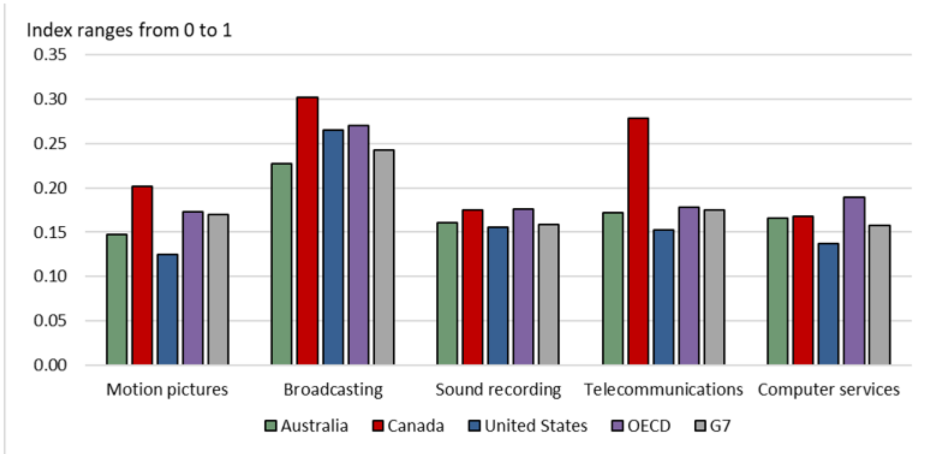
Charts 5 and 6 suggest that at least three important sub-industries within the information and cultural services industry exhibit substantially higher levels of trade restrictiveness, commonly associated with elevated markups and market power.[14] The STRI allows for comparisons between Canada and the United States as well as two broader categories, the OECD and G7 averages, as well as Australia, whose economic and geographic size, population, and natural resource-oriented economy are more similar to Canada than the United States.

The STRIs presented in Chart 5, indicate that Canada has similar levels of trade restrictions as its peers in sound recording and computer services industries. The index is relatively higher for motion pictures, particularly compared to the United States, and broadcasting. However, it is in telecommunications that Canada's trade restrictions are mostly clearly an outlier, at more than 80 per cent higher than in the United States and roughly 60 per cent higher than in Australia, the OECD and the G7.

The sub-indexes for each country and sector quantify restrictions on foreign entry, the movement of people, barriers to competition, regulatory transparency and other discriminatory measures that impact the ease of doing business. Of these five subcomponents, the index of restrictions on foreign entry, shown in Chart 6, most closely corresponds to the industry's overall STRI as it shows similar patterns for

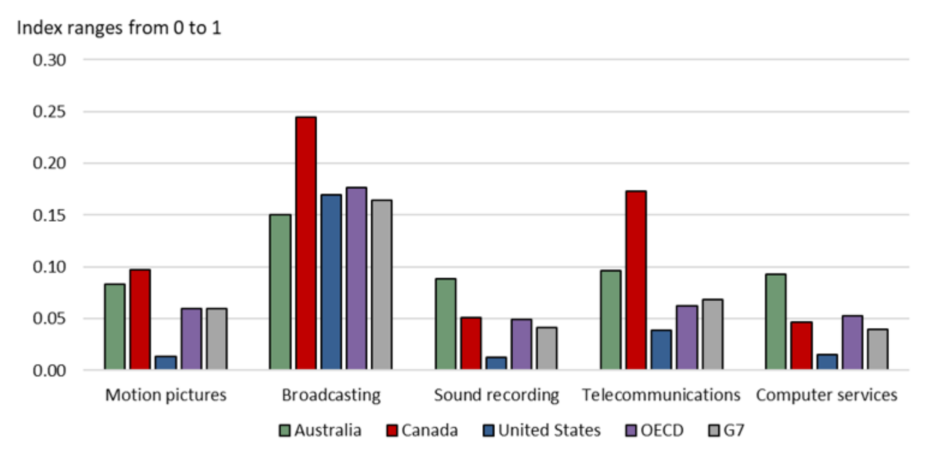
14 Some of the mostly frequently cited authors that associate trade and market power include Krugman (1979, 1980), Melitz and Ottaviano (2008), De Loecker (2011), and De Loecker and Van Biesebroeck (2016).

Chart 5: The OECD's Services Trade Restrictiveness Index (STRI)



Source: The OECD's Services Trade Restrictiveness Index (STRI) Regulatory Database accessed July 9, 2023.

Chart 6: The OECD's Restrictions on Foreign Entry Index, STRI Subcomponent



Source: The OECD Services Trade Restrictiveness Index (STRI) Regulatory Database, accessed July 9, 2023

trade restrictions when comparing Canada with its peers.[15]

The Relevance of International Competition and Market Power to the Information and Cultural Services Industry as a Driver of Canada's Productivity

Several studies have documented the essential role of investing in the production and general use of information and com-

15 Canada compares favourably with respect to the index on restriction on movement of people for each of the five information and culture sub-industries. For regulatory transparency Canada's scores are all identical to those for the United States for each of the five information and cultural sub-industries. Interpreting the indices for barriers to competition are comparatively opaque because the index reflects the existence of regulations and their flexibility, but their effectiveness is not directly measured. In addition, there is no score for barriers to competition score for Canada in computer services and sound recording.

16 For example, see Jorgenson and Stiroh (2017), Stiroh (2002), Gordon (2016) and Oliner and Sichel (2000).

munication (ICT) equipment as a driving force behind innovation and productivity growth.[16] Other studies have drawn clear connections between the importance of international trade to induce more intense competition among firms to reallocate resources from the least to the most productive firms as a critical source of aggregate productivity growth. For example, Melitz and Trefler (2012), report that tariff reductions implemented under NAFTA raised labour productivity by 13.8 per cent. Moreover, they explain that the increase in productivity growth occurs when heterogeneous firms with monopoly power transition from operating in separate economies to a more integrated economy, overall aggregate productivity increases "as market shares are reallocated from the low-productivity firms with high marginal costs to the high-productivity ones with low marginal costs."[17]

Many Canadian studies examining how the role of trade and firm turnover (Baldwin and Gu 2003, 2004, 2009; Lileeva, 2008) explain that stronger productivity growth in the manufacturing sector was due to more intense competition. In the United States, Foster *et al.* (2006) found similar evidence that more intense competition in the retail sector in the 1990s drove labour productivity growth higher.They argue that widespread use of cutting-edge information technology, that included introducing advances in inventory management and widespread use of scanners, intensified the reallocation of resources from failing low-productivity single-establishment enterprises to larger, higher-productivity national firms.

Another U.S. study (Faccio and Zingales, 2022) looking at the telecommunications industry found weak evidence that more competition and lower corporate profits lead to higher quality services for customers, higher investment in fixed capital, and higher employment and wages. Moreover, they soundly reject claims that less competition increases service quality, investment, employment, or wages.

The evidence described in this article suggests that the labour productivity growth divergence coincided with the dot-com recession in the United States shortly after the turn of the century. Enormous amounts of capital expenditure that had flowed into high-tech firms in the United States were wiped out, leaving only the strongest competitors to absorb the labour and capital resources of weaker, less competitive firms (Kraay and Ventura, 2007). This adjustment was followed by solid gains in labour productivity from ICT capital intensity growth (increasing from 2.07 per cent to 4.49 per cent average annual growth, see Table 2) among the remaining firms in information and cultural services industry and a sharp reversal of the industry's TFP growth (increasing from -0.83 per cent to 2.81 per cent).

The information and cultural services industry in Canada was not hit nearly as hard by the dot-com recession. Consequently, TFP growth was comparatively modest (increasing from 0.10 per cent to 0.52 per cent), while contributions to labour pro-

17 Page 101, in the section called "What Changes When Economies Integrate?".

ductivity growth from ICT capital intensity growth fell (decreasing from 2.15 per cent to 0.48 per cent). The difference in the direction of the contributions to labour productivity growth from TFP growth and ICT capital intensity account for three quarters of Canada's labour productivity gap with the United States for the information and cultural services industry.

Methodological Framework for Evaluating Market Power

This section presents a methodological framework to answer a simple question, what would have happened to labour productivity growth in Canada if the output price for the information and cultural services industry had grown at the same pace it did in the United States from 2001 onward? The United States was chosen for comparison, rather than another country or a group of countries, such as the OECD or G7, because the degree of economic integration makes the law of one price most likely to hold between Canada and the United States in the absence of market failures.

The empirical approach used to answer this question is a counterfactual in which the output price for the information and cultural services industry in Canada is replaced by that of the United States Because the output price in Canada is higher than in the United States, the difference can be interpreted as a measure of the industry's markup. By removing the markup to align the industry's output prices in Canada with the output price in the United States, a counterfactual is introduced to determine how a higher degree of competitive intensity in the information and cultural services industry would affect the Canada-United States labour productivity growth gap after 2001.

A well-recognized framework for understanding the relationship between markups and labour productivity growth that is amenable for analyses using aggregate KLEMS data associated with the Canadian System of National Accounts is presented in Hall (2018). A more thorough discussion of his approach can be found in the Appendix. Hall's central theoretical result is represented in equation 1 as follows:

$$\frac{\Delta \log Q}{\mu} - \sum \alpha_i \Delta \log X_i = \frac{\Delta \log A}{\mu} \quad (1)$$

The markup μ on the left-hand side of equation 1 is defined as the Canadian output price over the U.S. output price.[18] Output is represented by real gross output Q and a vector of factor inputs are expressed as X where i indexes factor inputs. The term α_i, represents the elasticity of the respective inputs. On the right-hand side, TFP is represented by A. All variables are logged and the operator Δ indicates the first difference. When the markup $\mu = 1$, the left-hand side of equation 1 is the Solow residual and TFP growth published by Statistics Canada and the U.S. BLS. In this situation, firm behaviour is consistent with assumptions embodied in

18 Equation 1 is adapted from Hall's equation 14 by rearranging terms and expressing the markup as μ^{-1} instead of one minus the Lerner index (1-λ) for simplicity as in Hall (2018).

the System of National Accounts such that markets are perfectly competitive, firms exhibit constant returns to scale, factor inputs are paid their marginal product, and the elasticity of an input is equal to the cost share of the input in total revenue.

Note that methods that econometrically derive markups ordinarily define the markup as the output price over the marginal cost. The difference is important because the definition used in this counterfactual does not imply that lowering the Canadian output price to match the price in the United States would result in perfectly competitive markets for Canada. Instead, it implies that Canadian markets would be equally competitive (or uncompetitive) as they are in the United States. In other words, the gap between Canadian and United States output prices is a markup in addition to any U.S. markup above marginal cost if Canadian and U.S. producers' marginal costs were the same. The theoretical implication of the counterfactual is therefore, not only that TFP growth should converge over the long term among well-integrated markets, but that prices and marginal costs of production should, too.

In the presence of market power, where $\mu > 1$, the Solow residual does not measure actual technical progress, $\Delta \log A$, because it does not adjust for market power. Moreover, Hall's equation shows that when market power reduces competitive intensity, permitting firms to increase output prices, the result is a proportionate reduction in real output and labour productivity growth due to lower TFP growth. That will be the case if total nominal expenditure on a product or service, such as information and cultural services, is fixed and does not vary with the price of the product.[19] A critical assumption in Hall's derivation of equation 1 is that changes in factor inputs and their prices are held constant. Relaxing this assumption would require some knowledge of how firms would reallocate factor inputs in response to changes in markups, which would require estimating a more extensive economic model rather than a simple and transparent counterfactual.

To implement a counterfactual to convey how market power in the information and cultural services industry might contribute to the Canada-United States productivity growth gap, two issues needed to be addressed. The first is related to the fact that Hall's framework is premised on gross output rather than value added output, which implies that when firms in the information and cultural services industry sell their output to other firms in the information and cultural services industry as intermediate inputs, the value added markup is not accounted for. Presumably, firms in the information and cultural services industry charge a markup to all customers regardless of whether they are individuals or other businesses regardless of their industry. An amendment to Hall's approach was made to account for higher priced intermediate inputs that drive up production costs. The increased cost of production is assumed to

19 When the cost function for producers and the utility function for consumers are Cobb-Douglas, the nominal expenditure on the product or service is fixed and does not change with input price.

be in proportion to each industries use of information and cultural outputs as a share of total gross output. The change in cost, in the long run, is passed on as higher prices of value added, even if industries other than the information and cultural services industry are perfectly competitive.

The second issue is that equation 1 does not provide any information about the level of the markup at any point in time. The difference in price information in KLEMS data for Canada and the United States is expressed as indexes, which also does not provide an initial starting value for the difference in output prices for the information and cultural services industries in the two countries.

The first issue is relatively easy to resolve. To see how large the hypothetical effect of removing the markup in the information and cultural services industry is, Hall's framework can be adapted by replacing the gross output markup with the value added measure following Basu and Fernald (1997) and Basu (2019). The adjustment accounts for the "double marginalization." Firms with sufficient market power pass their markups on to other firms driving up their intermediate input costs, which are reflected in the prices of final output. Equation 2 expresses the value added markup μ^{VA} as a function of the gross output markup.

$$\mu^{VA} = \frac{\mu\left(1 - S^{IC}\right)}{1 - \mu S^{IC}} \qquad (2)$$

Equation 2 is slightly different than it appears in Basu and Fernald (1997) and Basu (2019) because the counterfactual in this analysis assumes that only firms in the information and cultural services industry exercise significant market power. In Basu and Fernald (1997) and Basu (2019), it is assumed that firms in all industries impose the same markup. As a result, the intermediate input share of gross output includes all intermediate inputs. This is the case for the information and cultural services industry. However, for industries other than information and cultural, the share S^{IC} reflects only the value of output from the information and cultural services industries used as an intermediate input by an industry relative to the industries' value of gross output.

The second limitation is addressed by numerically solving for an initial value of the gross output markup that satisfies equation 1 by minimizing the mean squared differences in annual growth rates of real gross output for the information and cultural services industries between Canada and the United States. The solution to the minimization problem is an initial markup of 1.246, meaning that there is a 24.6 per cent markup over the U.S. price.[20]

Substituting the value added markup μ^{VA} from equation 2 into a value added, Y, expression of equation 1, rearranging terms, and assuming technological progress is Hick-neutral, Y=A(t)F(K,L), such that dividing through by hours worked

20 Alternative definitions of the markup could include normalizing gross output prices by the industries' combined input prices. Doing so produced nearly identical results for labour productivity and TFP growth for the business sector and by industry. Therefore, simple definition for the markup as the Canadian output price over the U.S. output price was chosen.

H yields an expression for labour productivity growth shown in equation 3.

$$\frac{\Delta \log(Y/H)}{\mu^{VA}} - \alpha_K \Delta \log(K/H) - \alpha_L \Delta \log(L/H) = \frac{\Delta \log A}{\mu^{VA}} \tag{3}$$

Note that X_i representing factor inputs is replaced by capital K and labour L. When they are multiplied by their respective shares in total primary costs and are divided by hours worked, their growth rates represent the contributions to labour productivity growth from capital intensity and labour composition, respectively. The last term on the right-hand side of equation 3 is the Solow residual, which in the System of National Accounts is interpreted as TFP growth, which assumes perfect competition ($\mu^{VA} = 1$). However, when the markup is greater than one, the Solow residual is less than TFP growth. To recover TFP growth, the Solow residual is multiplied by μ^{VA} to remove the influence of the markup. This adjustment contributes proportionately to labour productivity growth.

Note that the markup is defined as the difference between the output prices for information and cultural services industries in Canada and the United States. Therefore, if the output price of the information and cultural services industry in the United States exhibits a markup greater than one, the markup defined for the counterfactual is in addition to a U.S. markup.

The aggregate impact on business sector labour productivity growth is calculated by summing the industry value added markup weighted by industry shares of business sector nominal value added, S^{VA}, from 2001 to 2019 as shown in equation 4, where i indexes industries.

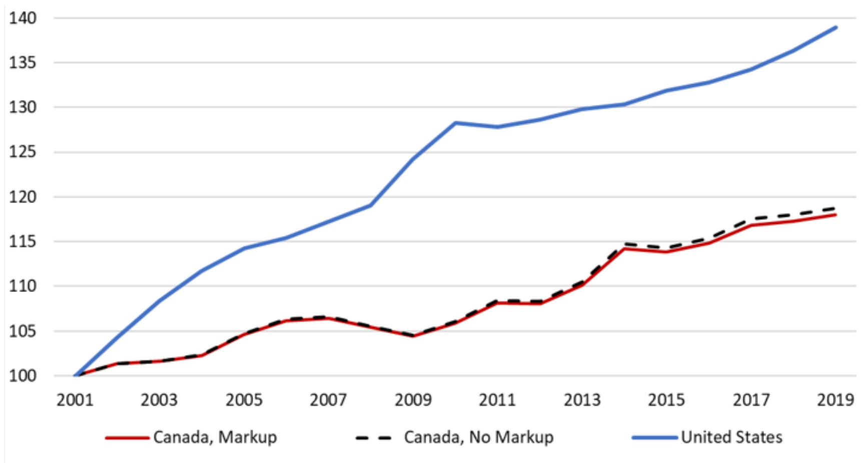
$$\Delta \log(Y/H) = \sum S_i^{VA} \left(\alpha_{K_i} \Delta \log \left(\frac{K}{H}\right)_i + \alpha_{L_i} \Delta \log \left(\frac{L}{H}\right)_i + \mu_i^{VA} \frac{\Delta \log A_i}{\mu_i^{VA}} \right) \tag{4}$$

It is important to recall that μ^{VA} for industries other than information and cultural is weighted by each industry's use of output from the information and cultural services industry as a share of gross output as described by equation 3. Therefore, the additional contribution to business sector labour productivity growth from industries varies according to their reliance on the Information and cultural services industry as a share of gross output. For example, petroleum and coal products manufacturers' use of output from the information and cultural services industry as a share of gross output was 0.1 per cent on average from 2001 to 2019. As a result, removing of the markup has a negligible effect on that industry's contribution to business sector labour productivity growth. By comparison, output from the information and cultural services industry as a share of gross output was the largest for the professional services industry at 4.4 per cent.

Advantages and Limitations of Counterfactuals

The decision to use a counterfactual to evaluate the competitive intensity of the information and cultural services in-

Chart 7: The Impact of the Markup in the Information and Cultural Services Industry on Business Sector Labour Productivity Growth



Sources: Statistics Canada, the Bureau of Economic Analysis, the Bureau of Labor Statistics, and authors' calculations.

dustry and its impact on the Canada-United States labour productivity growth gap stems primarily from the industry's contribution to the growing divergence in business sector labour productivity growth and changes in relative prices between Canada and the United States following the dot-com recession as illustrated in Charts 2 and 3. Counterfactuals also offer a simple and transparent means to explore policy-relevant "what-if" scenarios. This approach is particularly beneficial in contexts where traditional modeling and empirical validations pose significant challenges, enabling a detailed dissection of complex economic relationships.

For example, De Ridder *et al.* (2022) show that the absence of firm-level pricing data introduced a downward bias that produced markups one third as large as their true value. Deflating revenue with aggregate industry or national price deflators could mitigate the problem slightly but would still fail to capture firm heterogeneity. Along the same vein, Doraszelski and Jaumandreu (2020) found that popular control function methods such as in Ackerberg *et al.* (2015) used to correct for measurement errors in input variables and to isolate the influence of productivity shocks in the estimation of TFP are only free of bias when researchers observe markups. Observing measurement errors and productivity shocks is an equally relevant limitation for estimating markups.

Notwithstanding their limitations, statistical methods to estimate markups have some relative strengths that may warrant future areas for research. For example, Hall's (2018) approach "purges" changes in factor prices so that changes in markups have no impact on marginal rates of factor substitution. Although this assumption is amenable to the counterfactual employed here, Basu and Fernald (2002) demonstrate how markups can influence factor input prices and reallocation and, therefore, labour productivity growth. Consequently, incorporating the complex relationship between output elasticities with factor shares and markups with Hall's (2018) framework may be more suitably handled with an econometric model. Overall, combining both counterfactual and econometric approaches in future analyses may offer a balanced and holistic perspective.

Empirical Results

The overall impact of eliminating the markup, measured as the difference in Canada-United States output prices for the information and cultural services industries, had a relatively small effect on annual business sector labour productivity growth when compared to the size of the Canada-United States labour productivity growth gap. In Chart 7, Canada's business sector labour productivity growth with the markup removed is represented by the dashed black line. It is only slightly higher than growth reported in KLEMS for Canada, which includes the markup represented by the solid red line. The counterfactual Canadian business sector labour productivity growth closes the gap with the United States by 3.7 per cent.

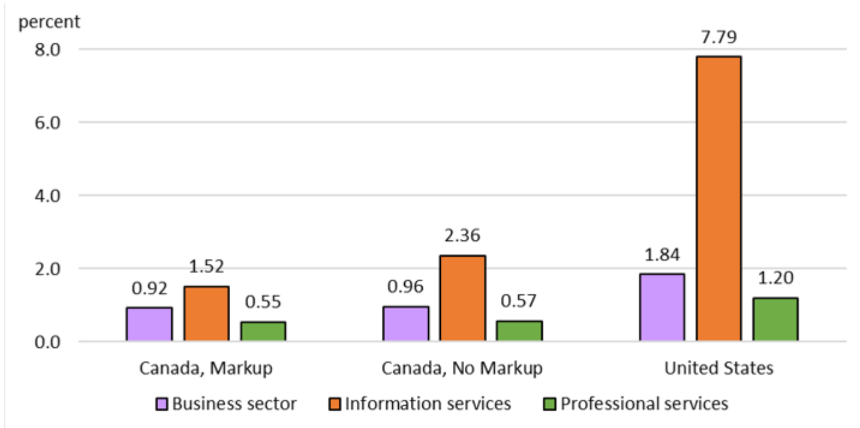
Part of the reason the markup for the information and cultural services industry has a limited impact on the business sector labour productivity growth rates is due to the relatively small use of the industry's services as intermediate inputs by other industries. In addition, substitution and income effects of removing the markup are not included in the counterfactual, consistent with Hall (2018). Chart 8 shows that eliminating the markup for the information and cultural services industry, where the benefit of more intense competition is the largest, has a substantial impact, raising labour productivity growth by about 56 per cent, or 0.84 percentage points. Despite this gain, it only reduces the labour productivity growth gap by 13.5 per cent due to the strong gains recorded by the industry in the United States.

The markup has even less influence in other industries. Even among industries that are proportionately the largest users of information and cultural services, like the professional services industry, eliminating the markup would only raise labour productivity growth by 0.02 percentage points and reduce the labour productivity growth gap by 2.2 per cent for that industry.

The counterfactual presented in this analysis provides an estimate of the effect of market power and limited competition on output prices and output. The relatively lower competitive intensity in Canada compared with that in the United States also affects investment, innovation, and technical progress. As shown in Table 2, the information and cultural services industry in Canada had lower contributions from capital intensity and TFP growth, and a slowdown in the shift towards more skilled workers compared to the U.S. since 2001. Previous studies conclude that market power and limited competition lowers investment, reduce innovation and technical progress. (Fernald and Inklaar, 2022; Goldin *et al.*, 2020; Goodridge and Haskel, 2023; Andrews, 2016). Therefore, much of the difference in labour productivity growth between Canada and the United States could be due to greater market power in Canada compared with that in the United States.

Additional analysis may find that market power in the information and cultural ser-

Chart 8: Labour Productivity Growth, 2001-2019



Sources: Statistics Canada, the Bureau of Economic Analysis, the Bureau of Labor Statistics, and authors' calculations.
Note: Percent changes represent compound annual growth rates.

vices industry has a much larger negative impact on aggregate business sector productivity growth than what simple counterfactual analyses can reveal. For example, removing the markup, defined as the difference between output prices in Canada and the U.S., only represents an improvement in competitive intensity that matches that of the same industry in the United States.

If the markup in the U.S. information and cultural services industry were 1.15, as Baqaee and Farhi (2020) find for the aggregate U.S. economy, the size of the adjustment to TFP growth required to achieve perfect competition (i.e., where price equals marginal cost) would result in an additional 15 per cent increase in TFP and labour productivity growth in the information and cultural services industry. In this case, the change in growth would filter through to the rest of the Canadian economy in proportion to the information and cultural services industry's share of gross output by industry and would have reduced the labour productivity growth gap by 2019 by 5.9 per cent rather than the 3.7 per cent estimate, which reflects no adjustment for a U.S. markup. Using an estimated markup for the aggregate U.S. economy of 1.25 from Edmond *et al.* (2023) and 1.60 from De Loecker and Eeckhout (2018) would close the gap by 7.5 per cent and 15.9 per cent, respectively.

Additional analysis could also measure how market power leads to the misallocation of resources, which also negatively impacts TFP growth. In a U.S. study, Baqaee and Farhi (2020) find that eliminating the misallocation resulting from markups would raise TFP by about 15 per cent from 1997 to 2015. A more complex economic model could capture the extent to which TFP growth would increase as industries invest more in ICT inputs to take advantage of the lower cost of using them.

Overall, the counterfactual results presented in this article may be regarded as confirming that market power in the information and cultural services industry has had a negative impact on labour productivity growth and, consequently, the living standards of Canadians. In addition, they represent a minimalist or partial estimate of the potential for mitigating market power to reduce the Canada-United States labour productivity growth gap.

Conclusion

Since 2001, labour productivity growth rates in Canada and the United States have diverged in sharp contrast to the previous four decades. The analysis in this paper underscores the significance of the information and cultural services industry for this great divergence since the dot-com recession, which may have set it on different competitive paths within each country. The difference in the economic performance of the information service industries in Canada and the United States is distinctly related to the timing of the dot-com recession when observing output price growth after 2001. The sharp increase in output prices for the information and cultural services industry in Canada compared to the United States where they fell slightly combined with weak foreign competition in Canada, suggest the price difference may have been due to an increase in market power in Canada.

To evaluate the role of market power a counterfactual analysis describing the price divergence as a relative markup indicates that had prices for the information and cultural services industry in Canada followed the same trajectory as in the United States the information and cultural services industry would have experienced a substantial increase in labour productivity growth from 2001 to 2019. However, that increase would have done little to reduce the Canada-United States labour productivity growth gap for the information and cultural services industries and even less for the business sector overall.

The counterfactual result in this paper may be regarded as confirming that market power in the information and cultural services industry has had a negative impact on labour productivity growth and the living standards of Canadians. It represents a minimalist or partial estimate of the potential for mitigating market power to reduce the Canada-United States labour productivity growth gap. Since 2001, the information and cultural services industry in Canada has had lower capital intensity contribution, lower TFP growth and slower shifts towards more skilled workers. Reducing market power has the potential to increase investment, technical progress, and innovation, and to narrow the Canada-United States labour productivity growth gap in the information service sector and the aggregate business sector.

The information and cultural services industry was not alone in experiencing weaker labour productivity growth after 2001, suggesting that a general lack of innovation and technical change and weak investment may be more pervasive dilemma across the Canadian economy in general that is most serious in the information and cultural services industry. For example, in the computer and electronic product manufacturing industry, professional service, and oil and gas sector, Canada had much slower labour productivity growth than the United States after 2001.

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Appendix: Hall's Framework on the Relationship between Markup and Productivity Growth

Hall's 2018 study, "Using Empirical Marginal Cost to Measure Market Power in the US Economy," establishes a theoretical framework to show how market power influences total factor productivity (TFP) growth and output growth. Hall's approach is ideal for implementing in a counterfactual because of its simple derivation of a markup as price over marginal cost using KLEMS data. In his framework, summarized in part below, marginal cost is the ratio of the change in cost not associated with changes in input prices to the change in output not associated with productivity change.[21] In time-series data, a natural measure of marginal cost is the change in cost divided by the change in output. More precisely, the numerator is the change in cost not associated with changes in factor prices and the denominator is the change in output not associated with the change in Hicks-neutral productivity. Cost is expressed as follows:

$$c = \sum w_i x_i \tag{5}$$

and the change in cost is:

$$dc = \sum x_i dw_i + \sum w_i dx_i \tag{6}$$

The first summation is the component associated with changes in factor prices, while the second is the desired component purged of effects from changing factor prices.

The technology is represented by

$$y = Af(x) \tag{7}$$

so output growth is given as

$$dy = Adf(x) + f(x)dA = Adf(x) + y\frac{dA}{A}. \tag{8}$$

The desired component purged of effects

21 A good discussion the strengths and weaknesses of Hall (2018) can be found in Basu (2019).

from changing productivity is:

$$Adf(x) = dy - y\frac{dA}{A} \tag{9}$$

Marginal cost is the ratio of adjusted cost change to adjusted output change,

$$mc = \frac{\sum w_i dx_i}{dy - y\frac{dA}{A}} \tag{10}$$

The Lerner index is

$$L = \frac{p - mc}{p} = 1 - \frac{\sum w_i dx_i}{p\left(dy - y\frac{dA}{A}\right)} \tag{11}$$

So

$$1 - L = \frac{\sum w_i dx_i}{p\left(dy - y\frac{dA}{A}\right)} \tag{12}$$

Now let:

$$\alpha_i = \frac{w_i x_i}{py} \tag{13}$$

be the share of factor i in revenue, py. The equation can then be written as:

$$(1 - L)\left(dy + y\frac{dA}{A}\right) = y\sum \alpha_i \frac{dx_i}{x_i} \tag{14}$$

Dividing by y and rearranging yields a useful result,

$$(1 - L)\frac{dy}{y} - \sum \alpha_i \frac{dx_i}{x_i} = (1 - L)\frac{dA}{A}. \tag{15}$$

Equation 13 can be written in discrete time as follows:

$$\begin{aligned}(1 - L)\Delta \log y - \sum \alpha_i \Delta \log x_i \\ = (1 - L)\Delta \log A\end{aligned} \tag{16}$$

This formulation is useful because the left-hand side is the Solow residual when L = 0. However, when L > 0, the Solow residual does not measure actual technical progress because it does not adjust for market power. Note that there is no adjustment to factor inputs x_i. This reflects Hall's assumption that markups do not influence the marginal rate of technical substitution such that any change in factor prices associated with changes in the markup impact capital and labour equally, leaving their shares α_i unchanged. This simplifying assumption makes the framework in Hall (2018) ideal for counterfactual analyses. However, Basu (2019) highlights important limitations related to this and other assumptions in Hall's framework that a more sophisticated economic model should address.

Appendix Table 1: Contributions to Business Sector Labour Productivity Growth by Industry in Canada and the United States, 1987-2001

	Canada	United States	Canada less United States
	Percentage point change, compound annual growth rates		
Business sector	1.71	2.17	-0.46
Crop and animal production	0.06	0.08	-0.01
Forestry, fishing, and related activities	0.01	-0.01	0.02
Oil and gas extraction	0.04	0.03	0.01
Mining (except oil and gas extraction)	0.03	0.04	-0.01
Support activities for mining and oil and gas extraction	0.00	0.01	-0.01
Food, beverage and tobacco products	0.04	0.01	0.03
Textile and textile product mills	0.01	0.02	-0.01
Clothing, leather and allied product manufacturing	0.01	0.02	-0.01
Wood product manufacturing	0.02	-0.01	0.03
Paper manufacturing	0.04	0.00	0.04
Printing and related support activities	0.00	0.00	0.00
Petroleum and coal products manufacturing	0.01	0.04	-0.03
Chemical manufacturing	0.09	0.05	0.04
Plastics and rubber products manufacturing	0.02	0.03	-0.01
Non-metallic mineral product manufacturing	0.01	0.01	0.01
Primary metal manufacturing	0.06	0.02	0.04
Fabricated metal product manufacturing	0.02	0.01	0.01
Machinery manufacturing	0.03	0.01	0.02
Computer and electronic product manufacturing	0.16	0.49	-0.33
Electrical equipment	0.02	0.01	0.01
Transportation equipment manufacturing	0.10	0.02	0.08
Furniture and related product manufacturing	0.02	0.00	0.01
Miscellaneous manufacturing	0.02	0.02	0.00
Wholesale trade	0.17	0.30	-0.13
Retail trade	0.18	0.33	-0.15
Transportation and warehousing	0.06	0.10	-0.04
Information and cultural industries	0.12	0.05	0.06
Finance and insurance	0.33	-0.05	0.38
Professional services	0.07	0.01	0.06
Administration, waste management	0.01	-0.01	0.02
Educational services	0.03	0.01	0.02
Health care and social assistance	-0.03	-0.04	0.01
Arts, entertainment and recreation	-0.01	0.01	-0.02
Accommodation and food services	0.02	0.06	-0.04
Other services	0.02	0.03	-0.02

Sources: Statistics Canada, the Bureau of Economic Analysis, the Bureau of Labor Statistics, and authors' calculations.
Note: Percentage point changes represent compound annual growth rates.

Appendix Table 2: Business Sector Labour Productivity Growth by Industry in Canada and the United States, 1987-2001

	Canada	United States	Canada less United States
	percent change, compound annual growth rates		
Business sector	1.71	2.17	-0.46
Crop and animal production	3.87	5.08	-1.21
Forestry, fishing, and related activities	1.54	-2.56	4.09
Oil and gas extraction	1.82	2.59	-0.77
Mining (except oil and gas extraction)	2.26	7.92	-5.66
Support activities for mining and oil and gas extraction	1.38	7.75	-6.37
Food, beverage and tobacco products	1.58	0.45	1.13
Textile and textile product mills	1.71	3.89	-2.18
Clothing, leather and allied product manufacturing	2.73	3.90	-1.18
Wood product manufacturing	2.47	-2.48	4.96
Paper manufacturing	2.75	0.43	2.31
Printing and related support activities	0.20	0.62	-0.42
Petroleum and coal products manufacturing	2.16	7.26	-5.10
Chemical manufacturing	4.15	2.41	1.74
Plastics and rubber products manufacturing	2.70	3.34	-0.64
Non-metallic mineral product manufacturing	2.18	1.22	0.95
Primary metal manufacturing	5.20	2.16	3.04
Fabricated metal product manufacturing	1.60	0.80	0.80
Machinery manufacturing	2.53	0.37	2.16
Computer and electronic product manufacturing	8.45	20.51	-12.06
Electrical equipment	3.97	1.65	2.31
Transportation equipment manufacturing	4.59	1.21	3.39
Furniture and related product manufacturing	3.56	0.65	2.91
Miscellaneous manufacturing	3.82	3.83	-0.01
Wholesale trade	2.55	4.28	-1.73
Retail trade	2.33	3.88	-1.54
Transportation and warehousing	1.17	2.58	-1.41
Information and cultural industries	2.50	0.96	1.54
Finance and insurance	1.82	-0.24	2.06
Professional services	0.97	0.08	0.88
Administration, waste management	0.40	-0.43	0.83
Educational services	4.98	0.99	3.99
Health care and social assistance	-0.69	-0.64	-0.05
Arts, entertainment and recreation	-1.32	0.93	-2.25
Accommodation and food services	0.50	1.97	-1.46
Other services	0.58	1.18	-0.60

Sources: Statistics Canada, the Bureau of Economic Analysis, the Bureau of Labor Statistics, and authors' calculations.
Note: Percentage point changes represent compound annual growth rates.

Appendix Table 3: Contributions to Business Sector Labour Productivity Growth by Industry in Canada and the United States, 2001-2019

	Canada	**United States**	**Canada less United States**
	Percentage point change, compound annual growth rates		
Business sector	0.92	1.84	-0.92
Crop and animal production	0.06	0.02	0.04
Forestry, fishing, and related activities	0.01	0.00	0.01
Oil and gas extraction	-0.03	0.03	-0.06
Mining (except oil and gas extraction)	-0.02	0.00	-0.01
Support activities for mining and oil and gas extraction	0.00	0.00	0.00
Food, beverage and tobacco products	-0.02	0.00	-0.02
Textile and textile product mills	0.00	0.01	0.00
Clothing, leather and allied product manufacturing	0.01	0.00	0.00
Wood product manufacturing	0.03	0.01	0.02
Paper manufacturing	0.01	0.01	0.00
Printing and related support activities	0.01	0.02	-0.01
Petroleum and coal products manufacturing	-0.03	0.00	-0.03
Chemical manufacturing	0.00	0.03	-0.03
Plastics and rubber products manufacturing	0.01	0.01	0.00
Non-metallic mineral product manufacturing	0.00	0.01	-0.01
Primary metal manufacturing	0.01	0.02	-0.01
Fabricated metal product manufacturing	0.01	0.01	0.00
Machinery manufacturing	0.02	0.02	-0.01
Computer and electronic product manufacturing	0.01	0.24	-0.23
Electrical equipment	0.00	0.01	-0.01
Transportation equipment manufacturing	0.03	0.04	-0.01
Furniture and related product manufacturing	0.00	0.00	0.00
Miscellaneous manufacturing	0.00	0.02	-0.02
Wholesale trade	0.17	0.11	0.05
Retail trade	0.11	0.13	-0.03
Transportation and warehousing	0.03	0.04	-0.01
Information and cultural industries	0.08	0.39	-0.32
Finance and insurance	0.30	-0.31	0.61
Professional services	0.05	0.13	-0.08
Administration, waste management	0.02	0.01	0.00
Educational services	0.01	0.00	0.01
Health care and social assistance	-0.03	0.02	-0.05
Arts, entertainment and recreation	0.00	0.02	-0.01
Accommodation and food services	0.01	0.01	0.01
Other services	0.03	-0.02	0.04

Sources: Statistics Canada, the Bureau of Economic Analysis, the Bureau of Labor Statistics, and authors' calculations.
Note: Percentage point changes represent compound annual growth rates.

Appendix Table 4: Business Sector Labour Productivity Growth by Industry in Canada and the United States, 2001-2019

	Canada	United States	Canada less United States
	percent change, compound annual growth rates		
Business sector	0.92	1.84	-0.92
Crop and animal production	4.87	2.40	2.47
Forestry, fishing, and related activities	1.44	-0.07	1.51
Oil and gas extraction	-0.90	3.64	-4.54
Mining (except oil and gas extraction)	-2.31	-1.19	-1.13
Support activities for mining and oil and gas extraction	-0.45	0.74	-1.19
Food, beverage and tobacco products	-1.05	-0.03	-1.02
Textile and textile product mills	1.53	1.91	-0.38
Clothing, leather and allied product manufacturing	1.92	2.21	-0.29
Wood product manufacturing	3.19	2.76	0.43
Paper manufacturing	1.13	1.61	-0.49
Printing and related support activities	1.42	3.36	-1.94
Petroleum and coal products manufacturing	-3.54	0.46	-4.00
Chemical manufacturing	-0.09	1.27	-1.36
Plastics and rubber products manufacturing	1.25	1.53	-0.28
Non-metallic mineral product manufacturing	0.26	1.49	-1.24
Primary metal manufacturing	0.86	3.94	-3.08
Fabricated metal product manufacturing	0.64	0.74	-0.10
Machinery manufacturing	1.39	2.03	-0.64
Computer and electronic product manufacturing	1.07	12.60	-11.53
Electrical equipment	0.85	2.57	-1.72
Transportation equipment manufacturing	0.98	3.31	-2.32
Furniture and related product manufacturing	0.50	1.39	-0.89
Miscellaneous manufacturing	0.45	3.17	-2.72
Wholesale trade	2.48	1.69	0.79
Retail trade	1.66	1.68	-0.02
Transportation and warehousing	0.72	1.32	-0.60
Information and cultural industries	1.52	7.09	-5.58
Finance and insurance	1.53	-1.32	2.85
Professional services	0.55	1.33	-0.78
Administration, waste management	0.53	0.45	0.08
Educational services	1.03	0.09	0.94
Health care and social assistance	-0.44	0.34	-0.78
Arts, entertainment and recreation	0.19	1.43	-1.23
Accommodation and food services	0.44	0.25	0.19
Other services	1.20	-0.58	1.78

Sources: Statistics Canada, the Bureau of Economic Analysis, the Bureau of Labor Statistics, and authors' calculations.
Note: Percentage point changes represent compound annual growth rates.

A Critical Juncture: Assessing Canada's Productivity Performance and Future Prospects

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Abstract

It is widely acknowledged that Canada has faced long-standing issues with productivity growth, both in comparison to its past performance and relative to other advanced economies. Additionally, it is recognized that as the transformation brought on by population aging continues, improvements in the living standards of Canadians will increasingly depend on productivity growth. This situation arises at a time when Canada, along with the global economy, is at the forefront of major structural transformations, including the green transition, the realignment of global trade, and the increasing digitization and use of AI. The necessity to adapt to the scale and scope of these transformations will create pressures for all economic actors to make renewed efforts to address Canada's longstanding productivity challenges. To better understand the direction of Canada's future productivity growth, this article chronicles Canada's productivity growth over recent decades and highlights key structural factors that have likely constrained Canada's productivity performance. We then explore how these factors might shape the trajectory of productivity growth in the context of these impending structural transformations and identify areas where further research should be prioritized.

Over the long-term, economic growth is driven by two factors, increases in the labour force and increases in labour productivity. Although population growth can drive significant GDP growth—and indeed it has for several decades in Canada—growth in GDP per capita, which is more closely aligned to living standards,

1 Carlos Russell and Kaleigh Dowsett are senior economists in the Economic Studies and Policy Analysis Division (ESPAD) at Finance Canada. Nelson Paterson is the Director General at ESPAD. We thank Andrew Sharpe, Jim Stanford, and an anonymous reviewer for their helpful comments. We would also like to acknowledge the invaluable support from Alex Armstrong, Matt Calver, Jessica Gallant, Kar-Fai Gee, and Jacob Loree. Special thanks go to Hankook Kim who provided important insights into productivity issues that helped shape this paper for the better. The views expressed in the paper are solely those of the authors, and no responsibility for them should be attributed to the Department of Finance Canada. All errors are our own. Corresponding author: Carlos Rosel, Email: carlos.rosell@fin.gc.ca.

is primarily driven by improvements to either employment rates or productivity.

As a modern economy facing long-term demographic challenges of population ageing, there is limited room for Canada to increase its working-age participation rate. The labour force participation rate in Canada is higher than the OECD average and the United States and has increased by almost 15 percentage points since 1976, driven mainly by improvements in women's participation.[2] Although further improvements can and should be made (e.g., women's participation rates),[3] the potential gains to GDP per capita from further increases in labour force participation rates are estimated to be similar in size to the gains from just a few years of labour productivity growth, even at the low average pace of labour productivity growth seen in the years leading into the pandemic. As prospects for improved growth in GDP per capita through increases in labour force participation run thinner, the imperative of confronting Canada's productivity challenges has clearly increased.[4]

The latest OECD projection for GDP per capita growth (Guillemette and Turner, 2021) highlights the potential consequences of Canada's productivity challenge. According to the OECD, Canada could see the slowest growth in real GDP per capita of any advanced economy from 2020 to 2060. This projected outcome stems largely from a poor productivity performance as measured by labour efficiency (i.e., labour-augmenting technological progress) and capital per worker, which were both projected to trail every other OECD country over the 2020-2060 period. Although Canada's standing in the OECD on demographic fundamentals (i.e. labour force and employment rate growth) are slightly better, they are not projected to be sufficient to offset Canada's low standing on productivity fundamentals that weigh on its future GDP per capita growth.

This projected outcome does not need to become a reality. Even modest improvements in Canada's productivity growth, as defined by labour efficiency and capital per worker, can make a notable improvement in terms of Canada's GDP per capita ranking in 2060. For instance, if Canada's labour productivity were to grow at the average rate projected for the other G7 members, rather than the weakest growth in the G7, real GDP per capita in Canada would improve from the 23rd to the 15th highest level in the OECD by 2060 (Chart 1).[5] This would leave Canada's rank largely unchanged from 2019 (i.e., Canada would decline from 14th in 2019 to 15th in 2060) and behind only the United States and Ger-

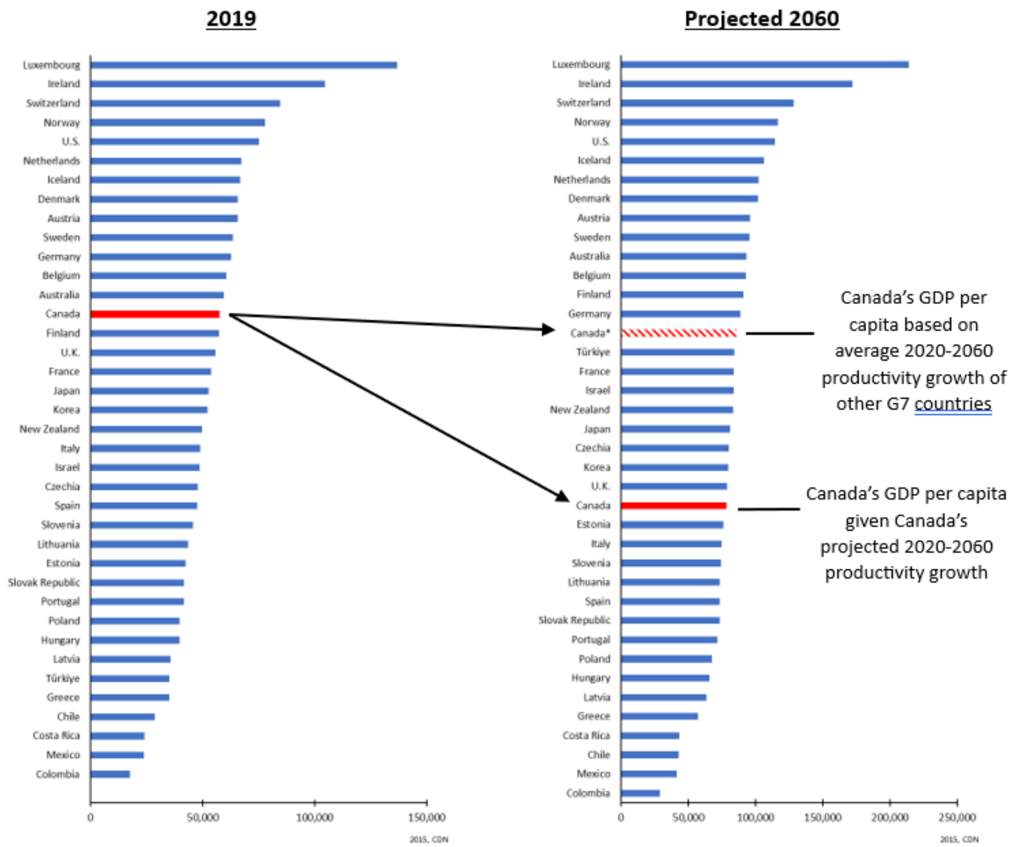
2 Sources: https://data.oecd.org/emp/labour-force-participation-rate.htm, https://www150.statcan.gc.ca/t1/tbl1/en/cv.actionpid=1410001701

3 For example, some improvement is possible with respect to women in their prime working years, Indigenous people, persons with disabilities, and older Canadians.

4 In this article, productivity is defined as labour productivity unless noted otherwise.

5 The projected range in GDP per capita growth over the 2020-2060 period within the G7 is estimated to be about 0.4 percentage points. If Canada were to have the average growth of other G7 countries over this period, Canadian growth would rise by nearly 0.25 percentage points.

Chart 1 : GDP per Capita in OECD countries, 2019 and 2060 (OECD projection), Real 2015 C$)



Source: OECD Productivity and ULC – Annual, Total Economy database and Guillemette and Turner (2021). Authors' calculations.
Note: 2060 projections reflect 2019 GDP per capita after compounding for 40 years GDP per capita growth rates inferred from Guillemette and Turner (2021). *This projection is compounded after adjusting the Canadian GDP per capita growth rate to reflect the average productivity (i.e., labour efficiency and capital per worker) growth of the other G7 countries over the 2020-2060 period.

many in the G7 in 2060.

In this article, Section 1 presents a broad overview of Canada's productivity performance, including recent developments since COVID-19, Section 2 explores the role of business investment in driving Canada's weak productivity growth. Section 3 examines the potential factors that may hinder Canada's investment and productivity performance. We conclude by looking ahead and explore areas for future research that could help us better understand how the key structural forces of population ageing, the green transition, the reshaping of global trade and the continuing expansion of the digital economy and AI may shape Canada's productivity challenges, in what is now no longer a far away long-term horizon but increasingly a near term reality.

Trends in Productivity Growth in Canada

In this section, we take stock of Canada's productivity growth in the past four decades. We begin by looking at the long-term trends, and how productivity growth can be sorted into within-sector growth or sectoral shifts. We then more closely examine the productivity challenges since the pandemic, including large swings in labour and its implications for recent productivity dynamics. To round out our comparative assessment, we also provide international perspectives on Canada's productivity performance.

Long-term trends in productivity growth – Within-sector growth versus. sectoral shifts

Canada's productivity performance has been a source of concern spanning several decades. Business sector productivity was strong during the 1960s, 1970s, and early 1980s , with an average rate of 2.8 per cent from 1961 to 1985. Following this period of strong growth, a discernible slowdown began to emerge, with productivity growth averaging 1.4 per cent leading up to the Financial Crisis . This rate of growth further decelerated to 1.0 per cent following the 2008 Financial Crisis, through to the 2014-2015 commodity prices shock. This period saw Canada's economy subjected to the negative impact of declining commodity prices, with productivity growth declining further to an average of 0.7 per cent leading up to the pandemic (Table 1).[6]

Although a complex set of factors are behind these long-term dynamics of Canada's productivity growth, a sectoral decomposition provides interesting perspectives for how productivity at the sectoral level shapes aggregate productivity growth. Several methods exist for the constructing decompositions. For example, De Avillez (2012) employs three different versions to untangle the sectoral contributions to Canadian growth over the 2000-2010 period and finds these methods provide complementing rather than competing views. For this exercise, this article uses a method developed by Almon and Tang (2011) that break apart productivity growth into within-sector effects and effects driven by changes in the "economic significance" of sectors (also referred to as "shift effects", they are size changes in terms of resource use and output valuation). Changes in the economic significance, capture traditional real-value-based reallocation effects as well as changes in the sector's importance due to its output becoming relatively more (or less) valuable. In this respect, the Almon and Tang (2011) method differs from more traditional decomposition approaches by incorporating the role of nominal price shocks in shaping productivity growth. Extended discussions on how these differences in methodology affect the sectoral decomposition is beyond the scope of this article. For more details on various decomposition approaches.[7]

Table 1 parcels-out business sector productivity growth based on 15 2-digit NAICS sectors. It also tracks growth across various time spans; while the earliest pe-

6 The decline in commodity prices can cause the influence of the resource sector in aggregate productivity to decline. Given that this sector has relatively higher productivity levels, the resulting compositional change would drag aggregate growth even as growth in the sector rises as lower productivity opportunities in the sector shutdown.

7 See De Avillez (2012) and and Reinsdorf (2015).

Table 1: Decomposition of Labour Productivity Growth, Business Sector, 1961-2019

	Average annual percentage-point contribution to the labour productivity growth rate			
	1961-1985	**1985-2007**	**2007-2014**	**2014-2019**
Within-sector effects	2.6	1.4	1.0	1.1
Shift effects	0.2	-0.0	0.1	-0.5
Total	2.8	1.4	1.0	0.7

Source: Statistics Canada Table 36-10-0208-01. Authors' calculations.
Notes: Decomposition based on the methodology from Almon and Tang (2011). Annual average calculated by performing the decomposition for each year and averaging over the period. Totals may not add up due to rounding .

riod summarizes a span with growth considered high by today's standards, later periods are punctuated by notable years such as 2007 (the peak before the Great Recession), 2014 (roughly the turning point in resource prices), and 2019 (the year prior to the start of the COVID-19 pandemic). Overall, for most periods, aggregate growth is driven by the growth within each sector while shift effects generally play a minor role. In other words, the decline in overall productivity growth in Canada over time has been mainly due to the decline in productivity growth within each sector. For instance, the within-sector effects declined significantly from 2.6 per cent in the 1961-1985 period to around 1.0 per cent by 2007-2014 while aggregate productivity growth in the business sector fell from 2.8 per cent to 1.0 per cent between the two periods.

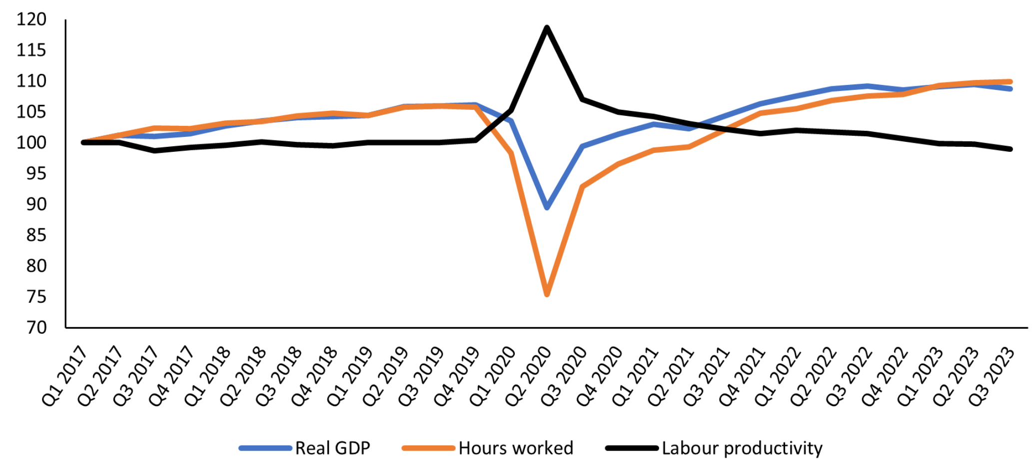
However more recently, over 2014-2019, shift-effects have become a much more significant factor behind aggregate productivity growth. In particular, within-sector effects were slightly higher in 2014-2019 than in 2007-2014 (1.1 per cent versus 1.0 per cent), however, due to sizable negative shift-effects (-0.5 per cent versus 0.1 per cent), the overall average annual productivity growth over 2014-2019 was below that of 2007-2014. This negative shift-effect was mainly driven by the resource sector, which experienced a significant negative price shock over the period. A more detailed breakdown of the decomposition is located in Appendix Table 1.

The experience over 2014-2019 could hold lessons for the future productivity growth in Canada. If the global economy becomes more volatile, inflicting various nominal price shocks on a small open economy such as Canada's, shift-effects could become an increasingly important influence on the aggregate productivity growth. Nevertheless, given aggregate productivity growth continues to be influenced relatively less by from shift effects, improving within-sector performance remains crucial. In Section 3, we explore some of the economic trends that could be a source of shocks to Canada's economy. More research around these trends will help us better understand the prospect for Canada's future productivity growth.

Post-COVID-19 Trends in Productivity Growth for Canada

More recently, during the COVID-19 Pandemic, Canada experienced significant productivity fluctuations. Year-over-year business sector productivity growth in 2020 spiked at 8.6 per cent (7.8 per cent for the total economy) before subsequently declining by 5.8 (5.1) and 1.5 (1.0)

Chart 2 : Real GDP, Hours Worked, and Labour Productivity, Business Sector, 2017Q1 to 2023Q3, 2017Q1=100)



Source: Statistics Canada Table 36-10-0206-01. Authors' calculations.,

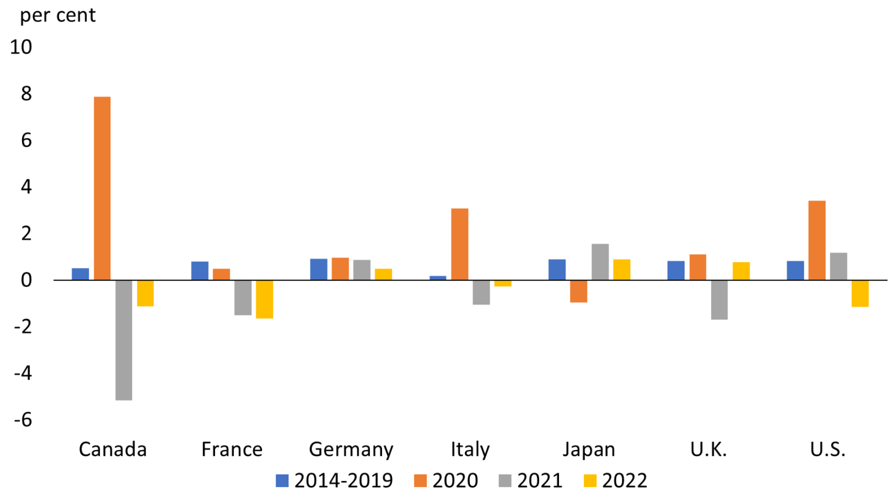
per cent respectively in 2021 and 2022. This was driven by disruptions caused by COVID-19, which led to sharp changes in hours worked, which were a more important driver of productivity growth than changes in value-added (Chart 2). Labour productivity growth has continued its decline from the COVID-19 high and is now lower than its pre-COVID level. By the third quarter of 2023, Canada's productivity in the business sector had fallen to a level not seen since 2017 (2018 for the total economy). Since the trough of the pandemic in the second quarter of 2020, total hours worked have increased faster than growth in real GDP highlighting the driving role growth in hours has played in driving the declining trend in Canada's labour productivity growth.

This general pattern is seen in other advanced economies to varying degrees (Chart 3). In Canada as in the United States, this initially seems to have been related to the disruptions from compositional effects from COVID. COVID-19 initially affected relatively more workers in non-essential activities (e.g., hospitality and personal services) that also tend to be less productive than essential activities, and Wang (2021) shows that that this composition change helped drive the spike in Canada. A similar story is suggested by Stewart (2022) for the United States in that the increase in productivity was due to labour quality increases arising from initial steep job losses focused on lower-wage industries.

More broadly, COVID's disruptions in hours worked would not only have influenced productivity growth through compositional effects on labour quality. It would have also affected growth if it disproportionately affected workers in less capital-intensive jobs. In Canada, the effects are seen in the recent contributions to productivity growth from labour composition and capital deepening.

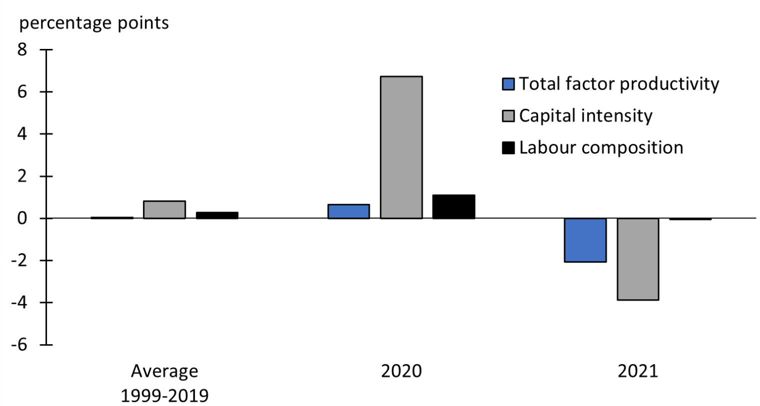
Generally, national statistical agencies decompose drivers of labour productivity growth, which are typically sorted into growth in labour quality (or composition), capital intensity and changes in total factor

Chart 3 :Annual Labour Productivity Growth, Total Economy – G7 Countries)



Source: OECD Productivity and ULC – Annual, Total Economy database, Authors' calculations
Note: Labour productivity reflects GDP per hour worked in the total economy. Annual growth rates reflect the geometric average over the 2015-2019 period or the year-over-year percentage change in productivity.

Chart 4 :Percentage Point Contribution to Average Annual Labour Productivity Growth by Factor for Canada, Business Sector, 1999-2021



Source: Statistics Canada Table 36-10-0208-01. Authors' calculations.
Note: The sum of contributions from each factor (i.e., TFP, capital intensity, and labour composition) equal annual average labour productivity growth.

productivity (TFP). Labour quality refers to the distribution of education and skills of the workforce, capital intensity refers to the ratio between capital and labour, and TFP is essentially what is left after accounting for measurable capital deepening and changes in labour quality—generally assumed to capture technological (potentially including those embedded in capital) and process advancement.

While labour composition contributed around 0.3 percentage points on average to labour productivity growth in Canada's business sector over the 1999-2019 period, this rose to 1.1 percentage points in 2020. More starkly, capital deepening saw its contribution increase from 0.8 percentage points between 1999 and 2019 to 6.7 percentage points in 2020 (Chart 4). Part of this increased contribution in capital intensity could have come mechanically as the decline in hours left fewer workers with the same stock of capital. However, the hours drop-off could also have had a compositional effect like that suggested by Wang (2021) and Stewart (2020) with respect to the type of labour that continued working. If the loss of hours disproportionately applied to occupations or industries with low capital intensity then, this compositional effect would have further raised capital intensity and productivity across the industries that were still operating smoothly .

The continued strong rise in hours worked post-COVID, due to potential factors such as labour hoarding, highlights capital deepening's sizable contribution to productivity at the onset of the pandemic followed by the sharp negative contribution in 2021 as these increases in labour inputs reduced capital intensity. For instance, the current tight labour market may be prompting firms to hire and retain more skilled labour than needed to ensure they have a sufficient supply of workers in the future (i.e., labour hoarding). Recent media reports suggest that the practice of labour hoarding is occurring in Canada as well as in other advanced economies [8]. While hoarding could improve the resilience of firms and their productivity in the long-run by preserving firm-specific human capital and avoiding future hiring costs, in the short-run it can negatively impact productivity if demand does not keep pace.

More research is needed to determine if labour hoarding is happening and dampening productivity growth but sectoral data since the onset of COVID may already provide some evidence for this (Table 2). Sectors where skill shortages seem the most acute, thus the most compelling case for labour hoarding, have seen some of the highest labour gains but without commensurate increases in output. For example, from 2019Q4 to 2023Q3, professional services, and information and cultural industries saw respective annualized growth of 6.8 and 3.3 per cent in employment and 6.8 and 2.6 per cent in total hours. However, these sectors saw some of the greatest declines in productivity as real GDP growth was much lower than employment and hours growth. That said, the output gains in these sectors are also some of the highest, suggesting the strong employment growth was not purely driven by labour hoarding, but also by the strong growth of these sectors.

The labour market has played a large role in labour productivity growth post-COVID and may continue to do so over the near-term. However, labour market developments may only have temporary impacts and, with sufficient time to adjust, there is no fundamental barrier to productivity growth as a result of the growth in employment. Over the long run, capital and innovation assume a more important role in determining productivity. In this context, the usefulness of Canada's recent experience for setting expectations about medium term productivity growth is questionable. It remains uncertain when the

8 For example,for Canada see: Lord, 2020; Olive, 2023; for the United States: Weiss, 2022; Wallace, 2023; Kemp, 2023; Aeppel, 2023

Table 2: Annualized Quarterly Labour Productivity Growth, 2019Q4 – 2023Q3

Per cent	Real GDP	Employment	Hours	Labour Productivity
Total economy	1.1	1.3	1.2	-0.1
Business Sector	0.6	1.2	1	-0.4
Goods	-0.1	0.8	0.6	-0.7
Agriculture, forestry, fishing and hunting	-3	-3.2	-4.5	1.6
Mining and oil and gas extraction	1.8	1.1	0.8	0.9
Utilities	-1.4	1.8	0.7	-2.1
Construction	0.4	1.8	1.8	-1.4
Manufacturing	-0.5	0.6	0.5	-1
Services	0.8	1.3	1.2	-0.4
Wholesale trade	0.7	1.3	1.1	-0.4
Retail trade	1.7	-0.3	-0.3	2
Transportation and warehousing	-2.3	0.3	-0.3	-2
Information and cultural industries	0.9	3.3	2.6	-1.7
Finance and insurance, and holding companies	1.7	1	0.7	1
Real estate and rental and leasing	-0.4	-2.3	-2.1	1.7
Professional, scientific, and technical services	3.3	6.8	6.8	-3.2
Administrative, waste and remediation	-1.9	0.8	0.9	-2.7
Arts, entertainment, and recreation	-2.3	0.8	0.1	-2.4
Accommodation and food services	-2.1	-0.9	-1.1	-1
Other business services	1.9	2.1	1.8	0.1
Non-business sector and others	2.3	1.7	1.9	0.4

Source: Statistics Canada Table 36-10-0206-01 and 36-10-0207-01. Authors' calculations.
Note: Labour productivity defined on a per-hour basis.

current trend will reverse and how long it will take to recoup the declines in productivity levels that have been experienced. Naturally, the longer this process takes, the more important it becomes to consider whether structural factors are impeding the recovery of productivity.

International Comparison of Long-run Productivity Growth

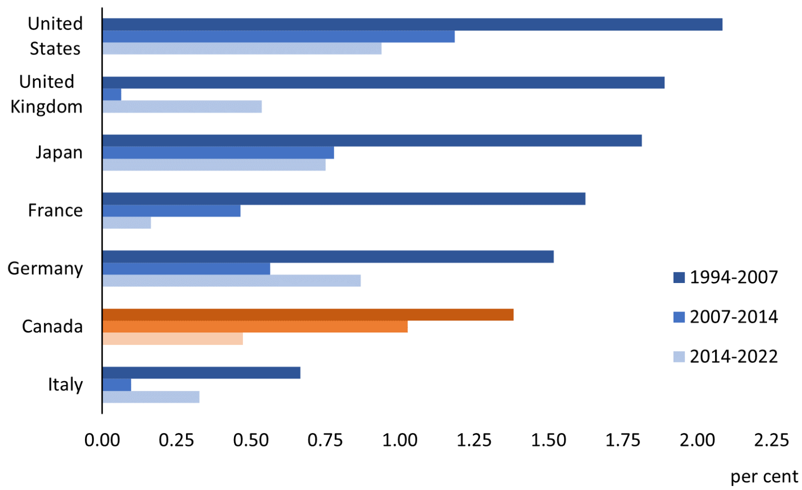
In addition to the slowing productivity growth over the decades, Canada's productivity has been lagging many of its G7 peers. At the total economy level,[9] Canada's productivity growth over the 1994-2022 period averaged 1.0 per cent, ahead of Italy and France. Canada's growth was particularly weak in comparison to the United States which experienced annual growth of 1.5 per cent.

However, this long-term view masks periods of relative strength and weakness. From 1994 to just before the Great Recession, Canada's productivity growth ranked second last in the G7, averaging 1.4 per cent per year (Chart 5). Between 2007 and 2014, this growth deteriorated to just 1.0 per cent per year. This decline was broadly experienced by all of Canada's G7 peers and felt by some as early as 2000. And, though no factor can be identified as the cause, some think that it may be due to recent technological advancements not having the same punch to boost productivity as those introduced earlier in the post-

9 International comparisons must be made at the total economy level as the OECD data does not have complete coverage of the business sector and the availability of business sector productivity data for Canada in OECD datasets is limited to the period from 2008 to 2019.

10 This is the technological pessimist opinion most associated with Gordon (2012).

Chart 5 :Labour Productivity Growth, Total Economy – G7 Countries (Average Annual Rate of Change)



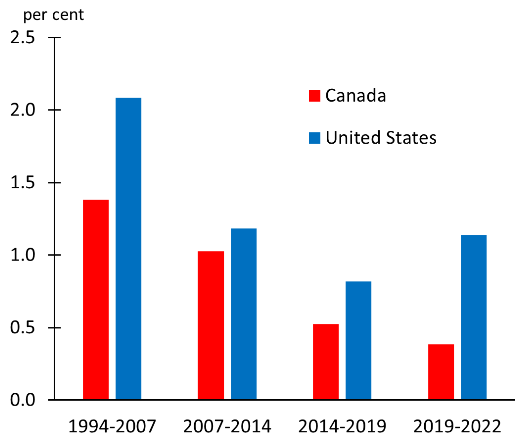
Source: OECD Productivity and ULC – Annual, Total Economy database, Authors' calculations
Note: Labour productivity reflects GDP per hour worked in the total economy. Growth rates reflect the average geometric growth rate over the three different periods. The base year for these calculations is the first year shown in each label.

war era.[10] Yet, what is key to understand Canada's relative performance is that its decline was small, allowing its performance to improve to second in the G7 during the 2007-2014 period.

Canada's relative improvement in productivity growth after the 2008-09 Financial Crisis was notable enough that it led some to anoint Canada as one of the leaders among G7 countries (Tang and Wang, 2020). However, this was short lived. The relatively stronger productivity growth in Canada that followed the Financial crisis soon slowed in 2014, partly as a result of an economic shock due to the sharp decline in commodity prices , and continued until the beginning of the pandemic. Although productivity in Canada surged during the first year of the pandemic, it then normalized as hours worked rebounded faster than output. But well after the initial economic recovery, labour productivity continued to trend downwards, contracting over the last few quarters. All in all, Canada's productivity growth over 2014-2022 has declined to 0.5 per cent and ranks fifth in the G7 over this period, only ahead of Italy and France.

A similar trend is seen when comparing Canada to the United States (Chart 6). From 1994 up to the Financial Crisis, U.S. productivity growth was about 0.7 percentage points higher than in Canada. Between 2007 and 2014, while Canada's productivity growth declined modestly, the United States experienced a larger deceleration in productivity growth which narrowed the Canada-United States gap. However, in the wake of falling commodity prices in 2014-2015, Canada's performance relative to the United States was on the decline again, similar to how it performed relative to other advanced economies (Chart 5). This gap has continued to widen over the pandemic and subsequent recovery with the percentage-point gap over 2019-2022

Chart 6 :Labour Productivity Growth, Total Economy – Canada and the United States (Average Annual Rate of Change)



Source: OECD Productivity and ULC – Annual, Total Economy database, Authors' calculations.
Note: Labour productivity reflects GDP per hour worked.

reaching back to the level last seen over 1994-2007.

As a result, productivity levels compared to the United States have deteriorated significantly over time. Chart 7 shows that Canada's productivity relative to the United States has declined 16 percentage-points from the mid-1980s, when Canadian productivity was just shy of 90 per cent of the U.S. level, to 2022, where it stood at 72 per cent. Canada's relative productivity dipped to a low of 71 per cent in 2010 but plateaued around 74 per cent from 2015 to just before the pandemic.

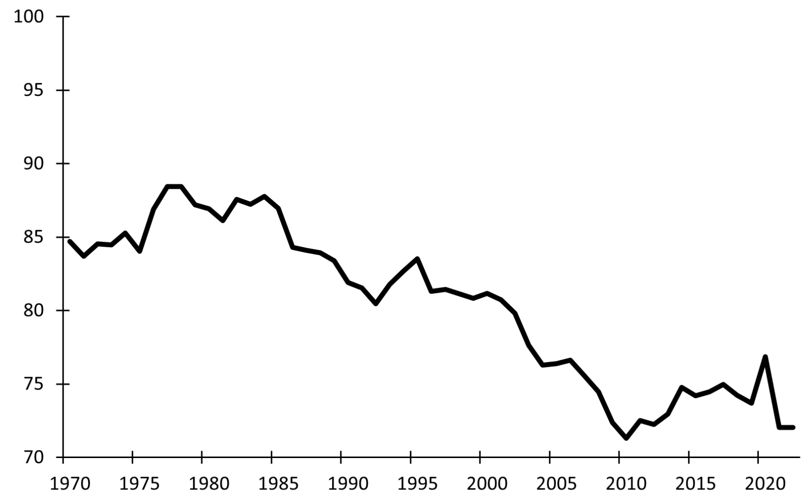
Investment and Productivity Growth

A lack of investment in Canada is often cited as a key driver of its poor productivity performance vis-à-vis other advanced economies. The story is complex and there is a tendency for commentators to place excess focus on the objective of boosting investment for the sake of boosting investment. For example, many would be surprised that the contribution of productivity growth from capital deepening was about the same in Canada as in the United States between 1999 and 2019 with only 0.06 percentage-point difference on average (Chart 8). The contribution of TFP to labour productivity growth was, however, much weaker in Canada with a 0.76 percentage point gap compared to the United States over the period. Although difficult to estimate, some of this is due to weaker investments in Canada in the types of capital (such as Information and Communications Technologies, ICT) that would have the capacity of boosting TFP and how well capital investments are exploited by Canadian businesses.

International Comparison of Long-run Productivity Growth

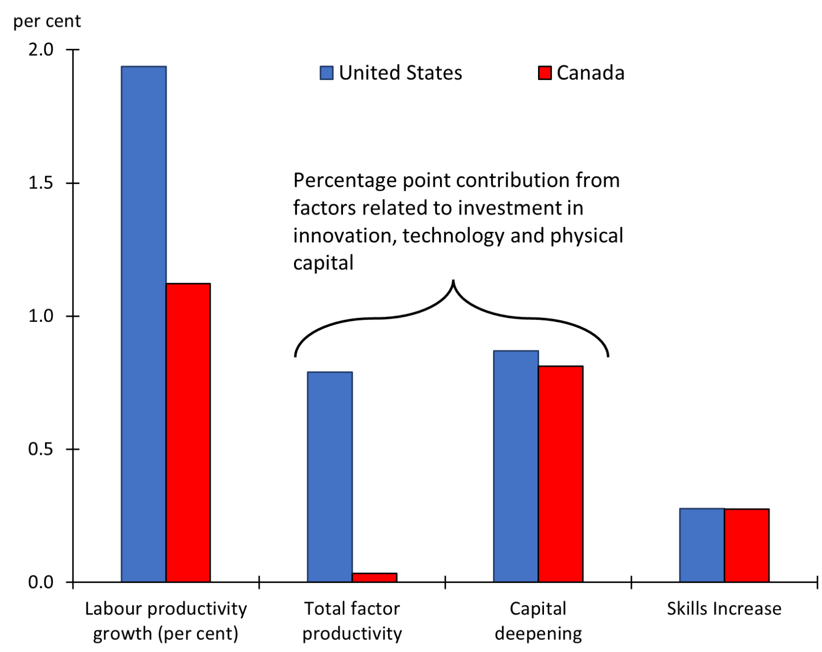
A major shortcoming in Canada's investment performance has been lagging investments in productivity-enhancing tech-

Chart 7: Canada-United States Relative Labour Productivity Level, Total Economy, 1970-2022 (United States = 100)



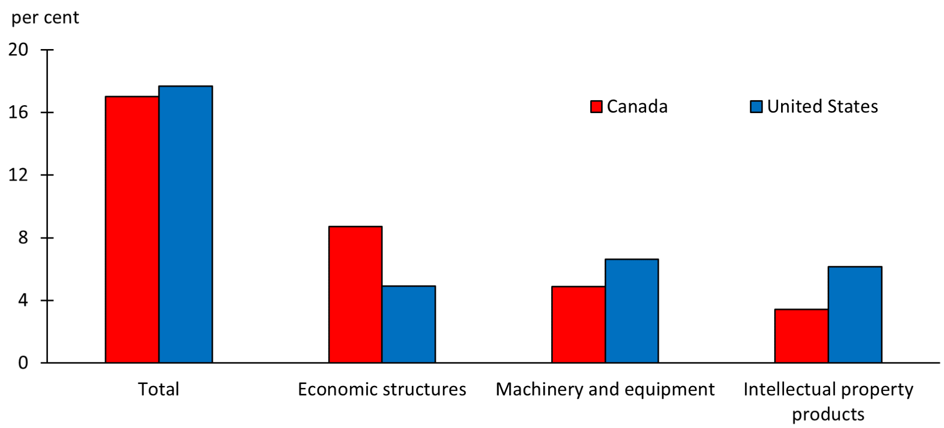
Source: OECD Productivity and ULC – Annual, Total Economy database, Authors' calculations Note: Labour productivity reflects GDP per hour worked. Relative productivities are evaluated in constant prices and adjusted for purchasing power.

Chart 8: Canada-United States Decomposition of Labour Productivity Growth in the Business Sector*, 1999-2019



Source: Canada: Statistics Canada Table 36-10-0208-01; United States: U.S. Bureau of Labour Statistics, Authors' calculations.
Note: Labour productivity reflects real GDP per hour worked. *Data reflects growth in the business sector for Canada and the private business sector for the United States

Chart 9: Non-residential Investment Intensity by Type of Investment – Canada and the United States, 2019

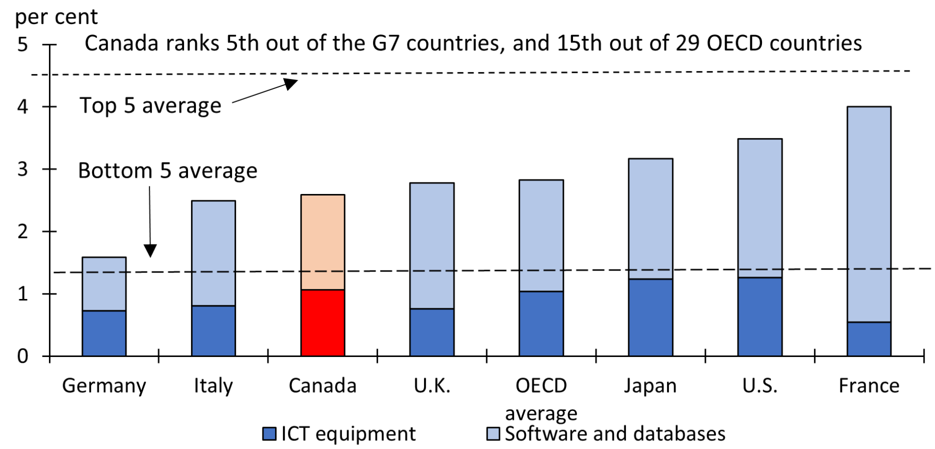


Source: OECD and authors' calculations.
Notes: Investment intensity is calculated by dividing nominal investment by gross value added for the total economy. Canadian gross value-added data is adjusted using GDP PPPs, while Canadian investment data is adjusted using nominal gross fixed capital formation PPPs. Does not include investment in dwellings.

nologies such as machinery and equipment (M&E) and intellectual property products (IPP). When looking at total investment (gross fixed capital formation – construction excluding dwellings, M&E and IPP – by all sectors) intensity in Canada compared to the United States, there is only a small difference (17.0 vs. 17.7 per cent of nominal PPP-adjusted GDP). However, this masks significant differences in the composition of investment. While Canada has significantly higher investment intensity in economic structures (i.e. non-dwelling structures) due in part to its relatively larger resource extraction sector, it has significantly lower investment intensity in IPP (e.g. investment in research and development, or software and databases) and M&E (e.g. transportation and ICT equipment) (Chart 9). Lower investment intensity in these assets was seen across most industries, including the manufacturing and the ICT sectors. This is not to say that investment in structures is not important for productivity. However, investment shortfalls in M&E and IPP underweights the direct link these investments can make to an individual worker's productive capacity as they provide tools necessary to implement new ideas and become more productive in a technology-driven economy.

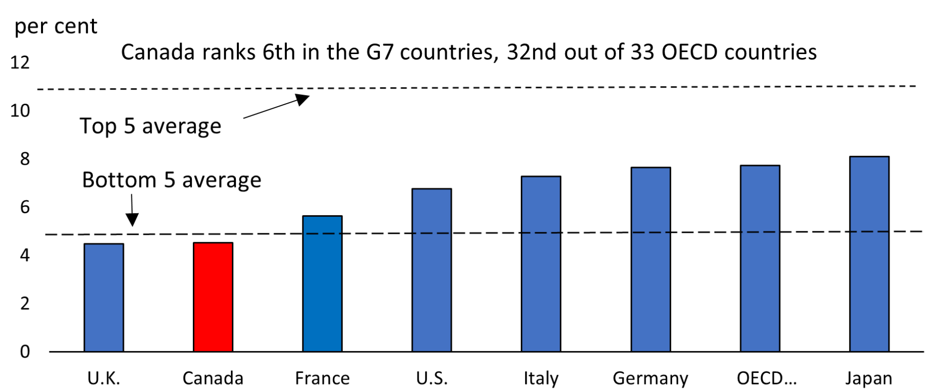
Canada's poor investment performance in key capital assets is not limited to the comparison to the United States For instance, with M&E investment intensity at 4.5 per cent, Canada was ranked nearly last among 33 OECD countries over 2015-2019 (Chart 10). Canada does slightly better when examining ICT investment, including both ICT hardware and software (Chart 11). In ICT investment intensity, Canada ranked around the middle of OECD countries and 5th out of the G7 countries. However, the overall ICT investment figure is mostly driven by the relatively better performance in physical ICT equipment (3rd among the G7), rather than intangible ICT assets such as software and databases.

Chart 10: Average Annual Machinery and Equipment Investment Intensity G7 Countries, 2015-2019



Source: OECD and authors' calculations.
Notes: Investment intensity is calculated by dividing machinery and equipment and weapon systems investment by gross value-added for the total economy. OECD countries are only included if they have data for every year under consideration. Top 5 and bottom 5 are among the countries with data.

Chart 11: Average Annual ICT Equipment and Software and Database Investment Intensity G7 Countries, 2015-2019



Source: OECD and authors' calculations.
Notes: Investment intensity is calculated by dividing ICT equipment and software and database investment by gross value-added for the total economy. OECD countries are only included if they have data for every year under consideration for both ICT and software and database investment. Top 5 and bottom 5 are among the countries with data, and their averages reflect total rate of ICT equipment and software and database investment rates.

When looking only at those two assets, Canada is second last in the G7.

Sectoral Composition and Investment Intensity

There are several factors that could be behind Canada's weak investment performance, some of which we explore in Section 4. However, one factor that does not seem to be a major driver of this weak investment performance is the sectoral composition of Canada's economy. Although some sectors naturally invest more in M&E and IPP than others, Canada's weak investment is broad-based and does not appear to be purely driven by its sectoral composition.

Charts 12 and 13 show the differences in investment intensities in M&E and IPP between Canada and the United States decomposed into the difference in sectoral composition (structural effect) and within sector gaps (intensity effect). The results show that within sector intensity gaps rather than structural effects are the main factor behind Canada's weak investment performance vis-à-vis the United States Of the 3.3 percentage-point gap in IPP investment between Canada and the United States in 2019, almost 80 per cent of it is due to intensity effect. Similarly, all of the 2.3 percentage-point gap in M&E investment intensity is due to intensity effect.

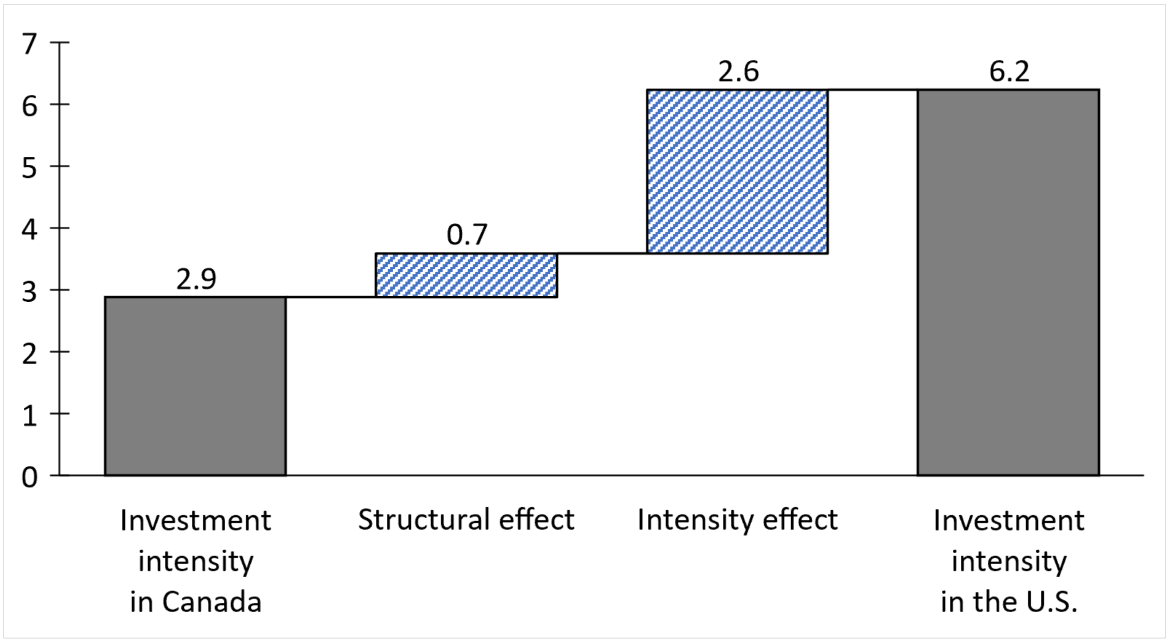
These results highlight the significant gap in investment performance for Canada as compared to other advanced economies and the broad-based need to improve the investment intensity across sectors. Will the situation for Canada be better in the post-COVID world? So far, Canada's economic recovery has been driven by growth in employment, and a corresponding increase in investment has yet to materialize. One might expect that investment would catch up to allow for a rebalancing of the capital to labour ratio. With a steep rise in employment, the marginal productivity of capital increases, which should create greater incentives for investment, and as time progresses, more investment could take place in Canada.

That said, there are also headwinds against investment in the current economic environment. The cost of capital has risen with the increases in the interest rate. Although real wage growth has been stronger lately, making investment more attractive, the rise in capital cost has been as high, if not higher, potentially offsetting investment incentives. Adding to these headwinds is Canada's long-standing weak investment performance, driven by the poor performance within each sector. Regardless of the near-term advantages or challenges, it is important to understand potential factors behind Canada's broad-based long-standing poor investment performance, some of which are explored in the next section.

Potential Factors behind Investment and Productivity Performance

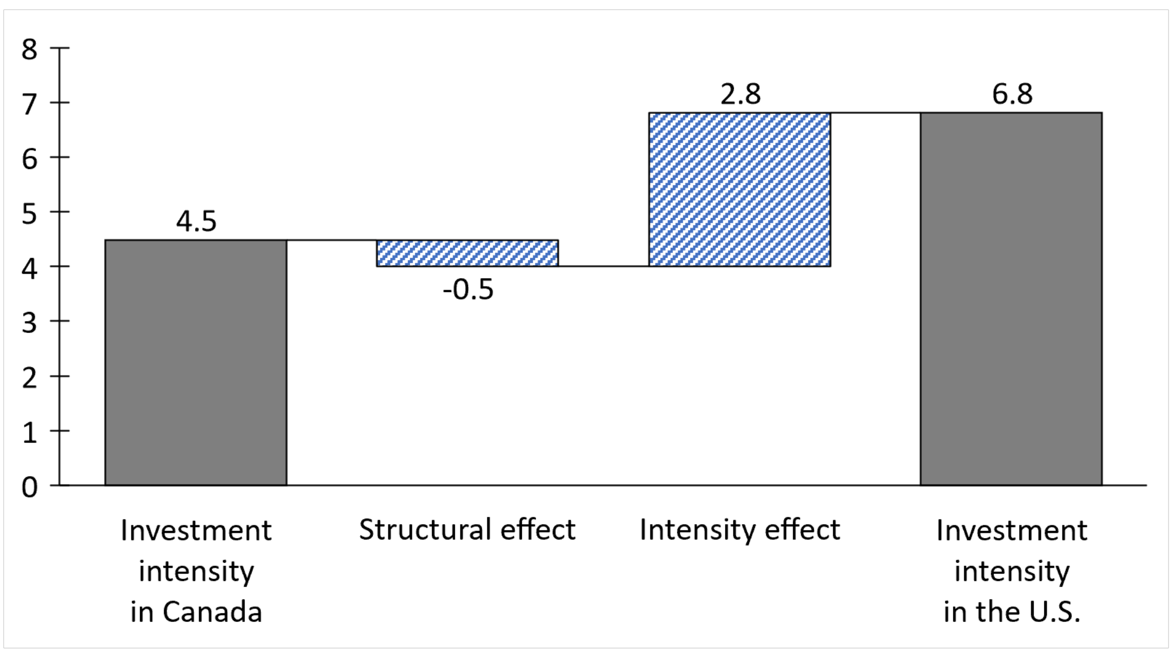
No one factor is responsible for Canada's low investment and weak productivity performance on its own; various components shaping the country's economic environment contribute to these issues. These factors are often interrelated and self-reinforcing, for example some of the fac-

Chart 12: Decomposition of Intellectual Property Products Investment Intensity – Canada and the United States, 2019



Source: OECD and authors' calculations.
Notes: Investment intensity calculated by dividing gross capital formation by gross value added in that industry. Canadian data is adjusted using 2017 PPPs. Business sector investment excludes public administration, education, and human health and social work activities.

Chart 13: Decomposition of Machinery and Equipment Investment Intensity – Canada and the United States, 2019



Source: OECD and authors' calculations.
Notes: Investment intensity calculated by dividing gross capital formation by gross value added in that industry. Canadian investment data is adjusted using 2017 PPPs. Business sector investment excludes public administration, education, and human health and social work activities.

tors highlighted below are a symptom of weak competition, while others are likely contributing to weakness in competition. Some factors are observed across many advanced economies, others are more unique to Canada. Further still, some of these factors have worsened over the last decade, while others are more static but their impacts may have been amplified due to other ongoing trends (e.g., interactions between market size and growing importance of agglomeration and network economy).

In this section, we examine various potential factors behind the poor investment and productivity performance, namely:

- Small market size and dispersed markets;
- Regulatory framework;
- Large presence of small firms;
- Zombie firms in Canada;
- Growing gap between frontier and non-frontier firms;
- Skills and skill mismatch; and
- Management education.

The factors are not listed by order of importance and are by no means exhaustive. We have selected them in part to highlight the diversity of likely factors and draw focus on the difficulties inherent in addressing these areas of concern. Some factors such as regulatory issues could be addressed through direct policy changes while others such as an abundance of small firms pose more nuanced challenges.

Small Market Size and Dispersed Markets

Canada is a relatively small country with markets scattered across a large landmass, limiting economies of scale in local markets. For instance, the Quebec City-Windsor corridor, the most densely populated area in Canada, is 1100 km long representing a large distance between major cities. Vancouver, which is the third largest city in Canada, is nearly 1000 km away from the next major city, Calgary. Although free trade and modern transport and communications have greatly alleviated this challenge, the literature has shown that the international borders and distances between cities can still pose barriers to productivity growth.

Ahrend *et al.* (2017) finds that a 10 per cent rise in the distance-weighted count of city residents within a 300 km radius is associated with a 0.1–0.2 per cent increase in productivity. This implies that cities can, to some extent, leverage the agglomeration of their neighboring counterparts. Likewise, OECD (2015) finds that spillovers from larger cities to smaller cities and surrounding regions are significant. In particular, population growth in smaller municipalities is higher the closer they are to large cities while cities with more than half a million inhabitants experience significantly higher growth than those without a large urban centre.

The impacts of distance and density seem to also apply to innovation and investment performance as they ease search frictions in labour and product markets, which helps with attracting high-skill workers, facilitating economies of scale, and fostering start-up communities. Carlino and Kerr (2015) find that there are positive innovation spillover effects of being within one mile of another company in one's own industry, which is at least 10 times greater than the positive effect realized when locating two to five miles away. Turning to investment, research based on German data estimates that the probability of a financing relationship decreases if the journey time increases (Lutz *et al.*, 2013).

Regulatory Framework

Regulations are critical for protecting consumers, the environment, and social objectives. Regulations also have an essential role to play in providing certainty to businesses seeking to make investments. Ensuring that regulation is well tuned to meet multiple objectives and balance appropriate trade-offs poses a challenge for all governments. An excessively restrictive regulatory environment has clear consequences for business costs, competitiveness, and investment incentives. This direct effect receives much of the attention and call for action. However, poorly tuned regulation can also have potentially more negative effects on competition in cases where they limit contestability by presenting barriers to entry.

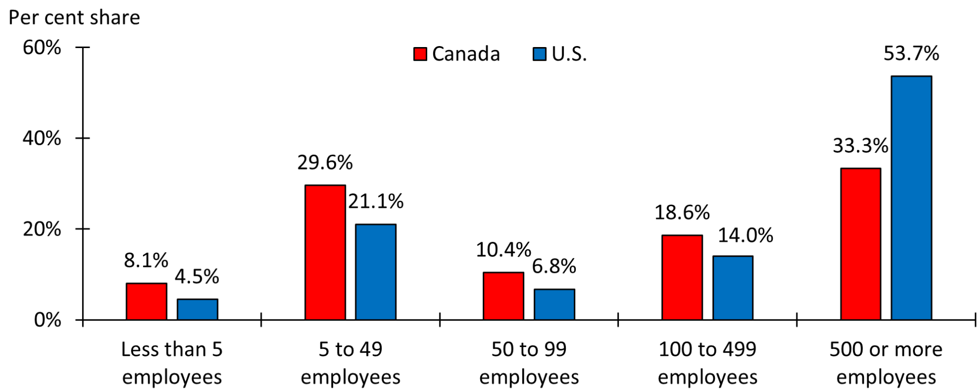
The OECD's Product Market Regulation (PMR) index attempts to provide a measure of the restrictiveness of regulations in terms of deviation from best practices. At the economy wide level Canada's regulatory system ranks in the bottom 5 among OECD countries (2018 PMR Index). Of particular concern are regulations that raise barriers to trade and investment (e.g. barriers to FDI, barriers to trade facilitation, and differential treatment of foreign suppliers) as these can limit competition and opportunities for technology spillovers from abroad in important areas of the economy. Improving regulations could have significant positive impacts on productivity growth. ab Iorwerth and Rosell (2018) estimate improving the general competitiveness of regulations in Canada (as measured in the PMR) to the standard of better performing peers like the United States has the potential to raise GDP per capita by as much as 5.3 per cent in the long-run.

The challenges of establishing efficient and well-balanced regulations in Canada is made more difficult by the division of regulatory authorities across Canada's different levels of government. This is most apparent in the area of inter-provincial trade and labour mobility where despite improvements over the years, regulatory difference between provinces and territories continue to inhibit the potential for productivity gains through lower costs, greater economies of scale, and improvement in allocative efficiency. The impacts on productivity from regulatory misalignments and other barriers to internal trade is difficult to assess but could be significant. For example, the Bank of Canada (2017) estimated that a 10 per cent reduction in internal trade barriers in Canada introduced in 2018 could increase potential output growth by an average of 0.2 percentage points per year out to 2020. Likewise, an International Monetary Fund study by Alvarez *et al.* (2019) estimates that a complete removal of internal trade barriers in Canada could increase GDP per capita by as much as 4 per cent.

Large Presence of Small Firms

Canada has a large number of small firms, and when compared to the United States a larger portion of our labour force is

Chart 14: Distribution of Employees by Enterprise Size, Non-agricultural Business Sector, 2019



Sources: Statistics Canada Table 14-10-0215-01. U.S. Census Statistics of U.S. Businesses. Authors' calculations.
Notes: Unclassified businesses and Agriculture (NAICS 11) are excluded. Public Administration (NAICS 91) is excluded from Canada to align with U.S. Private Sector estimate. Enterprises with over 500 employees in Educational Services and Health Care (NAICS 61 and 62) in Canada were excluded, as they were assumed to be public sector enterprises. Employee counts exclude enterprises without paid employees.

concentrated in small firms (Chart 14). In Canada, large firms (500 or more employees) only accounted for one-third of employment while the figure was more than half for the United States in 2019.

This high concentration of resources tied to small firms could be contributing to Canada's poor productivity performance as small firms tend to be less productive on average compared to larger firms, in part as a function of their limited ability to benefit from economies of scale. For example, Baldwin *et al.* (2014) find that, in Canada, small firms (i.e., those with less than 500 workers) were 47 per cent as productive as large firms (i.e., those with 500 or more workers). As a result, they estimate that the relative abundance of smaller firms in Canada and their much lower productivity compared to large firms account for about 60 per cent of the aggregate labour productivity gap between Canada and the United States countries in 2008 . In the same research, large Canadian firms performed relatively on par with their U.S. counterparts, although the data used in the study is now quite dated and since then the United States has seen the emergence of a number of super-star firms in high-tech sectors.

The large presence of small firms in Canada may have more significant implications than their own contributions to the aggregate productivity. Research has shown that there could be congestion effects among firms, where they compete for inputs in short supply (e.g. labour), and having a large number of unproductive small firms competing for the resources that can be used by more productive firms may hinder the latter's performance.[11] Such congestion effects could also pose as a barrier to scaling-up by produc-

11 For example, Banerjee and Hofmann (2020) find that zombie firms, which tend to be smaller, create congestion effects by competing for resources that negatively affect other firms and reduce aggregate productivity.

tive small firms, which in turn, would hinder their ability to challenge large firms and may end up creating a fragmented marketplace with lower aggregate productivity as a result. We explore these issues further in the next two subsections (4.4 and 4.5).

Zombie Firms in Canada

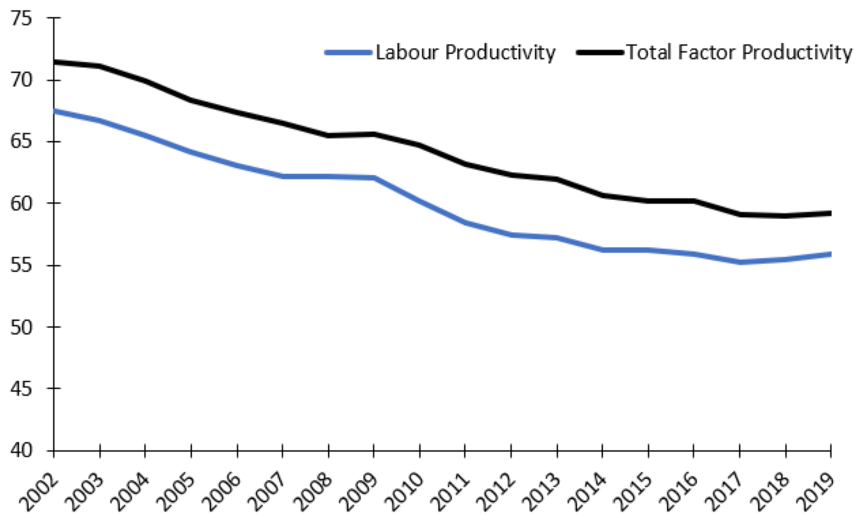
There has been a growing interest in understanding the effects on aggregate productivity from firms that are systemically underperforming from a financial perspective (Hoshi, 2006; Acharya *et al.*, 2019; Carreira *et al.*, 2022). These firms are colloquially referred to as zombie firms and are commonly defined as at least 10 years of age with earnings less than interest payments for three consecutive years (Amundsen *et al.*, 2023), although various definitions exist in the literature. These zombie firms weigh on aggregate productivity growth both directly as they tend to be less productive than healthy firms, and through their impact on allocative efficiency as their failure to exit traps resources that would be otherwise used by more productive firms.

Thus far, much of the research on zombie firms in Canada has focused on Canada's relatively small number of publicly traded firms. This research finds that as in other countries Canada has seen an increasing prevalence of zombie firms. Banerjee and Hofmann (2020) estimate that the share of zombie firms increased from about 5 per cent in 1985 to 35 per cent in 2017. Likewise, Altman *et al.* (2021) estimate the share increased from 4 per cent to 25 per cent between 1990 and 2021. However, a recent working paper by researchers at Statistics Canada and the Department of Finance Canada (Amundsen *et al.*, 2023) which leverages the universe of firms in Canada, puts the share at between 5 to 7 per cent of all firms and finds that rather than an increasing prevalence of zombie firms in Canada, it is their worsening productivity performances relative to healthy firms that is of greater consequence for aggregate productivity.

Amundsen *et al.* (2023) finds that when looking at the universe of firms in Canada, the share of zombie firms did not materially increase between 2002 and 2019, although they are more prevalent in some industries than others (e.g., Arts, entertainment, and recreation; Mining, quarrying and oil and gas extraction; Real estate and rental leasing; Wholesale trade). However, the relative productivity of zombie firms to healthy firms declined substantially over the period from 67 per cent to 56 per cent (72 to 59 per cent when for TFP) (Chart 15). All told, the presence of zombie firms is estimated to have reduced the aggregate level of labour productivity by 4 per cent in 2019, up from 2 per cent in 2002. This is a large effect. For example, based on the estimate for 2019, the implied gains from eliminating zombie firms would equate to more than $2,800 per person and would be of the same order as the estimated gains from complete liberalization of internal trade in goods in Canada as suggested by Alvarez *et al.* (2019).

Amundsen *et al.* (2023) also show that an increasing share of zombie firms within an industry could negatively impact the performance of the industry as a whole. The results show as the capital and payroll share of zombie firms increase, labour productivity declines at a rate of 0.6 and

Chart 15: Labour Productivity of Zombie Firms Relative to Healthy Firms in Canada, 2002-2019



Amundsen, Lafrance-Cooke, and Leung (2023).

1.0 percentage points, respectively, for each 1 percentage point increase in share. Although these results only imply a correlation, not necessarily causation they do provide some suggestion that the presence of zombie firms could be affecting the performance of healthy firms.

Growing Gap between Frontier and Non-frontier Firms

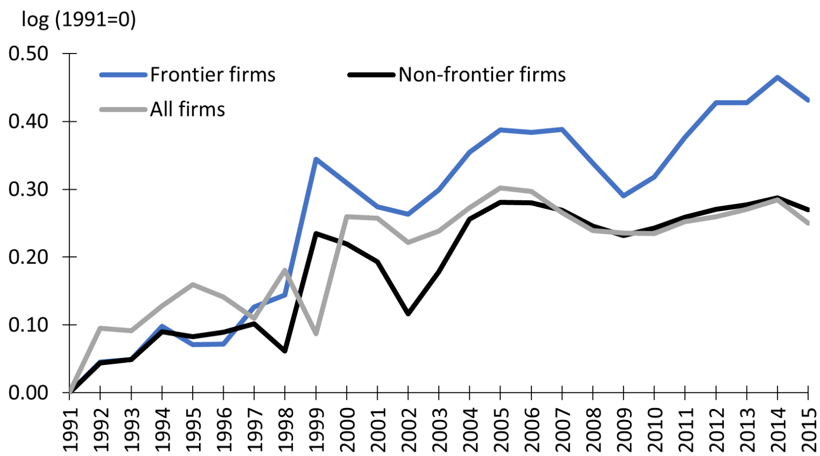
Just as zombie firms are falling increasingly behind healthy firms in productivity, frontier firms (i.e. firms that are at the leading edge of their respective industries in terms of productivity) are pulling farther ahead.[12] OECD analysis by Andrews *et al.* (2015)[13]has highlighted the productivity gap between non-frontier and frontier firms as a factor behind productivity slowdown observed in many OECD countries after 2000. This line of research suggests that slowing technology diffusion from global frontier firms to national frontier firms, which in turn slow down technology diffusion from national frontier firms to national non-frontier firms, may have been a factor behind the productivity slowdown observed in advanced economies.

Research conducted by Statistics Canada provides a similar insight for Canada. In particular, Gu (2020) shows lower productivity growth of national non-frontier firms in Canada accounted for about 90 per cent of the decline in Canadian aggregate productivity growth be-

12 The definition of frontier firms varies in the literature. The OECD (i.e., Andrews *et al.*, 2015) defines frontier firms using an absolute measure. Specifically, "global" frontier firms are the top 50 or 100 globally most productive firms within each year in each industry while "national" frontier firms are the top 10 most productive firms nationally each year within each industry. In contrast, Gu (2020) uses a relative measure. It defines national frontier firms as the top 10 per cent most productive firms in an industry each year. Gu (2020) focuses on Canadian firms and cannot consider global frontier firms.

13 This analysis used firm-level data across selected OECD countries. However, Canadian data was not included.

Chart 16: Labour Productivity of Frontier and Non-frontier Firms, 1991-2015



Source: Gu (2020).
Note: Log values of labour productivity are set to 0 in 1991.

tween the 1991-2000 and 2000-2015 periods. However, in contrast to the OECD study that finds evidence of strong catch-up from national non-frontier firms since the early 2000s, Gu (2020) finds that the productivity gap between the most and less productive in Canada has actually increased, continuing the trend observed before 2000 (Chart 16).[14]

The increasing performance gap between frontier and non-frontier firms is a concern because it could affect incentives for non-frontier firms to invest. Bérubé *et al.* (2012) find that, in the manufacturing sector, competition's influence to spur research and development (R&D) diminishes as the distance to the frontier grows. This result would be consistent with Gu (2020), in that a widening productivity gap between frontier and non-frontier firms could be because of the difference in investment and innovation performance. This could be driven by a declining incentive and capacity to compete against frontier firms as the gaps in productivity increases.

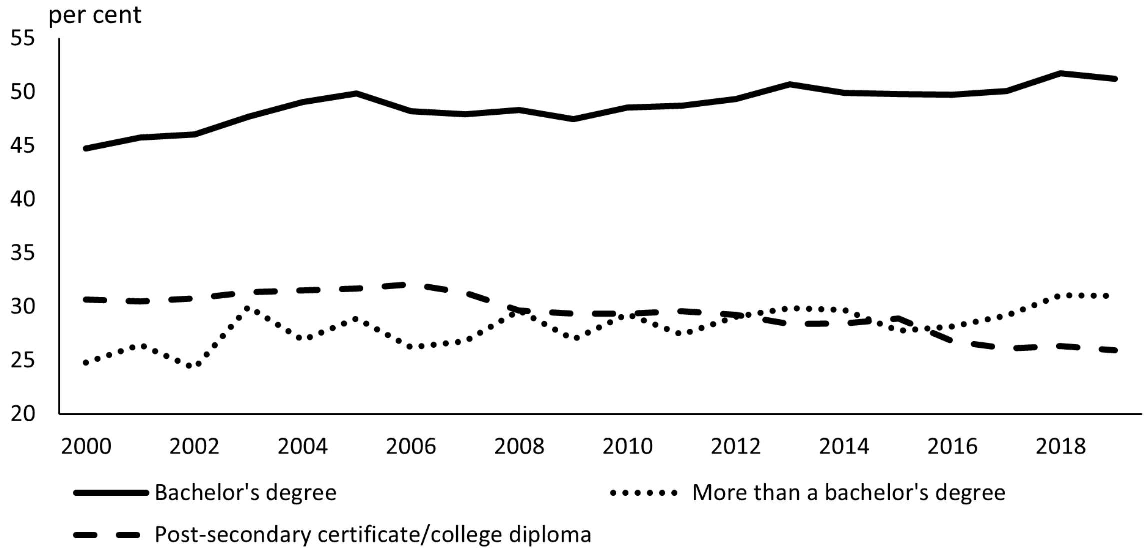
Skills and Skill Mismatch

Canadians are very well educated—the share of post-secondary educated Canadians in the 25 to 64 age group increased from 39 per cent in 1999 to 59 per cent in 2019, the highest share in the OECD and well above close peers like the United States (48 per cent in 2019). However, the story is more complex than these statistics suggest on their own. Canada sat behind our OECD peers in 2019 in terms of higher education ranking 18th out of 38 OECD countries in terms of the share of the population aged 25-64 with a university level

14 Andrews *et al.* (2015) contend that while diffusion is slow, the technology bottleneck resides where technologies make their way from the most productive firms globally to the most productive firms in each country.

15 In the OECD, Canada has the highest share of people who have attained a non-university post-secondary education (e.g., certificates or diplomas from a community college, CEGEP, or school of nursing). This share stood at 26 per cent in 2019 and combined with the share of people with a university education (i.e., 33 per cent had a Bachelor's degree or higher).

Chart 17: Share of Overqualified Workers in Employment by Education Level, 2000-2019



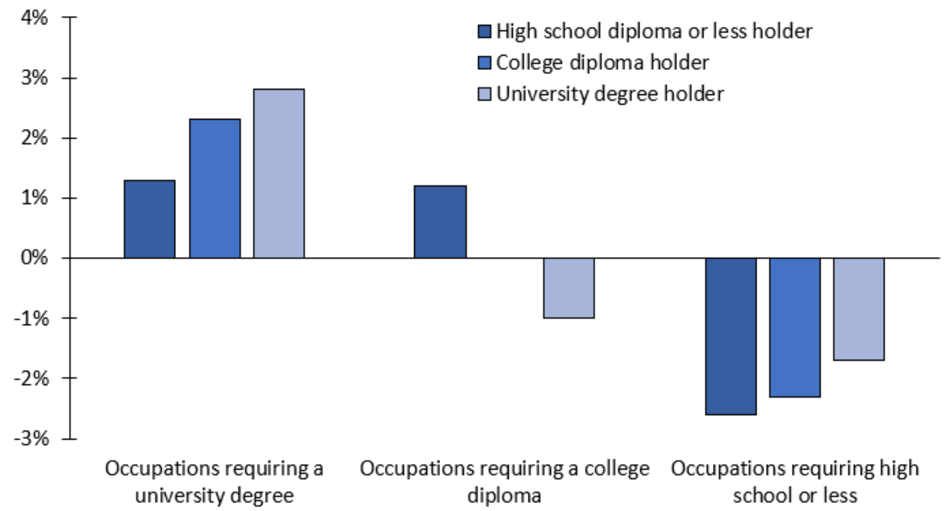
Source: Statistics Canada, Labour Force Survey, RTRA., Authors' calculations.
Notes: Sample is restricted to full-time, non-managerial workers aged 25-54 with a bachelor's degree. Overqualification defined as a worker employed in a job not requiring a university degree.

education.[15] This is despite the significant increase in the share of Canadians with university level education from 19 to 33 per cent between 1999 to 2019. Interestingly, the number of new STEM graduates as a share of the 25- to 34-year-old population was comparable to the United States in 2019 at 1.4 per cent. This is however lower than in other peer countries including Germany (2.3 per cent), France (1.9 per cent), and Finland (2.4 per cent).

Increased levels of educational attainment do not however guarantee that skills will be fully utilized. Even if workers have the skills that are in-demand by the business sector, they may not be currently matched with a job that requires their level of skill. In 2019, approximately a third of all post-secondary educated workers were employed in jobs that did not require post-secondary education. This is especially significant for bachelor's degree holders, whose rate of overqualification has increased from 45 per cent in 2000 to 52 per cent in 2019 (Chart 17). This increase is, at least partially, due to relatively slow growth in jobs requiring a university degree. From 2000 to 2019, the share of jobs requiring a university degree grew less than half as fast as the share of individuals with a university degree. Limiting overqualification can have significant impacts on productivity. For example, based on data for 19 countries, McGowan and Andrews (2015) estimate that a 1 per cent decrease in the rate of overqualification can increase productivity by 1.3 per cent.

Despite this longer-term trend of overqualification, since the pandemic there have been shifts in the types of employment available and skills that are demanded. Jobs in industries which typically require a higher level of education have been increasing fastest. In particular, as of 2023Q2 the number of jobs in Information and cultural industries is 15.1 per cent higher than

Chart 18: Change in Occupational Employment Share by Educational Attainment, 2019-2022



Source: Statistics Canada, Labour Force Survey, RTRA. Authors' calculations.

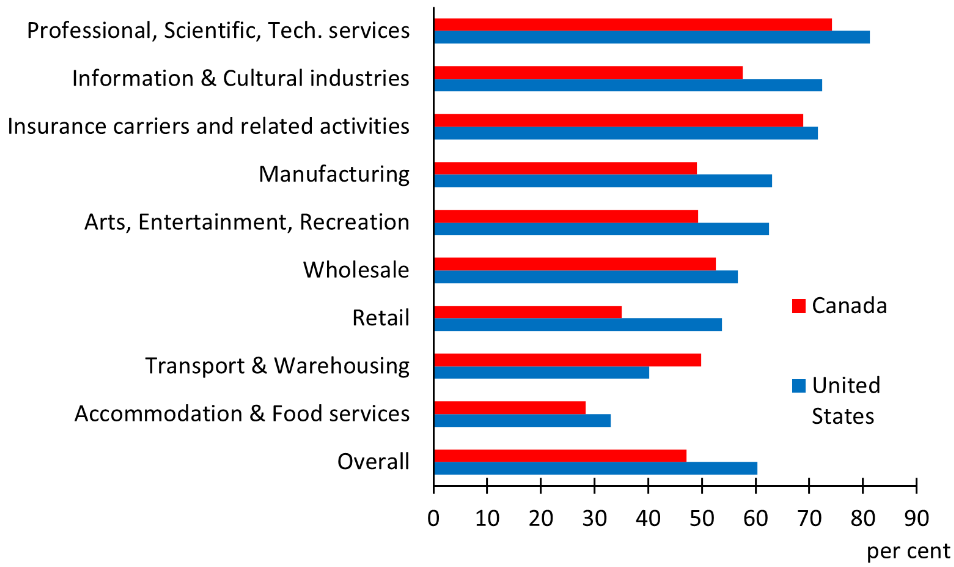
it was pre-pandemic (3 times faster employment growth than the overall economy since 2019Q4), and professional, scientific and technical services is a staggering 28.7 per cent higher (nearly 6 times faster than overall employment growth).

These sectoral shifts have led to more workers occupying higher-skill jobs, regardless of their own education level. Chart 18 shows that employment in occupations requiring a university degree has increased more than any other category, but these jobs are being filled not just by university degree holders, but by college diploma holders and those with high school or less. This could be evidence of a partial correction of previous over-qualification issues. However, this trend could also signal an increase in under-qualification or inexperience problems in the current labour market that could ultimately be negatively impacting productivity. Further research will be needed to better understand the implications of this shift including whether it will have transitory or more persistent impacts on Canada's productivity.

Management Education

Related to the skill issues, the education level of managers in Canadian firms has been raised as a possible impediment to productivity growth and weaknesses in innovation focused investment. The impacts of high-quality management practices on firm performance, productivity and innovation have been well documented (Bloom *et al.*, 2013; Brouillette and Ershov, 2014), as have the effects of university education on better management practices Bloom (2011). Intuitively, the positive link between management education and better firm performance makes sense. Managers are responsible for making important decisions, often under clouds of uncertainty. It is important to have broad-based knowledge and understanding of the world to be able to make an informed decision that helps the company. This link is likely more important as the economy becomes more

Chart 19: Share of university managers in selected industries and overall, 2021, Canada and US



Source: Statistics Canada Labour Force Survey, RTRA; U.S. Census Bureau Current Population Survey. Author's calculations.
Note: Shares of managers with a university degree reflects the portion of managers 30-64 years of age in 2021 with a bachelor's degree or higher.

technology-driven as the education is more critical to understanding the technology.

In Canada, managers are generally less educated than their U.S. counterparts, in that Canadian managers are less likely to have university education, despite being more likely to have some sort of tertiary education. According to data from the Canadian Labour Force Survey (LFS) and the U.S. Current Population Survey (CPS), only about 47 per cent of managers have a university degree in Canada compared to 60 per cent in the United States (Chart 19). This gap is broad-based with Canada trailing the United States across almost all industries, including industries associated with technology (i.e. Information and Cultural industries, professional, scientific and technical services), but also in industries that are not as technology driven such as retail and accommodation and food services. Even in such industries, management education could be important as they would have to adopt more and more technologies to become productive in an economy that is becoming more technology-driven overall. In spite of this management education gap, business administration and management is a popular field for Canadian university graduates comprising 21 per cent of the bachelor's degree holding population according to the 2021 census. This may suggest that many these graduates are not using their management education when they enter workforce.

Perspectives on Canada's Future Productivity Challenges

Thus far, we have provided insights into the history of Canada's lagging productivity, focusing on both the trends and the underlying factors of this persistent challenge. In this section, we offer perspectives on how four fundamental structural transformations—population aging, the green transition, the realignment of global trade, and the increasing digitization and use of AI—will impact productivity growth going forward. Each of these has uncertain implications for productivity, potentially exacerbating existing challenges while offering opportunities for improvement. In providing these perspectives, although we raise more questions than answers, our aim is to highlight areas that could shape an agenda for future research on productivity in Canada.

Population Aging

As with most other economically advanced countries, Canada will contend with a decreasing working-age to population ratio in the coming years as the baby boom generation continues to move into retirement. On balance, it is not yet clear whether population aging will increase or decrease productivity. Should we expect that older workers have experiences and skills that younger workers have yet to obtain and that an ageing workforce may result in reducing productivity if many of the most skilled and experienced workers exit the workforce? Conversely, can we expect this effect will be counteracted by the fact that younger workers tend to be more educated, may have more of a risk-taking or entrepreneurial spirit and have a better capacity to adapt to new production processes or the use of new technologies in the workplace? The existing research on this dynamic is largely inconclusive. However, as the consequences of population aging begin to take hold the answer is likely to become clearer. From a structural perspective, should we expect the aging population to dampen aggregate productivity growth as the composition of the economy shifts towards lower-productivity service industries such as health care?

Immigration can help to mitigate the effects of population aging on Canada's labour force growth and public finances. However, the impact of immigration on productivity is ambiguous and largely depends on the skill level of the immigrants and their ability to integrate into the labour market. On average, principal applicant economic immigrants integrate swiftly, achieving labour market outcomes that match or exceed those of the average Canadian worker within five years.[16] This quick integration is expected, given that principal economic applicants are selected for their potential to assimilate effectively into the Canadian economy. However, it may take a decade or more for other immigrant categories, including secondary economic applicants and family-sponsored applicants, to reach similar outcomes than Canadian-born workers.

As other advanced economies continue to grapple with population aging and as the source countries of highly skilled immigrants to Canada continue to develop economically one question emerges: How effectively will Canada compete in attracting the most highly skilled immigrants

16 Authors' calculations using Statistics Canada tables 43-10-0010-01, 11-10-0239-01, and 18-10-0005-01.

who have the greatest potential to enhance Canada's productivity? One area for improvement is in credential recognition. Immigrants are of greater likelihood of being mismatched and overqualified for their positions, in part due to weaknesses in credential recognition. Resolving issues with credential recognition would have the dual benefit of enhancing the productivity of the current cohort of immigrants and increasing Canada's competitiveness for attracting future immigrants.

The Green Transition

The green transition is accelerating around the world, leading to shifts between sectors and economies. As countries pivot towards more sustainable energy, production and consumption, firms will need to innovate and adopt new technologies to stay relevant and the labour force must be capable of adapting to the skills required to match these changing needs.

The process of this transition can be disruptive but could also present opportunities for productivity. For example, the Porter Hypothesis (Porter, 1991; Porter and van der Linde, 1995) contends that environmental policy may induce innovation that can partially, if not entirely, offset negative impacts of satisfying environmental requirements.[17] This follows from the perspective that pollution is a manifestation of economic waste (Lanoie *et al.*, 2008), and policies meant to lower pollution could also improve resource utilization and productivity. However, the Porter Hypothesis remains very much a hypothesis, and research remains inconclusive on its potential and broad applicability.

Even within the context of the Porter Hypothesis, the net productivity impact on the economy will depend on how well and where resources are reallocated. Canada's experience with zombie firms and a large number of small firms pose difficult questions about how well Canada's economy is prepared to efficiently reallocate resources over the transition. Further research on this question is particularly important given the existence of zombie firms in the resource sector. Similarly, what does the growing gap between frontier firms and non-frontier firms imply about the potential for fluid technology diffusion from leaders in the adoption of green technologies to the broader business sector.

The green transition could also bring sectoral shifts that have impacts on aggregate productivity. As suggested by the sectoral decomposition, commodity price declines in 2014-15 increased the importance of shift-effects with a significant negative impact on aggregate productivity growth. While it is not clear if this is a beginning of a long-term trend, what is clear is that the potential for a negative impact from these sectoral shifts away from commodity producing sectors with a high productivity level is significant. This may mean that Canada needs to improve within-sector productivity growth, which requires broad-based improvement across sectors.

17 For example, for Canada, Lanoie *et al.* (2008) finds evidence that the long-run impact of environmental regulation on Quebec manufacturing productivity has been positive.

Realignment of Global Trade

The system of global trade has been undergoing a significant transformation, with rising geopolitical tensions ushering in a realignment of trade flows as countries aim to strengthen the resiliency of supply chains through reshoring and friendshoring. This shift could have important implications for small open economies like Canada. Historically, Canada has benefited significantly from the liberalization of international trade that evolved over the past 50 years. Although friendshoring and reshoring may help to increase resiliency, there is a risk that this increase in resilience could come at the cost of declines in efficiency.

A move toward friendshoring by our allies could also create opportunities for a stable democracy like Canada. If this realignment allows for greater interaction with firms at the global productivity frontier, as most would likely reside in "friend" countries, it may improve the ability of Canadian firms to take advantage of productivity and technology spillovers. Perhaps the greatest challenge for Canada is the speed at which this transition could unfold. Decisions made by our major trading partners could have significant impacts on Canada's economy with little predictability. Given Canada's experience with lagging investment and potentially relatively weaker management capacity, yet another question emerges: how well prepared is Canada to navigate these kinds of shocks and what impact will this added uncertainty have on productivity and investment decisions?

Digitalization and AI

Advanced technologies, such as digitalization, and artificial intelligence (AI), have the potential to be disruptive forces by enabling the automation of tasks currently performed by workers. In particular, the rapid advances in large language AI models and their recent release through various apps promise to revolutionize the way information is created and spread. This could increase productive efficiency, lower costs, and ultimately spur the demand for labour. As such, new technologies represent an opportunity to reverse sluggish productivity growth and to alleviate tight labour markets. In particular, it has been estimated that generative AI has the potential to boost labour productivity growth in the United States by 0.5 to 0.9 percentage points annually through 2030 (Ellingrud *et al.*, 2023).

The key issue about digitalization and the adoption of new technologies in Canada is whether businesses have invested enough and if, for any reason, many are holding back investments that would make them more productive. The overall proportion of businesses using AI in Canada is lagging the United States, likely reflecting the large presence of small firms, the growing gap between frontier and non-frontier firms, and less educated management. Canada is how-

18 Source of data: OECD.AI (2023), visualisations powered by JSI using data from Preqin, accessed on 14/11/2023, www.oecd.ai. World Development Indicators (World Bank).

ever out-performing the EU in cumulative venture capital investments in AI as a share of GDP.[18]

As highlighted earlier, uneven technology adoption has been suggested by the OECD to constrain aggregate productivity growth (Andrewsv *et al.*,2015). Digitalization and declines in the costs of automation have led to increased market concentration in many industries. Similar to past technologies, the commercialization of AI will entail large fixed costs, complement organizational complexity and require complementary innovations to enable the technology to generate growth. Advantages held by large technology firms in access to data and computational resources will become more consequential. The incorporation of AI into production is therefore expected to increase existing scale advantages, already reflected in substantial disparities in adoption rates between the largest firms and SMEs in Canada. Extreme gaps between the capabilities of leading private large language models and open-source alternatives may portend strong anti-competitive effects from AI diffusion.

Conclusion

In this article, we have chronicled Canada's productivity performance over recent decades up to the present, emphasizing the country's investment challenges and identifying potential factors contributing to productivity and investment outcomes in Canada. Currently, Canada, like most other advanced economies, is in a challenging situation, experiencing the lowest rates of productivity growth in a generation while confronting major structural changes. Understanding the historical context of Canada's productivity performance is crucial in identifying areas that require attention from both governments and the private sector. However, much more work is necessary to comprehend the forward-looking implications for productivity growth arising from population aging, the green transition, a realignment of global trade, and the increasing digitization and use of AI. It is our hope that this article inspires more researchers to delve deeper into the challenges of productivity growth that Canada has faced, both old and new, providing essential evidence and insights that enhance our collective understanding of Canada's productivity performance.

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Appendix Table 1: Detailed Sectoral Decomposition of Labour Productivity Growth, Business Sector, 1961-2019 (percentage points per year)

	Within-Sector Effect				Shift Effect				Total			
	1961-1985	1985-2007	2007-2014	2014-2019	1961-1985	1985-2007	2007-2014	2014-2019	1961-1985	1985-2007	2007-2014	2014-2019
Agriculture, forestry, fishing and hunting	0.2	0.1	0.1	0.1	-0.2	-0.2	0.0	0.0	0.1	-0.1	0.1	0.1
Mining and oil and gas extraction	0.1	-0.1	-0.2	0.4	0.3	0.2	0.3	-1.1	0.4	0.1	0.1	-0.6
Utilities	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
Construction	0.2	0.0	0.0	0.0	0.0	0.2	0.3	0.0	0.2	0.1	0.3	-0.1
Manufacturing	1.0	0.5	0.2	0.0	-0.5	-0.5	-0.5	0.1	0.5	0.0	-0.3	0.1
Wholesale trade	0.2	0.2	0.2	0.0	0.0	-0.1	-0.1	0.0	0.2	0.1	0.1	0.0
Retail trade	0.2	0.1	0.1	0.1	-0.1	-0.1	0.0	0.0	0.2	0.1	0.0	0.1
Transportation and warehousing	0.3	0.1	0.1	0.0	-0.1	0.0	0.0	0.2	0.1	0.0	0.1	0.2
Information and cultural industries	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.1
Finance, insurance, real estate and renting and leasing	0.1	0.3	0.2	0.5	0.3	0.1	0.0	-0.2	0.4	0.3	0.2	0.2
Professional, scientific and technical services	0.0	0.1	0.1	0.0	0.1	0.2	0.1	0.2	0.2	0.2	0.2	0.2
Administrative and support, waste management and remediation services	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0
Arts, entertainment and recreation	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Accommodation and food services	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.1	0.1
Other private services	0.1	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2
Total	2.6	1.4	1.0	1.1	0.2	-0.0	0.1	-0.5	2.8	1.4	1.0	0.7

Source: Statistics Canada, authors' calculations. Notes: Based on the methodology from Almon and Tang (2011). Annual average calculated by performing the decomposition for each year and averaging over the period. Totals may not add up due to rounding.

Recent Productivity Trends in Canada: Navigating the Twin Transitions of Green and Digitalization

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Abstract

Canada, like other countries, is undergoing an economic transformation as a result of the green and digital transitions. These megatrends create new challenges and opportunities for productivity growth. The green transition could place downward pressure on productivity growth given the current structure of the Canadian economy. That said, the Porter Hypothesis posits that well-formulated environmental regulations can actually spur innovation, which can in turn stimulate productivity. Canada's ICT and digitally intensive sectors have seen strong productivity growth since 2000, but Canada's overall performance in digitally- and R&D-intensive sectors trails other G7 countries. Embracing emerging clean and digital technologies and helping small and medium-sized business adopt them remain important issues to help unlock new productivity opportunities in Canada.

Productivity is a fundamental driver of growth, competitiveness, and overall economic sustainability. Productivity growth is important for workers, consumers, businesses and governments. High levels of productivity can help Canadian firms succeed in a global economy by enhancing their competitive edge, profitability, adaptability, and reputation. Productivity is also essential for sustaining economic growth, adapting to an ageing workforce, and improving living standards of the Canadian population.

Canada, like the rest of the world, is facing the twin transitions of green and digitalization. Both will likely involve fundamental shifts in the structure of the Canadian economy. The green transition refers

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to the shift towards a more sustainable and environmentally friendly economy, which typically involves reducing greenhouse gas (GHG) emissions, increasing energy efficiency, and transitioning to renewable energy sources. This global transition is already underway and involves the confluence of global treaties, like the Paris Accord, new governmental regulations and programs, and shifting consumer preferences. According to a joint study by McKinsey & Company and NielsenIQ (Frey *et al.* 2023), products making environmental, social, and governance (ESG) claims averaged 28 per cent cumulative growth over the 2018-2022 period, versus 20 per cent for products that made no such claims. Consumers are becoming more environmentally conscious and changing their consumption pattens, with searches for sustainable goods increasing globally by 71 per cent since 2016 (Economist, 2021). Together, these developments create conditions which encourage businesses to make the shift in what and how they do things.

Alongside the green transition, digital transformations are reshaping the Canadian economy. Digitalization is not a new phenomenon, but one that has seen steady progress in the use of digital technologies and services by businesses. The rise of e-commerce due to more fundamental technological advancements (AI, robotics, blockchain, quantum computing, etc.) is creating a new ecosystem in which businesses must learn to thrive. For Canadian businesses (especially SMEs), embracing digital transformation is not only necessary for economic survival but also a means to unlock new growth opportunities. Digitalization is crucial for growth because it can drive efficiency, innovation, and competitiveness. The adoption and adaptation of digital technology will be important for productivity growth, particularly in the context of potential long-term labour and skills shortages. Tepid adaptation to new digital technologies or a lack of investment in new tools for doing business will put firms at risk of falling behind those that innovate.

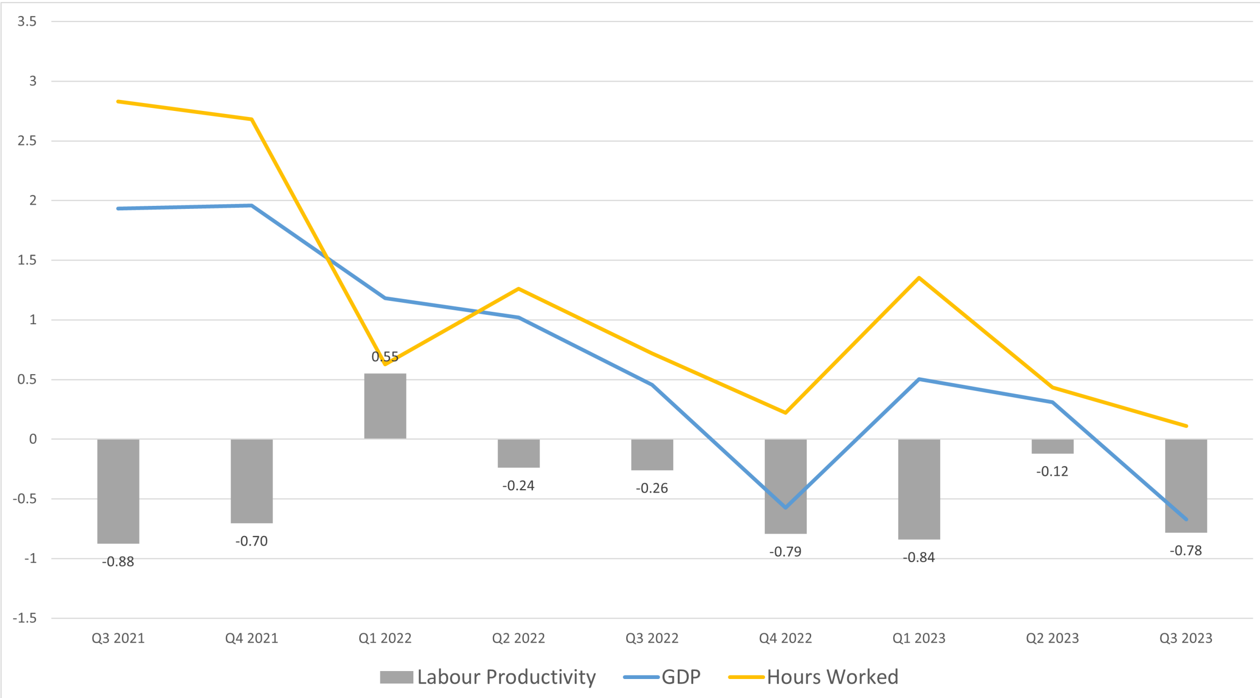
This article will examine factors that could impact Canada's future productivity performance in light of the twin transitions of green and digitalization. Section 1 starts by exploring recent productivity trends in Canada. Section 2 discusses challenges and opportunities for productivity associated with the green transition of the Canadian economy. Section 3 examines digitalization trends and how they are affecting productivity growth. Finally, the article offers some conclusions and highlights areas where future research and analysis might be warranted.

Recent Productivity Trends in Canada

Productivity is determined by the economic environment for investment, regulation, the broader R&D system, as well as human capital. Recent trends highlight how labour productivity growth has stalled in Canada during successive quarters following the pandemic. The most recent data available shows that labour productivity of Canadian businesses fell 0.8 per cent in the third quarter of 2023, extending the string of declines observed since the second quarter of 2022 (Chart 1).

Looking back at historical trends, there

Chart 1: Growth in Real GDP, Hours Worked, and Labour Productivity in the Canadian Business Sector:2021Q1-2023Q3 (per cent, quarterly change)



Source: Statistics Canada. Table: 36-10-0206-01.

has been a decline in labour productivity growth within the Canadian business sector since 2000. In 1981-2000, productivity growth in Canada, measured by output per hour, averaged 1.7 per cent annually. Following this period, it averaged 1.0 per cent annually in 2000-2019. Productivity growth was lower during the 2000-2008 period averaging 0.9 per cent annually, before increasing slightly to 1.0 per cent in the following decade (Chart 2).

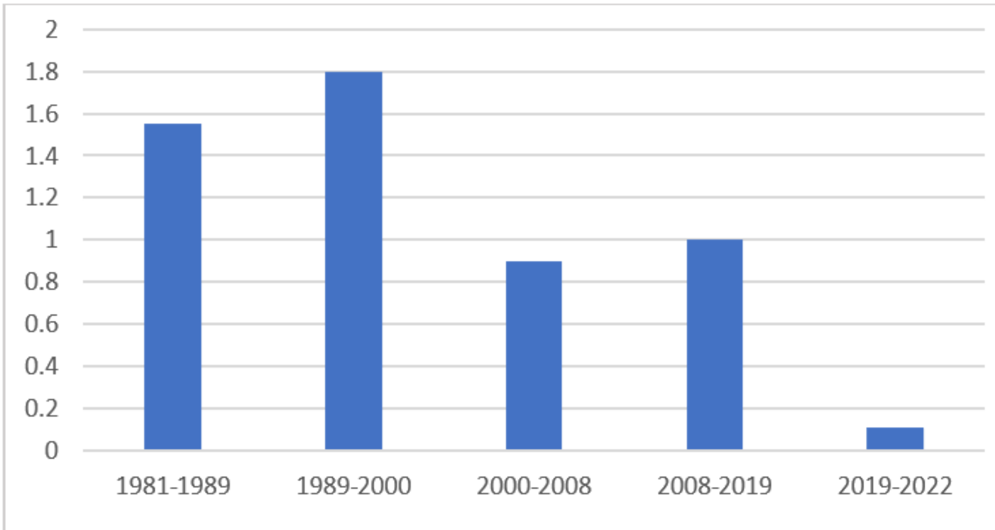
The overall productivity growth slowdown has mainly occurred in goods-producing industries such as the mining and oil and gas and manufacturing sectors. Some services industries (administrative and waste management; arts, entertainment, and recreation; and accommodation and food services) have experienced significant productivity growth during the period from 2000-2019 when compared to 1981-2000 (Chart 3).

Canada is not alone in grappling with slow productivity growth. All other G7 countries have experienced an aggregate productivity growth slowdown in 2000-2019 when compared to 1981-2000 (Chart 4).[2] The slowdown of 0.4 percentage points

2 Over the pandemic period 2020-2022, productivity growth decelerated further in Canada and in most other OECD countries, although we need some caution to interpret the numbers as non-market forces were influencing firms' operations over this period.

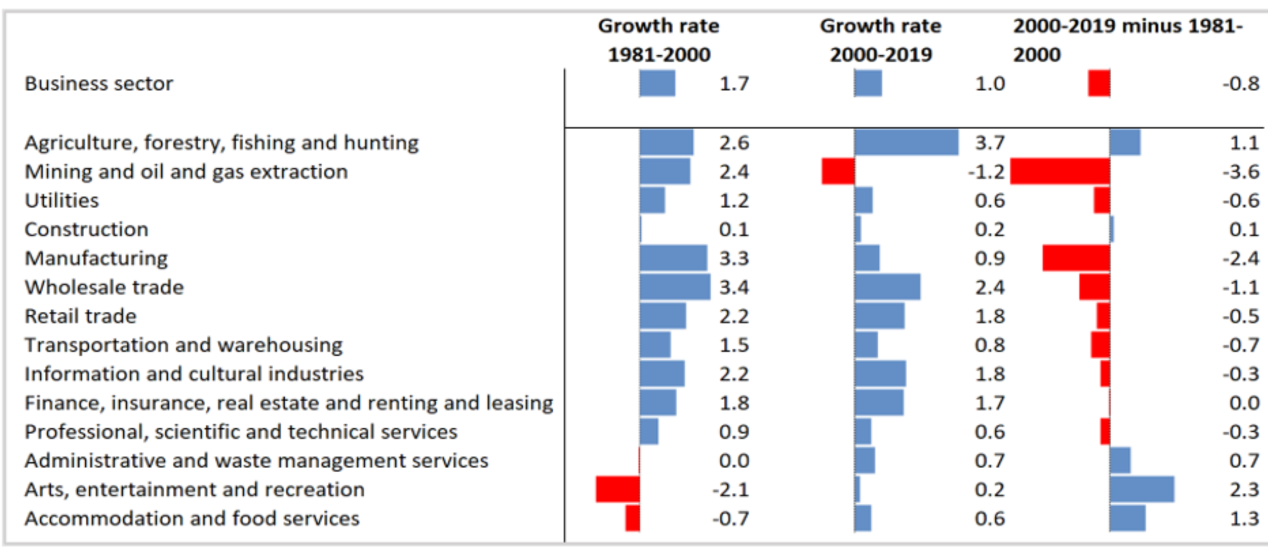
3 Note that the slowdown in labour productivity growth between 1981-2000 and 2000-2019 was 0.7 percentage points for the Canadian business sector, much higher than 0.4 percentage points for the total economy.

Chart 2: Labour Productivity Growth in the Canadian Business Sector (Per Cent per Year Compounded)



Source: Statistics Canada. Table 36-10-0208-01 and Table: 36-10-0207-01, ISED's Calculations.

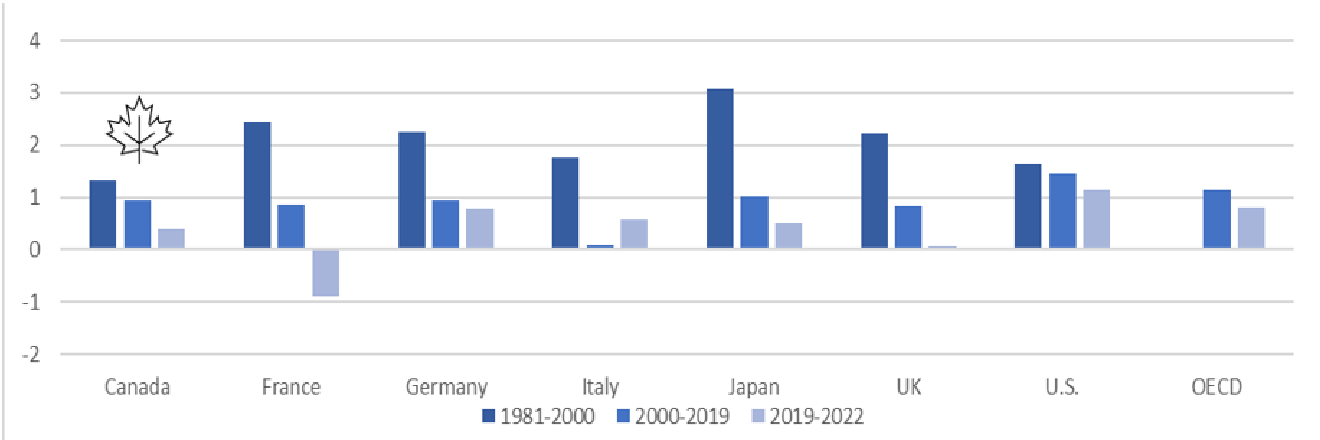
Chart 3: Canadian Labour Productivity Growth by Industry, 1990-2019 (per cent per year, compounded)



	Growth rate 1981-2000	Growth rate 2000-2019	2000-2019 minus 1981-2000
Business sector	1.7	1.0	-0.8
Agriculture, forestry, fishing and hunting	2.6	3.7	1.1
Mining and oil and gas extraction	2.4	-1.2	-3.6
Utilities	1.2	0.6	-0.6
Construction	0.1	0.2	0.1
Manufacturing	3.3	0.9	-2.4
Wholesale trade	3.4	2.4	-1.1
Retail trade	2.2	1.8	-0.5
Transportation and warehousing	1.5	0.8	-0.7
Information and cultural industries	2.2	1.8	-0.3
Finance, insurance, real estate and renting and leasing	1.8	1.7	0.0
Professional, scientific and technical services	0.9	0.6	-0.3
Administrative and waste management services	0.0	0.7	0.7
Arts, entertainment and recreation	-2.1	0.2	2.3
Accommodation and food services	-0.7	0.6	1.3

Source: Statistics Canada. Table: 36-10-0208-01, ISED's Calculations.

Chart 4: Total Economy Labour Productivity Growth, Comparing G7 and OECD Countries (per cent per year, compounded)



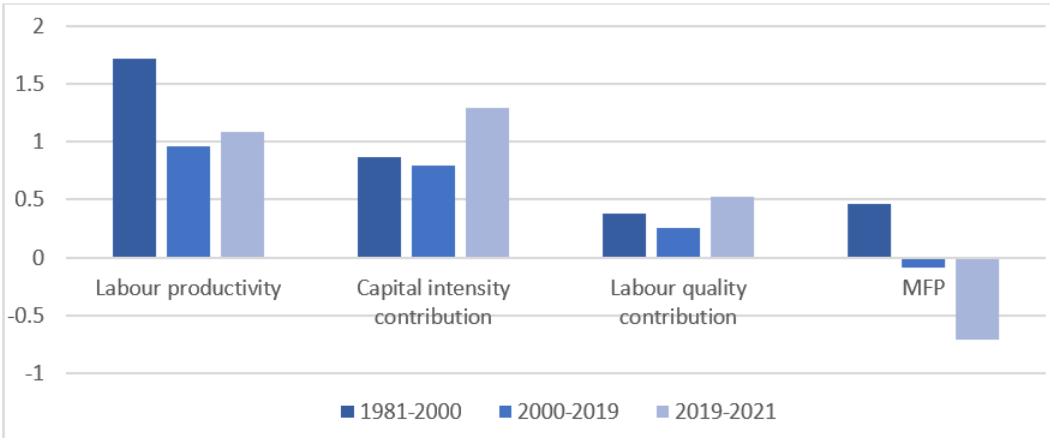
OECD STAN Database. OECD average is weighted, calculated as the sum of output over countries divided by the sum of hours worked over countries, not available for 1981-2000.

in Canada was smaller than any other G7 countries apart from the United States.[3] Notably also, after the global financial crisis, Canada has been performing relatively well compared to other G7 countries. It ranked second in total economy labour productivity growth, with 0.76 percent per year in 2010-2022, just behind the rate of 0.82 percent for the United States. While this is mainly due to a larger productivity growth slowdown in other G7 countries than in Canada after the global financial crisis, it might also reflect stronger fundamentals and the resilience of the Canadian economy in terms of a relatively more stable manufacturing base, a sound banking system as well as better financial regulatory frameworks (Tang and Wang, 2020).

Labour productivity growth measures the change in labour productivity levels over time. It quantifies the rate at which an economy is becoming more or less efficient in producing output for each unit of labour input. Another way of looking at productivity is to look at the labour productivity levels, which refer to the amount of output (goods or services) produced per unit of labour input (usually measured as hours worked or number of workers). It provides a snapshot of the current state of productivity in an economy or a specific industry. Labour productivity levels help assess how efficiently an economy or industry is utilizing its labour resources at a specific point in time. Higher labour productivity levels indicate greater efficiency. Importantly, in terms of labour productivity levels, Canada lags all other G7 countries except Japan and the gap with the United States is currently about 25 per cent. In 2022, Canada ranked 18th in labour productivity level among 37 OECD countries.

When looking at Canada's productivity performance, it is also important to look at multi-factor productivity (MFP). Unlike labour productivity, which only considers the efficiency of labour input, MFP accounts for multiple factors of production, typically labour and capital, to evaluate how effectively these inputs are being transformed into output or economic value. Arguably, it provides a more comprehen-

Chart 5: Sources of Labour Productivity Growth in the Canadian Business Sector (per cent per year, compounded)



Source: Statistics Canada. Table 36-10-0208-01
Note: The productivity estimates for 2019-2021 should be interpreted with caution as non-economic forces played important roles in business operations during the pandemic.

sive view of productivity and efficiency. Chart 5 shows that the slowdown in labour productivity growth in Canada was mainly due to the slowdown in MFP growth. MFP growth accounted for more than two-thirds of the decline in labour productivity growth between 1981-2000 and 2000-2019.

Canada's relatively weak performance in labour productivity reflects its performance in MFP. In 2000-2019 period, total economy MFP growth in Canada ranked 5th among G7 countries, just ahead of France and Italy, although by 2022, Canada improved its position (Chart 6).

Despite extensive research, there is no single explanation for the widespread slowdown in productivity growth across Canada and other G7 countries.[4] Several studies have highlighted that Canada's sub-optimal productivity performance may reflect weaker investment in innovation capacity and technology adoption by the business sector, lack of scale among SMEs, and barriers to an optimal allocation of resources in the economy, which may reflect low competition intensity caused by smaller and more fragmented internal markets.[5]

While Canada's productivity performance has been weak over the last decades, the economy is undergoing a significant transition as a result of global megatrends linked to the green and digital transformations. These megatrends provide Canada with both challenges and opportunities, which will be discussed in the next two sections of this article.

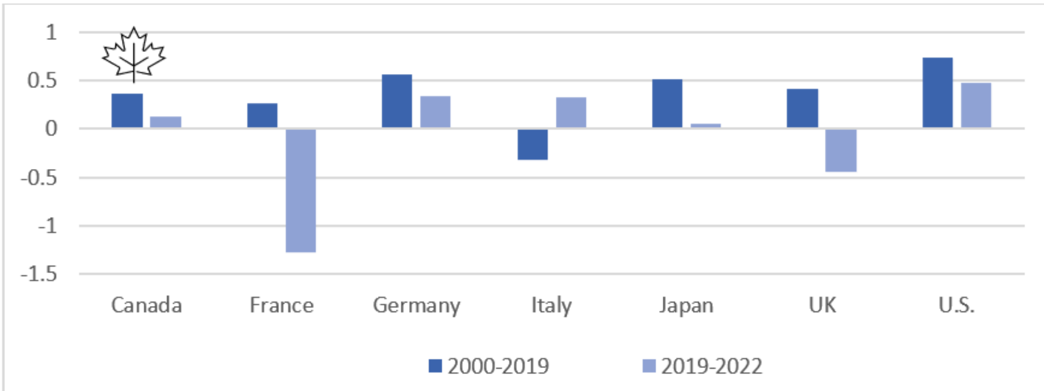
Green Transitions and Productivity

Countries across the world are taking steps to reduce greenhouse gas emis-

4 See Syverson, 2011; Almon and Tang, 2011; Andrews *et al.*, 2016; Li, *et al.*, 2013; Gordon, 2018; Sharpe and Tsang, 2018; St-Amant and Tessier, 2018; OECD, 2022; and Fernald 2023.

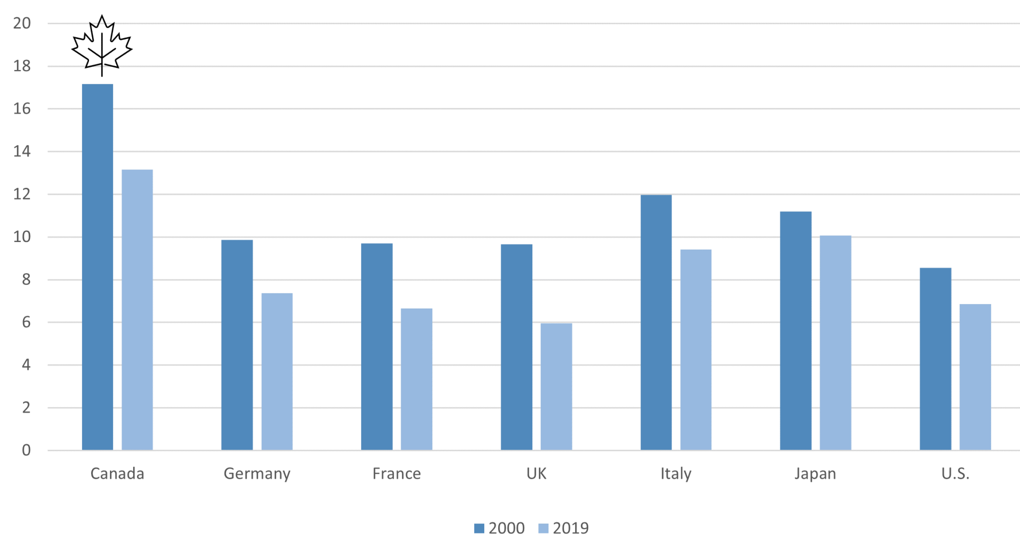
5 See Leung *et al.*, 2008; Nicholson, 2009; Tang, 2014 and 2016; Sharpe and Tsang, 2018; Gu, 2019; and Deslauriers and Gagné, 2023.

Chart 6: Total Economy Multifactor Productivity Growth across G7 countries (per cent per year, compounded



Source: OECD.

Chart 7: Nominal GDP Share of Resource-Dependent Activities in 2000 and 2019, Canada versus G7 countries



Source: OECD STAN database, author's calculations.
Note: Resource-depending activities include agriculture, hunting, forestry, and fishing; mining and quarrying; food products, beverages, and tobacco; wood and paper products and printing; coke and refined petroleum products; rubber and plastic products, and other non-metallic mineral products; and basic metals and fabricated metal products (excluding machinery and equipment).

sions, which involves transitioning their economies to greener and more sustainable economic development models that promote less resource-intensive forms of production and consumption. Oxford Economics (2023) estimates that the growth in demand for new green goods and services that will facilitate the green economy will create an opportunity worth $10.3 trillion by 2050 to the global economy, which is equivalent of 5.2 per cent of global GDP.

Reductions in greenhouse gas emissions in Canada will require both major energy savings and economy-wide replacement of fossil fuels with clean energy, as oil and gas extraction contributes about a quarter of Canada's yearly emissions and represents a substantial portion of Canadian exports. In addition to oil and gas, the Canadian economy is heavily concentrated resource-dependent industries. Among G7 countries, Canada has the highest value added share of resource-dependent industries, which includes agriculture, hunting, forestry and fishing; mining and quarrying; food products, beverages and tobacco; wood and paper products and printing; coal and refined petroleum products; rubber and plastic products, and other nonmetallic mineral products; and basic metals and fabricated metal products (excluding machinery and equipment) (Chart 7).

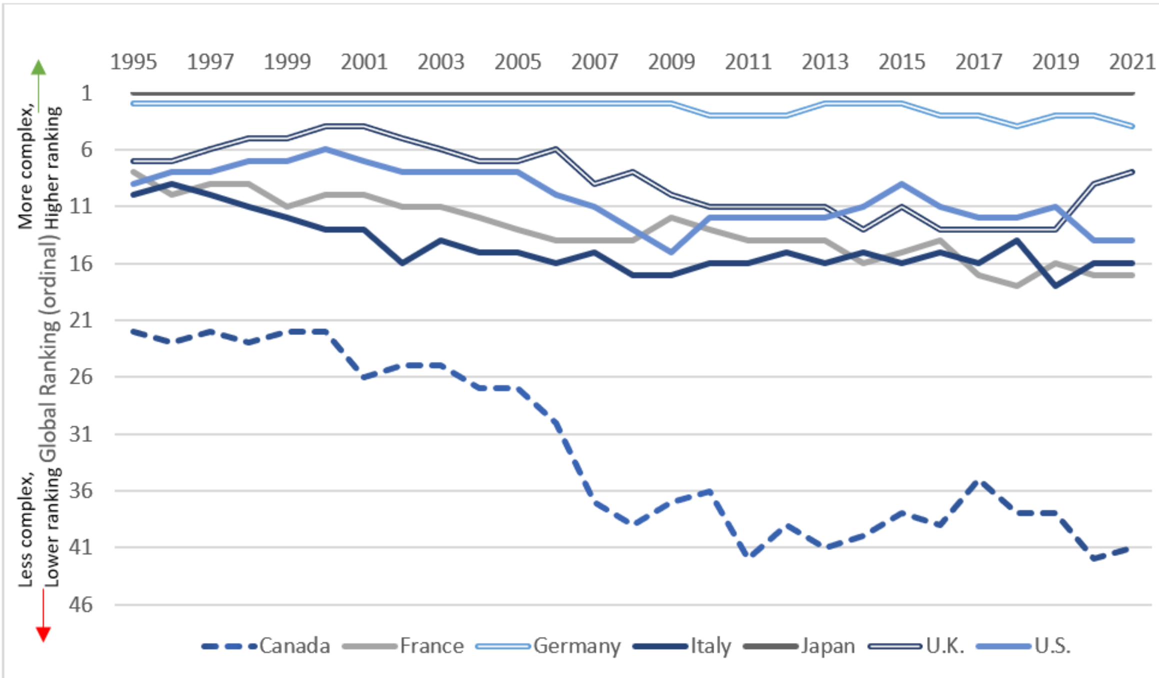
Over the past two decades, the Canadian economy shifted from resource-dependent industries to service industries, and the value-added share of resource-dependent industries declined from 17.2 per cent of nominal GDP in 2000 to 13.2 per cent in 2019, the largest decline among G7 countries. That said, Canada's share was still the highest among G7 in 2019 and double the share of the United States.

A declining share of resource-dependent economic activities has not been enough to stem a decline in Canada's relative capability in producing a diversified set of complex products and services for export. According to the Harvard Growth Lab, the ranking of Canada's product basket being exported in terms of sophistication and diversity has been falling over time relative to other countries (Chart 8).[6] Canada ranked 22nd out of 129 countries in 1995, but by 2021, its position had fallen to 41st. This means that many countries have overtaken Canada in its ability to produce diversified and complex products for international markets. In contrast, the change in the relative ranking was small for other G7 countries over this period. This is a concern because export sophistication has been linked to GDP per capita growth (Hausmann, Hwang, and Rodrik, 2007).

Canada's underperformance in producing diversified and complex products has important implications for its competitiveness in international markets and its economic growth in the future. Canada is a small open economy. International trade is crucial, with exports accounting for about one third of the GDP (World Bank, 2023) and supporting 3.3 million jobs in Canada (Global Affairs Canada, 2023). Currently, just over 80 per cent of Canada's exports

6 The Economic Complexity Index is a ranking of countries based on the diversity and complexity of their export basket. Higher ranking countries are able to produce a highly diversified set of complex products. Natural resource-based products are typically ranked low for the index.

Chart 8: Historical Trend of the Economic Complexity Ranking for G7 countries, 1995-2021



Source: Harvard Growth Lab, "Country and Product Complexity Ranking."

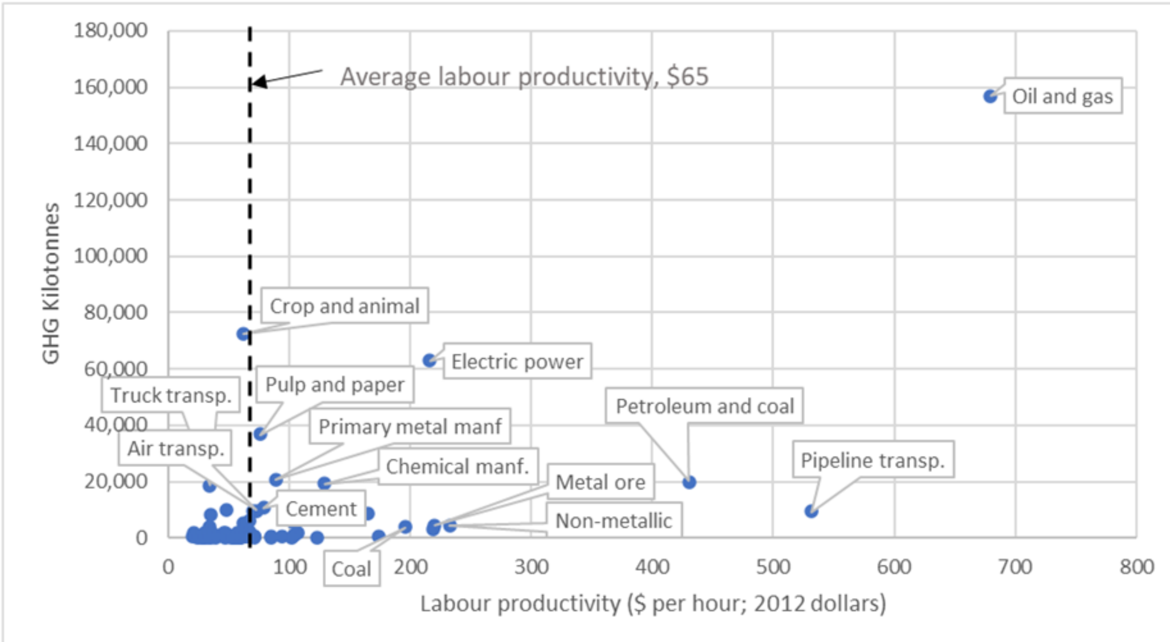
are goods, led by crude petroleum, followed by cars, petroleum gas,[7] gold, and sawn wood products. The dependence of trade of carbon-intensive products may not be sustainable, as the global economy and consumer consumption patterns move away from these products, driven by the global green imperative associated with climate change.

Another consideration for assessing the shift to a low-carbon economy on productivity is that it will place unique pressures on Canada, because the largest emitting sectors of the economy are also ones with the highest labour productivity levels. In Chart 9, we see that the oil and gas extraction sector was not only by far the highest emitter of GHG in 2020, but also had the highest labour productivity, over ten times higher than the Canadian average. By 2022, average labour productivity in Canada had fallen 6 per cent since 2020 to $61.09 while the labour productivity in the oil and gas extraction sector had increased a 1 per cent to $686.69. Excluding the oil and gas extraction sector from Canada's average labour productivity measure in 2022 would see it fall nearly 5 per cent to $58.08, representing the minimum productivity loss without any kind of productivity gains or mitigation elsewhere.

However, it is worthwhile to note that labour productivity growth rates within the mining and oil and gas sector in Canada have been negative since 2000, with an annualized labour productivity growth rate of -0.9 per cent (Statistics Canada, 2023c). When considering multifactor productivity,

7 Petroleum gases include natural gas, propane, butanes, and ethylene.

Chart 9: Industry Greenhouse Gas Emissions vs. Labour Productivity Levels, 2020



Source: Statistics Canada. Tables: 38-10-0097-01, 36-10-0480-01

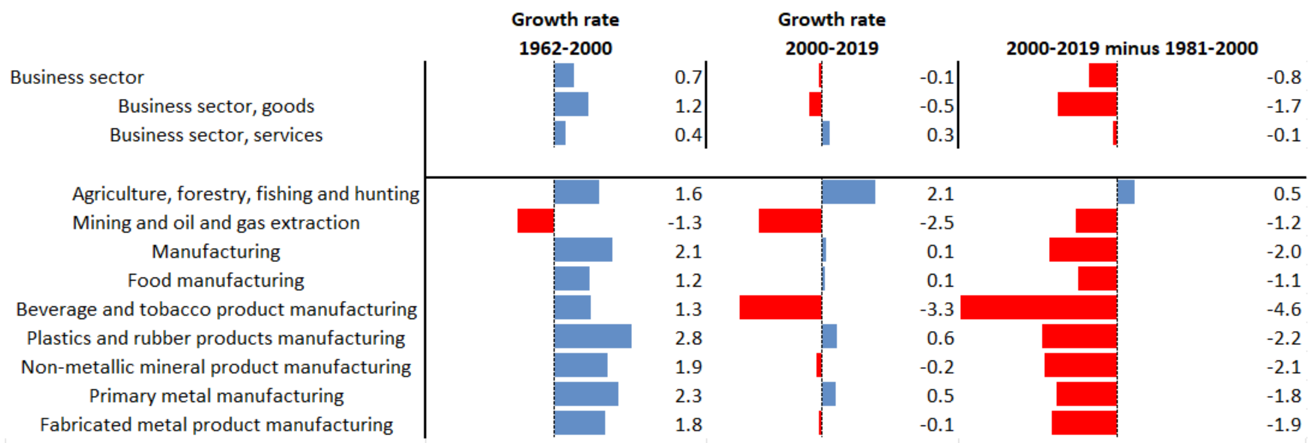
which factors in the cost of capital, the growth rate of the mining and oil and gas sector is even worse. Multifactor productivity (value-added based) declined from an average growth rate of negative 1.3 percent annually in 1962-2000 to an average growth rate of negative 2.5 percent annually in 2000-2019 (Chart 10). This led to a large decline in MFP growth in the goods producing sector from 1.2 percent per year to -0.5 percent over the two periods. In contrast, the growth rate for the service sector was 0.3 percent annually in 2000-2019. Pujolas and Loertscher (2023) argues that the observed stagnation of MFP in Canada can be entirely attributed to the oil sector, citing high oil prices for making capital-intensive sources of oil, such as the oil sands, commercially viable.

The shift to green will require transitions for Canadian firms, regions, and workers. Canada will need to look at opportunities to unlock new sources of economic growth and productivity given the global push to reduce carbon emissions through the development of renewable energy, electric vehicles, and conservation.

One way is to encourage the growth of the nascent environmental and clean technology (ECT) sector.[8] An analysis by Global Affairs Canada (Jiang, 2023) observed that this sector accounted for 2.9 per

8 Environmental and clean technology in Jiang (2023) and Carta and Demers (2023) is defined as "any good or service designed with the primary purpose of contributing to remediating or preventing any type of environmental damage or any good or service whose primary purpose is not environmental protection but that is less polluting or more resource-efficient than equivalent normal products that furnish a similar utility." This is the definition used for Statistics Canada's Environmental and Clean Technology Products Economic Account and its Survey of Environmental Goods and Services. As such, this sector does not have a one-to-one mapping with NAICS sectors.

Chart 10: Multifactor Productivity Growth (per cent compounded) in Resource – related industries



Source: Statistics Canada. Table 36-10-0208-01 & 36-10-0217-01.

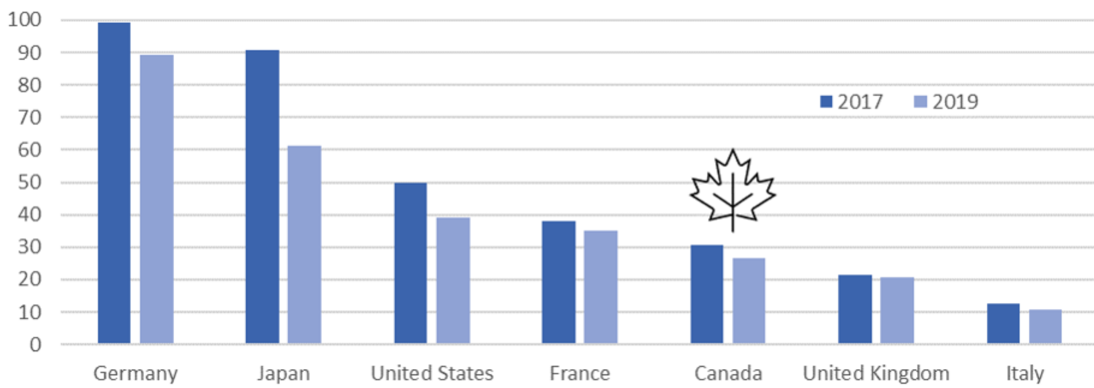
cent of Canada's GDP in 2021. This study also finds that the ECT sector grew by 21 per cent in real terms over the last decade, outpacing the economy's overall 15 per cent growth. Export growth was particularly strong, up 90 per cent from 2012 to 2021. Export growth came mainly from increased amounts of ECT goods, while ECT service exports were a small share concentrated mostly in scientific and R&D services.

In terms of productivity, there is emerging evidence in Canada that the environmental and clean technology sector is generating above-average productivity growth. A recent analysis published by Statistics Canada (Carta and Demers, 2023) looks at the business outcomes of firms supported by the Canadian government's suite of Business Innovation and Growth Support (BIGS) programs in 2016-2023.[9] They compare those receiving support through various clean tech projects and those receiving support through other programs. They found that ECT businesses tended to be smaller, were disproportionately goods-producing (though these still only made up only 39.1 per cent of supported green tech recipients) and had more educated workforces than other BIGS recipients. Business outcomes of the green tech beneficiaries tended to surpass other BIGS participants, most notably seeing greater productivity growth. Between 2018 and 2021, the median change in productivity for firms receiving clean tech support was $14,300 per employee, compared to $13,500 for all other BIGS participants.

Beyond the oil and gas and ECT sectors themselves, there is a concern that reducing GHG emissions in other sectors of the Canadian economy may harm productivity growth as firms are forced into adopting more expensive alternatives. However, the Porter Hypothesis instead argues that

9 BIGS programs are administered by a variety of federal government departments and have the goal of supporting business innovation and growth. Programs take various forms, including funding and grants, consulting services for enterprises, and industry-facing research and development, and can be provided directly or in-partnership. Statistics Canada maintains the BIGS database linking 123 programs delivered by 18 federal departments. Of these programs, 15 were clean technology programs.

Chart 11: Number of Environment-related Technology Patents Developed per 1,000,000 Citizens



Source: OECD, Innovation in environment-related technologies; Technology development

investing in green technologies and practices often leads to innovation and that this innovation can lead to the development of new products, services, and processes that are more efficient and productive. First outlined in Porter (1991), it argues against an efficiency trade-off and instead posits that well-formulated environmental regulation can trigger innovations that offset costs and improve resource efficiency.

The literature shows that the evidence is generally supportive, though it also shows that innovation is not always evenly distributed across firms or industries. Berman and Bui (2001) found that oil refineries in the Los Angeles Air Basin facing increasing regulation on air pollution saw higher productivity gains relative to refineries not subjected to these regulations. This is an intriguing case study that demonstrates that environmental regulation of even heavy polluters is not necessarily a death blow to productivity growth. Commins *et al.* (2011) found that energy taxes and the EU emissions trading scheme had an overall positive effect on MFP, but the effect varied by sector. Hottenrott *et al.* (2016) found that in the German manufacturing sector, the adoption of GHG abatement technologies did not harm productivity only if accompanied by organizational changes. An OECD working paper by Albrizio *et al.* (2014) finds that increasingly stringent environmental policies across OECD countries has had little aggregate productivity impact, though the most technologically advanced industries and frontier firms tended to see small productivity gains while the least productive firms have seen productivity declines.

As argued in Arrow *et al.* (2009), an important part of any climate change policy is support for innovation through investment in research and development. One way to measure the output of such efforts is to consider patents filed. Chart 11 shows the number of environment-related technology patents filed per million citizens across G7 nations in 2017 and 2019. Canada's rank is fifth among its peers. In 2019, about half of all Canadian green technology patents involved either energy storage and generation (e.g. batteries and alternative fuels) or cleaner manufacturing technology (e.g. GHG emission reduction in agriculture, cleaner feedstocks for the chemical industry), while carbon capture technologies only amounted to 1 per cent of all patents.

The green transition involves not just the development of new clean technologies, but also the adoption of them in the wider economy. In 2020-2022, businesses in Canada invested roughly $700M in advanced clean technologies,[10] making it the second most-common domain for investment in advanced technologies. The most adopted clean technologies were waste management, reduction, or recycling (26.9 per cent) and air and environmental protection or remediation (10.8 per cent) (Statistics Canada, 2023a). According to the Survey on Advanced Technologies, 2022, a low return on investment or long payback period and difficulty in accessing financial support were the most cited "very significant" obstacles for clean technology adoption (Statistics Canada, 2023b).

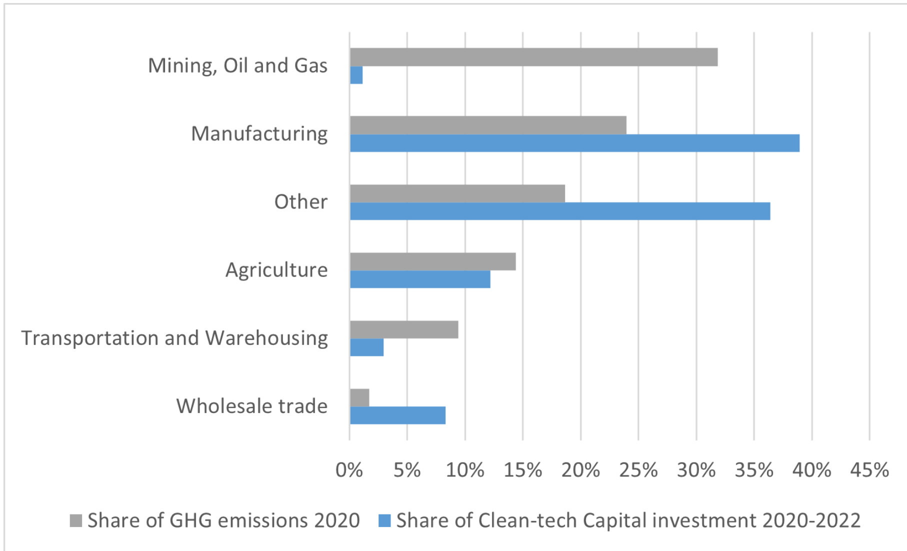
By sector, investments in clean technologies tended to correlate with overall share of GHG emissions (Chart 12) with the notable exception of the mining, oil, and gas extraction sector. This sector produced about a third of all GHG emissions in Canada in 2020 but made only 1.1 per cent of all clean technology capital investments over 2020-2022.

The Government of Canada has introduced several programs intended to help mitigate the costs of developing and adopting new, lower-emission processes as well as to invest in emerging clean technology industries. These include the Strategic Innovation Fund's Net Zero Accelerator and the Critical Mineral Strategy. The Strategic Innovation Fund involves the government making direct investments into various projects, helping to improve access to financing and increasing the bankability of large projects. The Net Zero Accelerator is focused on investments that will contribute to meeting Canada's GHG emission reduction targets. Thus far, about half of these investments have been specifically focused on heavy-emitting industries like energy, steel, and cement. The other half has been dedicated to supporting the establishment of a domestic electric vehicle and battery manufacturing sector. The Critical Minerals Strategy works to complement the latter, since Canada is a source of many of the rare minerals required for many new clean technology innovations, as well as driving research, innovation and exploration, project development, and building sustainable infrastructure. These investments are hoped to spur the development and adoption of new green technologies and supply chains and, in turn, enhance Canada's domestic productivity.

There are several avenues of future research that is needed to better understand and unpack the relationship between green technology adoption and productivity growth, both in Canada and in general. One example would be to use standard productivity decomposition techniques to see the impact of green industries on productivity growth. While there is data on the key obstacles for clean technology adoption, more analysis on what is required to

10 Similarly to Carta and Demers (2023), Statistics Canada defined clean technology as "processes, devices or applications designed to mitigate the effects of human activity on the environment or promote the sustainability of ecosystems." (Statistics Canada, 2023a)

Chart 12: Share of GHG Emissions and Advanced Clean Technology Capital Expenditures in Canada



Source: Statistics Canada; Survey of Advanced Technology Adoption 2022

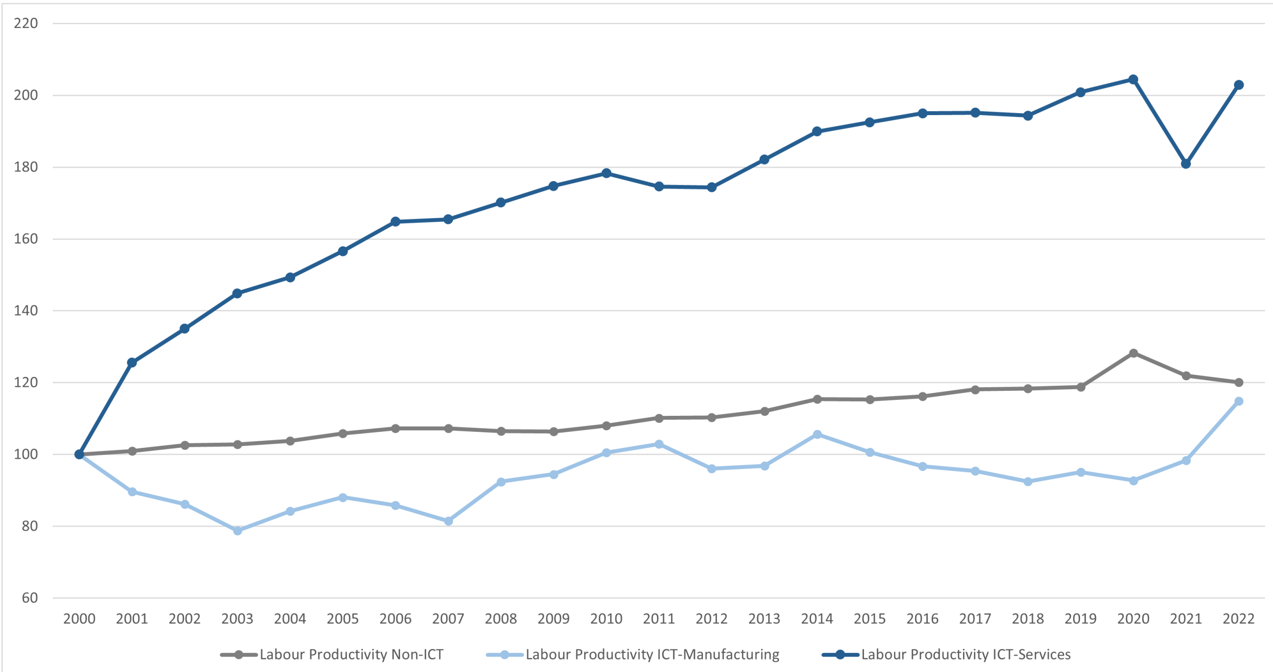
help firms overcome them is needed. Typical barriers include access to financing, uncertain returns on investment, and a lack of skills or technical knowledge required to implement new technologies. Finally, it is vital that steps are taken to help smooth the green transition, not just for firms but for workers as well. Understanding how the demand for skills will evolve and what are the shortest paths for displaced workers to new, more sustainable jobs will also help safeguard productivity by improving the efficient reallocation of human capital and forestalling the loss of human capital through long bouts of unemployment.

Digital Transformation and Productivity

According to the World Bank (World Bank Group, 2022), the digital economy accounted for more than 15 per cent of global GDP in 2016 and has been growing 2.5 times faster than the physical economy over the last decade. By 2030, it is expected to create 30 million jobs. Alongside the rise of e-commerce, new technological breakthroughs, such as those in AI, robotics, blockchain, and quantum computing, are creating a new ecosystem in which Canadian businesses must learn to thrive in.

Despite the promising emergence of the digital economy and related technologies, most OECD countries experienced a slowdown in labour productivity growth over the decade after the great recession (OECD, 2019). It is not obvious that this slowdown was despite increased digitalization or if new digital technologies mitigated what would have been more stark slowdowns without them. Brynjolfsson, Rock, and Syverson (2018) dubbed this the modern productivity paradox, an update to the original productivity paradox first observed by Robert Solow in 1987 that had been later resolved by improved measurement of ICT capital prices and quality (Spiezia,

Chart 13: Labour Productivity Growth for the Non-ICT, ICT-Manufacturing, and ICT-Services sectors (2000=100)



Source: Statistics Canada, Table: 36-10-0480-01

2012). Unpacking this new paradox has been the focus of much research since.

The literature generally supports the idea that digital technology adoption contributes positively to productivity growth, although the emerging consensus suggests the importance of the complementarities of digital adoption with the technologies themselves, technical and managerial skills within organizations, and strong pro-competitive policies (OECD, 2019). Gal *et al.* (2019) assess how the adoption of various digital technologies affects firm-level productivity of European businesses and finds that firms in industries with high levels of digital adoption are associated with productivity gains, particularly those in the manufacturing sector or with routine-intensive activities. Cette, Nevoux, and Py (2022) show that the employment of information and communication technology (ICT) specialists and the use of digital technologies improved labour productivity within French firms although at a modest cost to labour share. Brynjolfsson, Rock, and Syverson (2021) show that new technologies, especially general purpose ones, can temporarily drag down productivity measures before a period of investment in complementary intangible goods, such as new skills and processes, can deliver productivity results. A recent Bank of Canada Staff Discussion Paper, Mollins and Taskin (2023), shows that ICT capital deepening in Canada has contributed 0.2-0.3 percentage points annually to Canada's overall productivity growth since the early 2000s.

At the heart of the emerging digital economy is the ICT sector, which both manufactures and services the required equipment and machinery. The ICT sector in Canada has grown and evolved since 2000, seeing its share of real GDP increase from 3.2 per cent to 5.4 per cent in 2022. Its composition has also changed. ICT manufacturing made up over a quarter of the sector's output in 2000 but declined to just 4 per cent by 2022 (Statistics Canada, 2023c). The reason for the gradual dominance of the ICT services sector, as well as its increasing share of Canada's GDP, can be seen in Chart 13. Here we see the explosive growth in labour productivity in the ICT services sector, paired with mediocre performance of the non-ICT economy and the ICT manufacturing sector.[11]

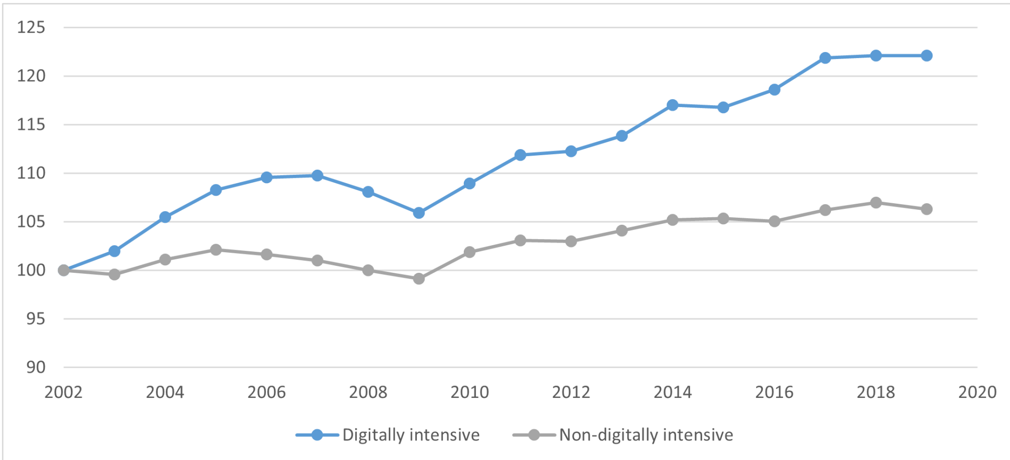
Beyond the highly productive ICT sector itself, there is evidence that digitally intensive sectors in Canada have experienced strong economic growth. Employing a measure of digital-intensity developed in Liu and McDonald-Guimond (2021), Liu (2021) sheds light on the economic performance associated with digitalization, which is shown in Chart 14. Digitally intensive sectors experienced stronger productivity growth in 2002-2019. This study also finds that during the pandemic, digitally intensive sectors suffered smaller decreases in employment and output than non-digitally intensive sectors. This provides evidence of the benefits of investing in the digital economy – strong productivity growth and increased resilience to economic shocks.

Despite strong productivity performance of digitally intensive sectors in Canada, the industry structure of Canada is behind its G7 peers in terms of the digital intensity of output. Calvino *et al.* (2018) developed an index of an industry's digital intensity based on the share of ICT tangible and intangible (e.g. software) investment; share of purchases of intermediate ICT goods and services; stock of robots per hundreds of employees; share of ICT specialists in total employment; and the share of turnover from online sales. Industries are then grouped into quartiles – low, medium-low, medium-high, and high digital intensity. Among the G7, the Canadian economy had the largest share of business activities being low digital intensive and the lowest share of business activities being high digital intensive (Chart 15).

Key to unlocking the potential of digital adoption and spurring productivity growth is business investment. When businesses invest in various aspects of their operations, they often experience increased efficiency, innovation, and competitiveness. In 2021, Canada ranked 6th in the G7 for investment per worker, only outscoring the United Kingdom (Chart 16). Further, while Canadian investment in ICT equipment as a percentage of GDP was similar to that of the United States, Canadian investment in other kinds of machinery and

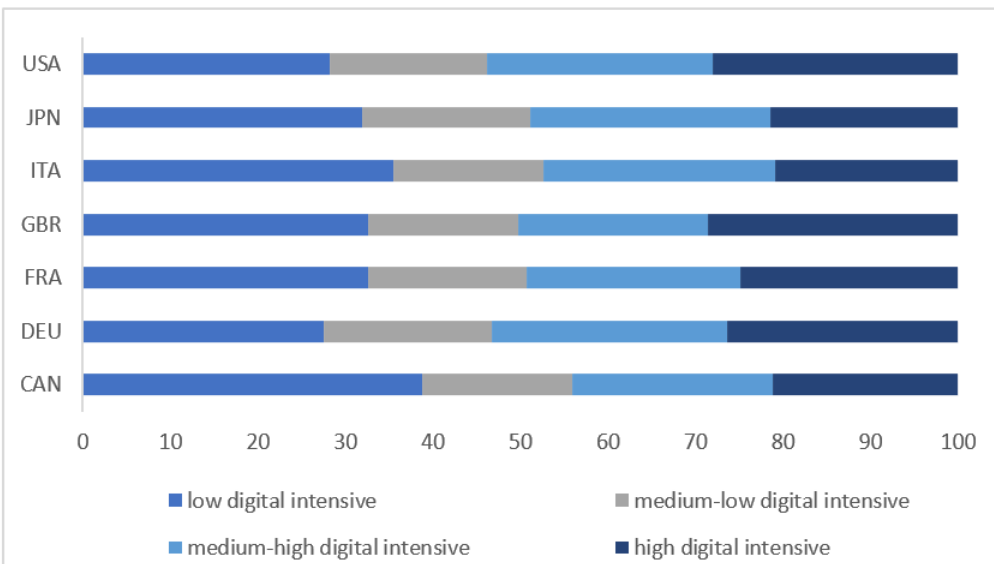
11 This article follows the definition for the ICT sector used in Statistics Canada Table 36-10-0480-01. It defines the ICT - Services sector as the business establishments of the North American Industry Classification System (NAICS) codes 4173 (Computer and communications equipment and supplies merchant wholesalers), 5112 (Software Publishers), 517 (Telecommunications), 518 (Data processing, hosting, and related services), 5415 (Computer Systems Design and Related Services) and 8112 (Computer and Office Machine Repair and Maintenance). It defines the ICT - Manufacturing sector as those with NAICS codes 334 (Computer and electronic product manufacturing), excluding 3345 (Navigational, measuring, medical and control instruments manufacturing).

Chart 14: Labour productivity Growth in the Digitally Intensive and Non-Digitally Intensive Sectors (2002=100)



Source: Liu (2021)

Chart 15: Nominal GDP Share of Industries with Different Digital Intensity by G7 country, 2019



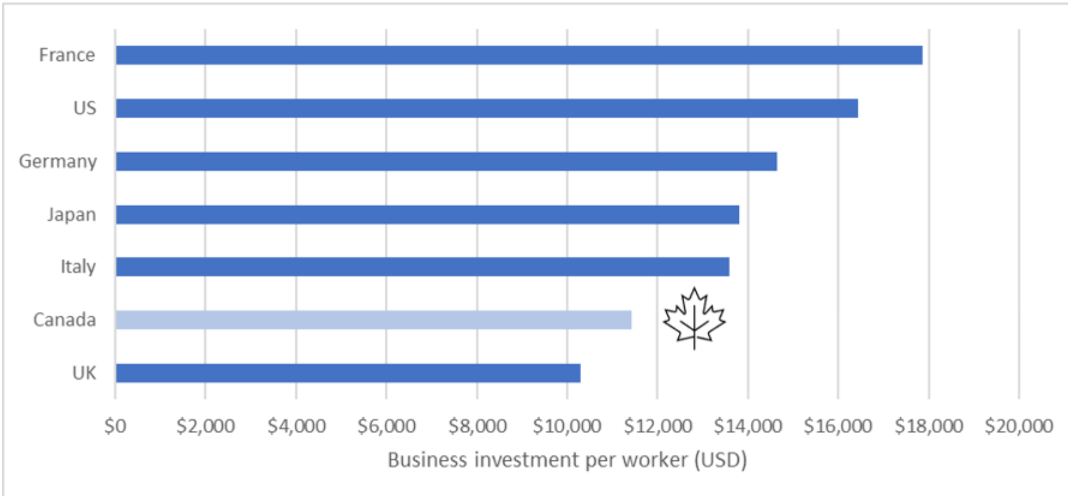
Source: OECD STAN Database.

equipment (M&E) and in intellectual property products (IPP) was about half the rate (OECD 2023).[12]

One explanation for Canada's lagging business investment is the shifting structure of gross fixed capital formation (GFCF). Over the past two decades, total investment composition in Canada has shifted more towards dwellings and away from M&E and IPP in response to persistently low interest rates and hot housing markets. In 2000, the share of investments

12 This article follows the convention of the OECD National Accounts database that includes software in the IPP category of gross fixed capital formation.

Chart 16: Business Investment per Worker, 2021



Source: OECD Labour force statistics 2022
Note: Gross fixed capital formation is in current United States dollars (PPP adjusted).

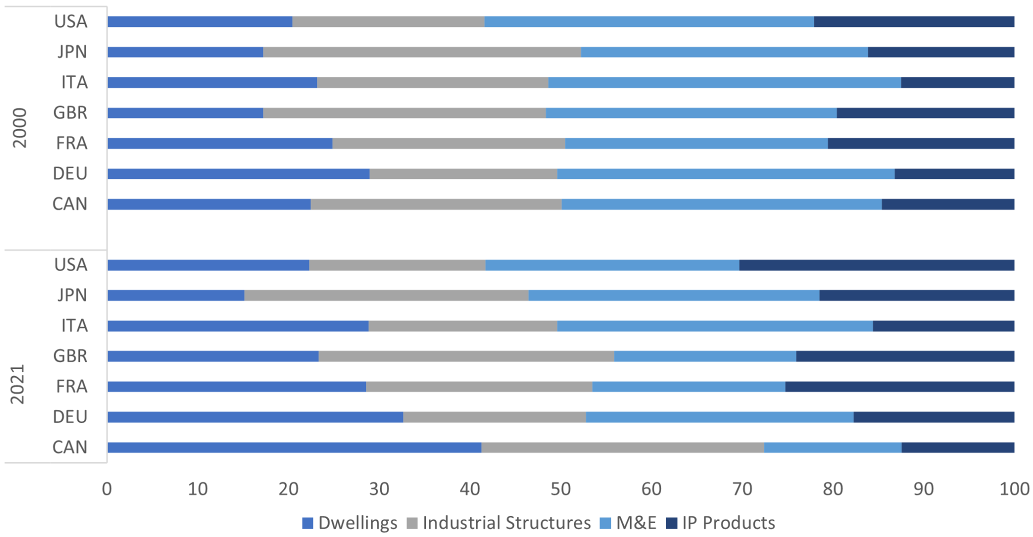
in dwellings was 22.4 per cent of total gross fixed capital formation, the 3rd highest among G7 countries, but by 2021, the share had almost doubled to 41.3 per cent, the highest among G7 countries (Chart 17). This means that Canada is investing less and less in productivity-enhancing forms of capital such as M&E and intellectual property products. In 2000, the proportion of investment in M&E and IPP for Canada was broadly like that of other G7 countries, but by 2021 that proportion was 40 per cent to 50 per cent lower. The shift is worrisome as investments in dwellings can crowd out investments in assets that are critical to productivity growth.[13]

Weak investment in IPP is a concern because the investment in and development of IPP can drive improvements to firm competitiveness, and high productivity firms tend to value IP as important for their innovation activities. Firms are at least twice as likely to innovate if they have filed for or registered any type of IP protection, have a formal IP strategy, or have licensing agreements in place (Statistics Canada, 2021). Chart 18 shows that IP is important for innovation activities among most firms in the ICT and clean technology sectors, as well as other high labour productivity industries like information and cultural industries and manufacturing. Canada is currently modernizing its IP framework, aligning with other jurisdictions, to better position businesses to compete globally through cost effective means for obtaining reliable and high-quality IP rights in multiple jurisdictions.

Another key component of IPP investment for improving productivity is research and development (R&D). Canada's businesses are lagging other G7 countries in in-

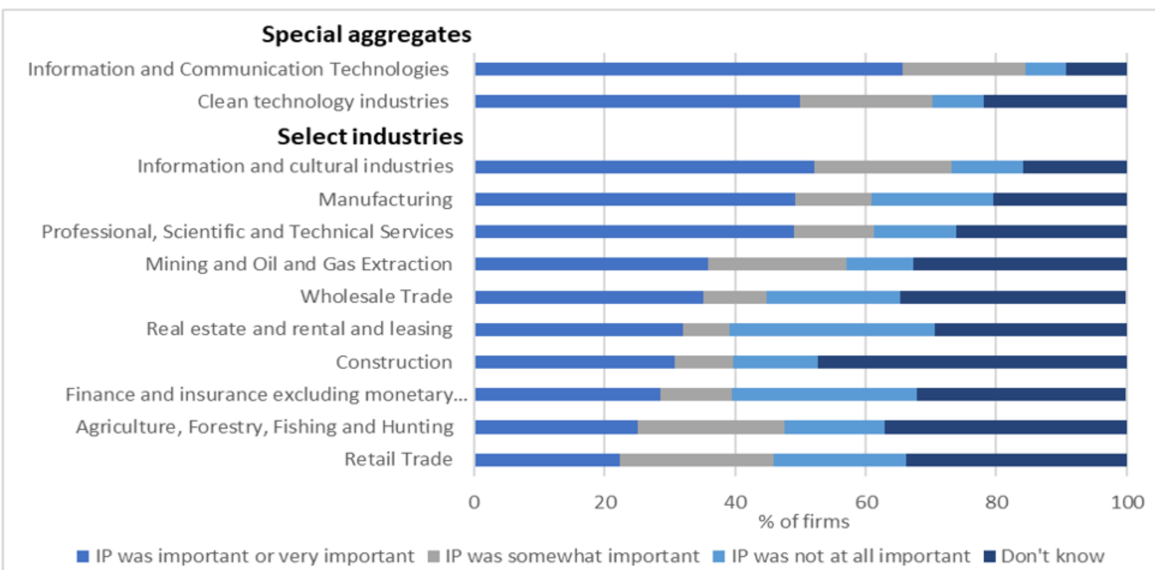
13 Globerman and Press (2018) indicate that "the environment for business investment in assets that are critical to productivity growth has apparently become less favourable in recent years than the environments for other categories of assets".

Chart 17: The Composition of Gross Fixed Capital Formation in the G7, 2000 and 2021



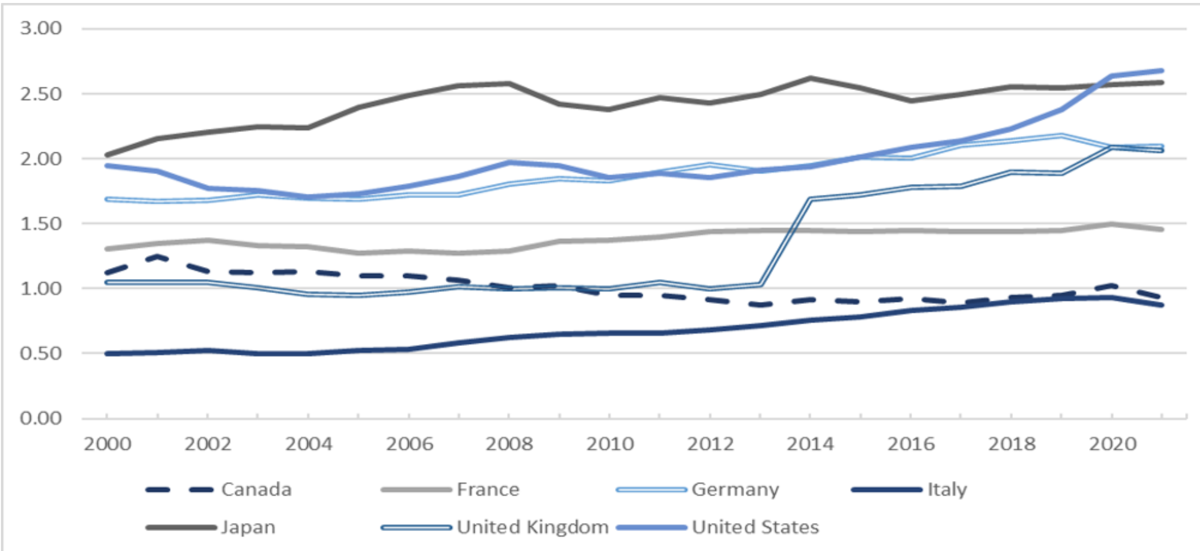
Source: OECD.
Note: Gross fixed capital formation is in current United States dollars (PPP adjusted).

Chart 18: The Importance of IP for Innovation Activities, 2019



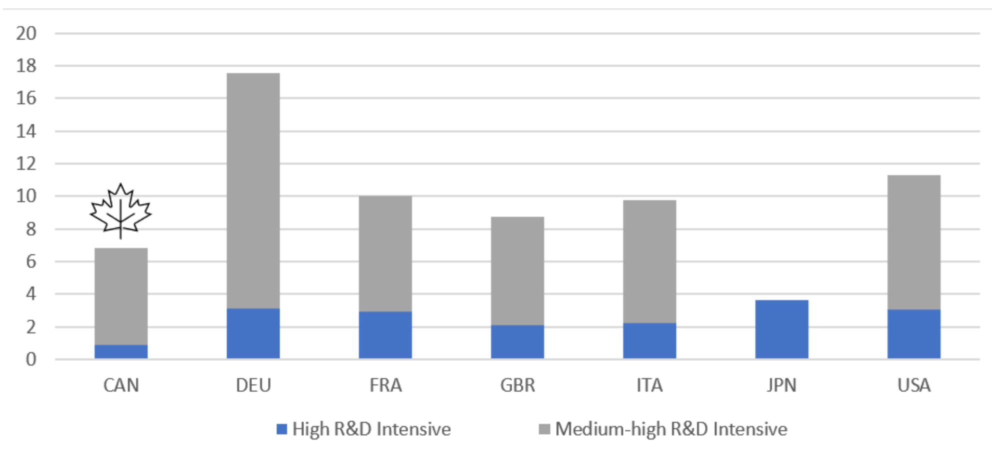
Source: Statistics Canada "Survey of Intellectual Property Awareness and Use."

Chart 19: Business Expenditures on Research and Development (BERD) as a percentage of GDP, by G7 Country, 2000-2021



Source: OECD Main Science and Technology Indicators (MSTI database).

Chart 20: Nominal GDP Share (per cent) of medium-high to high R&D intensive industries, 2019



Source: OECD.
Note: Data is not available for Japan for the share of medium-high R&D intensive industries. However, given Japan's strong performance in those industries, we expect the share of the industries with medium-high R&D intensity is well above Canada.

vesting in R&D activities, which is critical in supporting an innovative and productive economy over the longer term. Canada's investments in R&D activities by businesses as a percentage of GDP were the 2nd lowest among G7 countries in 2021 (Chart 19). Canada is the only country to experience a drop in business R&D intensity over the 2000-2021 period. In contrast, all other G7 countries have managed to increase R&D intensity over that period. Italy, the only country behind of Canada, has almost caught up to Canada by 2021.

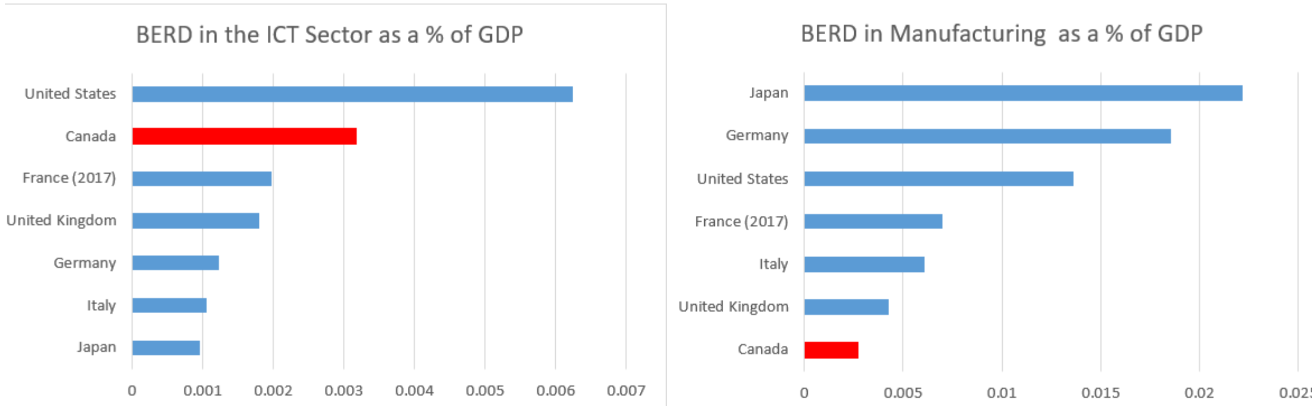
Industry structure is related to Canada's performance in BERD. To see this, consider a measure of industry R&D intensity developed by the OECD, which categorized industries based on the ratio of R&D to value added (Galindo-Rueda and Verger, 2016).[14] Industries classified as having high R&D intensity include air and spacecraft and related machinery; computers, electronic and optical products; pharmaceuticals; scientific research and development; and software publishing, while those having medium-high R&D intensity include machinery, electrical equipment, transportation equipment, chemicals and chemical products, and IT and other information services. Canada not only has the lowest share of business activities being high R&D intensive among G7 countries, but also has the lowest share of business activities being medium-high R&D intensive (Chart 20).

Drilling deeper into industry performance, the relative ranking of Canada in BERD in the ICT and manufacturing sectors is presented in Chart 21. Canada performs well in BERD in the ICT sector ranking second in the G7 behind the United States, though this sector only makes up a small portion of business investment into R&D. Manufacturing is an important sector for aggregate BERD and here Canada is last among the G7, investing far less than the likes of Japan, Germany, and the United States. Closing the BERD gap in the manufacturing sector would go a long way to help Canada catch up with its peers.

Embracing emerging technologies can help shift the Canadian economy away from its reliance on resource-heavy and low-R&D intensity sectors. One of the most exciting new developments in digital technology has been the emergence of artificial intelligence (AI). Aghion, Jones, and Jones (2017) argue that AI is just the latest frontier of automation that extends back to, at least, the industrial revolution and show that increasing automation does not mean that the capital share of the economy necessarily comes to dominate due to the shifting relative prices of capital and labour. The importance of smoothing transitions for workers as AI technologies is important for reaping the fully productivity gains of new AI advances. A recent report from McKinsey Digital (Chui *et al*, 2023) estimates that automation trends could provide an annual productivity boost of 0.2 to 3.3 per cent from 2023 to 2040 with generative AI contributing 0.1 to 0.6 percentage points of that growth, conditional on displaced workers being efficiently redeployed to new tasks. A Goldman Sachs re-

14 Industries are divided into five groups of R&D intensity: high, medium-high, medium, medium-low, and low.

Chart 21: BERD in Selected Sectors as a Per cent of Total GDP by G7 Countries



Source: OECD, ISED's Calculations.

port is even more bullish, projecting that global GDP could rise 7 per cent over the next ten years on the back of a 1.5 percentage point productivity gain from the adoption of generative AI (Goldman Sachs, 2023).

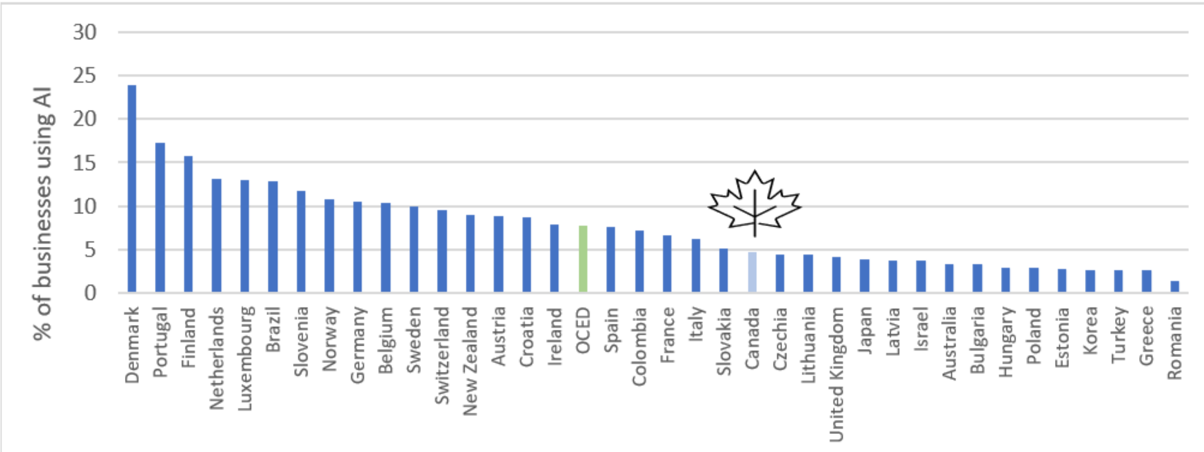
AI can improve productivity by automating tasks, identifying key patterns and trends, and help knowledge workers achieve more in less time, leading to cost savings and efficiency gains. The Brookings Institution (Baily, Brynjolfsson, and Korinek, 2023) has summarized the nascent literature on AI productivity effects. They cite research showing that using generative AI, many writing tasks, including coding, have shown to be up to twice as fast and that there is emerging evidence of this carrying over to the real world, with the example of call center operators seeing an average productivity gain of 14 per cent.

Canada was an early leader in AI, having the highest number of AI-related patents per capita among G7 nations in 2015-2018, although challenges persist in commercializing these technologies to scale within Canadian firms. Despite this, Canadian firms lag their OECD peers in terms of AI adoption (Chart 22). This low rate of adoption may be related to the greater prevalence of small and medium-sized enterprises (SMEs) in Canada than other countries. According to the Survey of Digital Technology and Internet Use, 20 per cent of large Canadian firms made use of AI, while only 6 per cent of medium-sized firms and 2.6 per cent of small.[15]

Artificial intelligence is not the only form of digital technology that SMEs are slow to adopt. As OECD (2021) notes, SMEs across the OECD tend to lag in all areas of digital adoption. Areas in which SMEs rival larger firms tends to be in basic services and the adoption gap widens for more sophisticated technologies. Canadian SMEs compare favourably to international peers when it comes to consumer-facing digital adoption (Table 1). They have some of

15 For this survey, Statistics Canada defines small enterprises as those with 5 to 19 full-time employees and medium-sized firms to have 20 to 99 full-time employees, except for enterprises in North American Industry Classification System (NAICS) code 31-33 where medium size enterprises have 20 to 499 full-time employees.

Chart 22: Proportion of Businesses with 10+ employees using AI by OECD country, Most Recent Year Available*



Source: OECD ICT Access and Usage by Businesses database
Note: Australia, New Zealand, and OECD figures are from 2022, Columbia, the UK, and Israel are from 2020, Japan is from 2019, while all others are from 2021.

Table 1: Proportion of SMEs Using Digital Technologies by Selected Geographies, Most Recent Year Available*

	Broadband Connection%		Cloud computing use%		Company website%		Social media use%	
	Small	Medium	Small	Medium	Small	Medium	Small	Medium
Australia	99.3	98.6	70.4	82.7	79.3	88.4	67.2	74.6
Canada	91.5	92.9	46.0	69.0	82.8	94.1	82.8	94.1
EU27	98.1	99.6	38.0	52.9	75.3	88.8	56.0	69.8
France	96.9	99.5	25.9	45.0	67.5	87.1	59.0	72.7
Germany	99.9	100.0	38.4	51.8	88.1	94.4	52.7	71.3
Italy	98.6	99.7	58.8	71.2	73.0	86.7	54.8	64.4
New Zealand	91.3	92.9	54.9	62.5	83.0	91.2	61.7	70.9
OECD	96.8	98.9	42.4	57.5	75.4	88.7	60.7	73.1
United Kingdom	94.7	98.9	59.8	57.7	81.4	92.2	69.6	81.7
United States	N/A	N/A	42.7	56.8	N/A	N/A	N/A	N/A

Source: OECD ICT Access and Usage by Businesses database.
* Australia, New Zealand, and OECD figures are from 2022, US are from 2018, UK are from 2019, and all others are from 2021. Comparable data from the United States is not available for all categories.

the highest rates of social media presence, well above EU and OECD averages, and have higher rates of having a company website. However, Canadian SMEs lag the EU and the OECD on broadband usage and Australia and Italy on cloud computing usage. Overall, Canadian SMEs perform well internationally in terms of ICT usage, although they lag behind large Canadian firms. Westerlund (2020) and Goldsmith (2021) note that the key barriers for adoption of digital technologies for SMEs in Canada include a lack of skills and knowledge as well as uncertain returns on investment.

The barriers SMEs face in adopting digital technologies represents a type of market failure for which government intervention aims to help firms overcome. Canada's Digital Adoption Program is helping SMEs adopt digital technologies to increase their competitiveness. The Government of Canada has also introduced the Canada Innovation Corporation to accelerate business investment in R&D, with an explicit emphasis on retaining and growing IP in Canada. In addition, Canada has created five Global Innovation Clusters which seek to improve productivity by encouraging new investments, partnerships, and knowledge transfers in several key fields, including supporting commercialization for AI and quantum computing, fighting climate change, and building more resilient supply chains. As of December 2022, the clusters had supported more than 500 projects worth $2.37 billion, involving more than 2,465 partners and generating over 855 patent applications, copyrights, trademarks, or trade secrets (ISED, 2023).

There are several knowledge gaps around digitalization and its relationship to productivity. While the importance of investment intangibles is understood to be important for firms, the only ICT-related intangible measured is software. However, with the rise of data science, the ability of some firms to exploit rich consumer data is an important competitive advantage. Understanding and quantifying that advantage is an exciting avenue for further study and could provide important evidence for firms to adopt big data analytics. Emerging technologies like artificial intelligence demand complex skills and substantial intangible investments like R&D and skills. Understanding how to effectively employ these cutting-edge technologies by, for example, identifying what complementary technologies and skills were required would help increase the rate of adoption. Certain digital activities have given rise to a small number of highly productive "superstar" firms. More study on what makes them dominant and how competition policies can foster a level playing field while encouraging productivity growth is required. As digitalization continues, effective methods for upskilling the workforce to succeed need to be developed and studied, with an eye on addressing persistent inequalities to ensure no segment of society gets left behind in the economy of tomorrow. Finally, research on identifying synergies between the emerging ECT sector and digitally intensive sectors will be important to ensure continued productivity growth while meeting environmental goals.

Conclusion

Productivity remains core to Canada's current and future economic prosperity. It drives growth, bolsters competitiveness, and fuels innovation. Seizing opportunities to enhance productivity, especially in light of the green and digital transformations, will be critical for Canada to navigate the fast changing global economic landscape.

As highlighted in this article, Canada's mining and oil and gas sectors boast impressive labour productivity levels but have experienced persistent productivity declines, creating a drag on overall productivity growth. Further, strong demand for Canada's natural resources has led to simplification in export complexity since the 1990s. This, coupled with the green transition, represents a risk for future Canadian productivity growth. A key consideration is how Canadian firms will best adapt to new and evolving economic realities. The Porter Hypothesis, and its supporting literature, suggest that there may not be a trade-off between reducing emissions and productivity growth. Investing in environmental and clean technology can put Canadian firms in a position to meet global demand for clean technology solutions and the raw materials needed to produce them. There has been some evidence showing a positive link between green technology development/adoption and productivity improvements.

Digitalization is another force reshaping Canada's productivity landscape. Higher labour productivity growth is closely tied to digital adoption, with digitally intensive sectors outpacing the economy at large, with the COVID-19 pandemic demonstrating this sector's robustness to economic shocks. Business investment plays a pivotal role in adopting or adapting digital technologies, potentially unlocking increased efficiency, driving innovation, and enhancing competitiveness. Investment in intellectual property (IP) and the adoption of AI technologies can further stimulate firm competitiveness and productivity.

Yet challenges in digital adoption persist. Canada's production is more concentrated in low digital- and R&D-intensity sectors than its G7 peers. Additionally, a persistently hot housing market has led investments to shift from productivity-enhancing business investment like M&E and IPP to dwellings. Small and medium-sized enterprises trail their larger counterparts in embracing green and digital technologies. Canada can gain an edge amongst its peers if it can find ways to address these issues.

There are several knowledge gaps that remain with regards to the relationship between productivity and the green and digitalization transitions. Future research could use standard productivity decomposition techniques to see the impact of green industries on productivity growth over time. Data on the key obstacles for clean technology and digital adoption provide a promising starting point to better understand how to help firms overcome them. The green and digital transitions will create demand for new skills, so understanding how this demand will evolve and what are the shortest paths for displaced workers to new, more sustainable jobs will also help maintain productivity levels. Finally, research on productivity synergies between the emerging ECT sector and digitally-intensive sectors is needed in order to help firms and countries to take full advantage of these megatrends.

In navigating this complex landscape, Canada must strike a delicate balance between its resource wealth, environmental stewardship, and technological advancements—a journey that promises both challenges and exciting possibilities.

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Canada's Patent Productivity Paradox: Recent Trends and Implications for Future Productivity Growth

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Abstract

Canada's slow productivity growth rate relative to peer countries has been the focus of considerable attention among academics and policymakers. In contrast to the relatively flat trajectory for total factor productivity, Canada's production of patents has grown considerably in the last three decades. In this article, we examine changes in Canadian patenting over the past 30 years, with a view to understanding this "patent productivity paradox": slower productivity growth than might be expected given significant increases in patenting. We draw on recent literature on patents as a measure of innovation as well as literature on the relationship between patents and productivity to study this paradox. We propose several explanations for the disconnect between TFP growth and patenting and examine the evidence. We find that the weaker relationship between productivity and patenting in Canada is not explained by the relative rate of invention in information and communications technology, nor by lower invention quality. However, we find suggestive evidence that foreign ownership of patents and inventor migration help to explain the weaker relationship between productivity and patenting in Canada.

Canada's slow productivity growth relative to peer countries has been the focus of considerable attention among academics and policymakers (Baldwin *et al.*, 2014 and Sharpe and Tsang, 2018). According to the Penn World Tables, Canada's total factor productivity (TFP) at constant national prices increased by 7 per cent between 1990 and 2018. By contrast, in the United States and Germany TFP grew by 20 per cent and 24 per cent respectively, while in South Korea it increased by 46 per cent. Be-

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cause technological innovation is associated with TFP growth, this has led to questions about how the rate of innovation in Canada compares to other countries, and numerous policy initiatives in recent decades have sought to increase the rate of innovation in Canada.

Although not without its limitations, patent data provide one of the most comparable measures of invention across countries, technological fields, and time. In contrast to its relatively flat trajectory for TFP, Canada's production of patents has grown considerably over the past three decades. In absolute terms, the total number of patents granted by the US Patent and Trademark Office (USPTO) with at least one inventor residing in Canada roughly tripled during this period, outpacing growth in the Canadian population and in real GDP. Using a different metric – the number of patents granted by the USPTO and also filed at the Japanese Patent Office, and the European Patent Office (known as "triadic" patents) – Canadian patents per capita increased by approximately 73 per cent during this period. Yet the trajectory of aggregate TFP growth in Canada over the same period has been relatively flat.

This presents a puzzle: if invention is alive and well in Canada, why is this not reflected in productivity growth? This apparent disconnect may simply be an artifact of measurement challenges. It has long been recognized that there need not be a tight, one-to-one relationship between patenting and TFP growth. Patents are an imperfect measure of the inventive output of an economy: not all inventions are patented, and not all inventions (patented or unpatented) are developed into new products or production processes that contribute to growth in TFP. There are, of course, potentially long and variable lags along the path from invention to innovation to productivity growth. Nor need the relationship between invention and productivity growth be geographically constrained: In an open economy, productivity-enhancing ideas and technology can be sourced externally and implemented domestically through licensing agreements, or by being embodied in imports, without leaving footprints in domestic patenting. Conversely, locally generated inventions may find their principal economic use in products or processes developed and sold abroad, with little impact on domestic productivity.

Not surprisingly, looking at the experience of the past 30 years in a sample of countries with high rates of R&D investment, we see that patenting and productivity are imperfectly correlated (with a 10 per cent increase in patents per capita associated with an approximately 1 per cent increase in TFP).[2] However, the relationship is unusually weak for Canada, whose recent history of strong growth in patenting but little improvement in TFP stands in sharp contrast to countries like Finland, South Korea or Sweden.

In cross-country regression analyses that compare the relationship between changes

2 A recent estimate from a long-run causal analysis of the relationship between patenting and productivity at the country-sector level (Berkes *et al.*, 2022) finds that a one standard deviation increase in patenting leads to a 1.1 per cent increase in growth of output per worker.

in patenting and changes in TFP, we show that the relationship between patenting and TFP growth is significantly weaker in Canada than in most other countries, so that a given increase in the number of patents filed by Canadians is associated with a smaller increase in productivity than is observed in other countries. It seems unlikely that there are sufficiently large Canada-specific idiosyncrasies in the relationship between patenting and inventive activity or in productivity measurement to account for this difference, and we are left with a "patent productivity paradox": if patents are an (albeit imperfect) measure of invention, and increases in invention lead to ultimately to increases in productivity, why has the growth in Canadian patenting not led to faster growth in TFP?

Prior research on Canadian patenting focused on several notable patterns. Trajtenberg (2000) highlighted the Canadian economy's deficiencies in innovation in information and communications technologies (ICT). In this article, we ask whether the share of ICT inventions among Canadian patents can help explain the patent productivity paradox. We find that Canada is no longer a laggard in ICT patenting: recent decades have seen a dramatic increase in the previously low share of Canadian-invented patents in ICT. However, it is possible that, due to challenges in the measurement of productivity growth in ICT-intensive sectors, the increasing number of ICT patents as a share of total patents may have led to a weaker correlation between patenting and TFP. As noted by Solow (1987), "you can see the computer age everywhere but in the productivity statistics."[3] We investigate this hypothesis in this article.

Trajtenberg (2000) also found that Canadian patents were on average of lower quality or importance than patents filed by U.S. inventors, using the best measures of patent quality available at the time. Attention has recently been drawn to the relationship between productivity and innovation quality by authors such as Akcigit and Ates (2021) and Bloom, Jones, Van Reenen, and Webb (2020). The latter asks whether radically productivity-enhancing technological innovations are becoming less common, replaced by more incremental innovations. One possibility, therefore, is that the Canadian inventions patented in recent years are less novel or important, and therefore have a smaller impact on firm productivity, than inventions produced in other countries. We evaluate the evidence in favor of this hypothesis by examining conventional as well as recently developed measures of patent importance or novelty.

Prior research has also documented a high and rising share of patents invented in Canada and owned by foreign firms. It has been suggested that this could be harmful for the Canadian innovation ecosystem (Gallini and Hollis, 2019). We examine data on Canadian patents held by foreign firms and consider the mechanisms through which this might affect productivity. In particular, we incorporate data on the mi-

3 Robert Solow, "We'd better watch out", New York Times Book Review, July 12 1987, page 36 (citation courtesy of https://standupeconomist.com/solows-computer-age-quote-a-definitive-citation/ accessed 12/14/2022).

gration of inventors based on a comparison of the nationality of inventors and their country of residence made available by the World Intellectual Property Organization (WIPO) (Miguelez and Fink, 2013, Ivus, 2016). We find that neither ICT patenting nor invention quality appear to explain the Canadian patent productivity paradox. In a regression that accounts for the share of patents in computing-related fields, we continue to find that increases in Canadian patenting are more weakly associated with increases in productivity than in comparable countries. We also continue to estimate a lower patent-productivity correlation for Canada in sector-level analyses that omit the ICT sector. Using both conventional and new measures of invention quality, we find that recent Canadian inventions are not on average less important or novel than inventions from other countries. Incorporating data on invention quality in the cross-country productivity regression fails to eliminate the estimated weaker correlation between patenting and productivity for Canada.

Another possible explanation is that, for whatever reason, new patented technologies generated by Canadian-resident inventors are less likely to be put into practice in Canadian production facilities. Canadian inventors may sell their ideas to foreign firms that implement them elsewhere, or even out-migrate i.e. take their patented ideas to other countries for implementation. Other inventions may come from Canadian employees of multinational enterprises that prioritize development and implementation of these technologies in other countries rather than in Canada. Consistent with this, we find that, after controlling for the share of patents held by assignee firms located in a country different from the inventor country, the Canadian patent-productivity gap is reduced, and it is completely eliminated after we control for the net migration of inventors (although the latter data is only available until 2012).[4] Moreover, foreign ownership of patented inventions may not be negatively associated with productivity when combined with net inflows of inventors. This suggests that productivity is positively associated with foreign ownership when it shifts foreign R&D workers into the country, and negatively associated with it when there is no associated inflow of R&D workers. Although there is likely to be endogeneity in the relationship between productivity and inventor migration, these findings suggest the importance of further inquiry into the relationship between inventor mobility, innovation, and productivity in Canada. The next section reviews prior literature and is followed by a description of our dataset. We then discuss the evidence for a Canadian patent productivity paradox, and evaluate several potential explations for this paradox using regression results. The final section concludes and discusses policy implications.

4 In 2012, the America Invents Act removed the requirement that applications at the USPTO list inventors as applicants. This removed the requirement that inventors' nationality be listed on the application (Ivus;2016:3).

Prior Literature

Interest in the relationship between patenting and productivity in Canada is not new. In the 1990s, Canada's relatively slow productivity growth led to an attempt to explain this lower growth rate, and since innovation is a source of productivity growth, several studies have focused on documenting rates of innovation in Canada and understanding its potential impact on productivity growth in Canada. Although an imperfect measure of innovation (Pavitt, 1988), data on patent filings and grants can provide highly detailed information on invention across countries, time and technological fields. Trajtenberg's (2000) survey of 30 years of Canadian patenting identified several ways in which Canada could be missing the "technology boat." Notably, Trajtenberg found that the technological composition of Canadian patents was out of step with the growth of information and communications technologies (ICT), the rate of unassigned and foreign-assigned patents was high, and the quality of Canadian patents was below average using the best measures of patent quality available at the time. Trajtenberg speculated that these disparities could be remedied by choosing appropriate innovation policies.

When Trajtenberg's analysis was conducted, the use of patent data by empirical economists studying innovation and growth was relatively new. The past two decades have seen an explosion of research on patents as well as the availability of more detailed patent datasets. Two surveys of patenting in Canada provide an excellent overview of recent trends, one by Greenspon and Rodrigues (2017) and the other by Gallini and Hollis (2019). Greenspon and Rodrigues (2017) study patenting by Canadian inventors at several patent offices[5], and found that the growth rate of patenting by Canadian inventors at the United States Patent and Trademark Office (USPTO) was the highest in the G7 between 2000 and 2014 (when the number of Canadian patents granted by the USPTO approximately doubled). Much of this increase can be explained by the growth of patenting in information and communications technologies (ICT). Greenspon and Rodrigues also document a divergence between R&D spending and patenting, with business expenditure on R&D falling slightly during the period in which patent grants doubled. They consider several potential explanations for this pattern and suggest that developments in ICT and other technologies may have increased the productivity of R&D spending, leading to greater research productivity, but conclude that more research is needed to understand this divergence between R&D and patenting. Other potential explanations include a rise in "strategic" patenting, an increase in the number of patents per innovation, and a shift away from business R&D toward R&D performed by the public sector.

While patenting by Canadian inventors

5 The Canadian Intellectual Property Office (CIPO), the United States Patent and Trademark Office (USPTO), the Japan Patent Office (JPO) and the European Patent Office (EPO)).

at the USPTO has increased significantly in our sample period, Eckert*et al.* (2022) show that filings by Canadian inventors at CIPO have declined. Katz and Raffoul (2022) point to a sharp decline in the number of international patent filings by Canadian applicants via the Patent Cooperation Treaty (PCT) between 2014 and 2017, citing the report to the province of Ontario by the Expert Panel on Intellectual Property which shows that the decline in filings by Canada during this period is the largest of any PCT member state (Expert Panel on Intellectual Property, 2020) (Appendix A, p. 34). It is worth noting that PCT applications, which allow an application at the applicant or inventor's home country office to be used to obtain patents in foreign patent offices, are less commonly used by Canadian applicants/inventors to access the USPTO.

As shown by Greenspon and Rodrigues (2017), more Canadian-invented patents are filed at the USPTO than at the CIPO, and Eckert *et al.* (2022) show that only 8 per cent of USPTO patents issued to Canadians were via the PCT (implying that Canadian patents are much more likely to be filed directly at the USPTO).[6] This suggests that the number of PCT applications is not ideal as a single proxy for Canadian inventive output. However, it is worth noting that Eckert *et al.* (2022) find that Canadian-controlled firms are more likely to file patents via the PCT, which is relevant given trends in the percentage of Canadian-invented patents held by foreign firms.

Gallini and Hollis (2019) also provide an overview of recent patenting trends in Canada, with a focus on commercialization. They find that most patents with a Canadian inventor are assigned to a foreign firm or to a Canadian subsidiary of a firm with foreign headquarters (Gallini and Hollis; 2019:20-21) [7]. They argue that Canadian innovation is disproportionately focused on the early stages of research – Canada has strengths in academic science and researchers per capita, but lags in the application of research to commercialization (Gallini and Hollis 2019, :4). They emphasize the importance of encouraging Canadian small and medium-sized enterprises (SMEs) to use patents to "scale up" rather than selling to larger (mostly United States) acquirers of IP, and discuss policy interventions that may encourage this behavior. Plant (2017) shows that Canada ranks third (after Israel and Switzerland) in the number of inventions assigned to foreign firms (per million $ of GDP).

The high share of Canadian patents held by foreign firms has received attention among researchers as well as in the popular press (for example Gallini and Hollis, 2019 and Synder, 2021). The extent to which foreign ownership of patents invented in Canada may contribute to slow productivity growth is an open question. As sug-

6 Eckert *et al.* (2022) argue that the PCT is primarily used by Canadian applicants to access patent offices other than the United States and Canada. Miguelez and Fink (2013) note that a rule change in 2004 required PCT applicants to automatically designate the USPTO.

7 Gallini and Hollis classify Canadian-invented patents as those patents with at least one Canadian resident listed as an inventor.

gested by Gallini and Hollis (2019), when Canadian-invented patents are assigned to foreign firms, those firms are more likely to "scale up" the invention outside Canada, and as a result, any ensuing impacts on productivity growth would occur in other countries.

However, a substantial literature has documented the potential benefits of international collaboration in patenting. Ferucci and Lissoni (2019) draw on data from WIPO applications which lists the nationality of inventors and find that inventor teams with more diverse nationalities produce higher quality patents (as measured by forward citation counts). Equally, inward FDI can enhance technology spillovers: several papers have found that inward FDI and R&D collaborations are associated with knowledge diffusion as measured by patent citations (e.g. Branstetter 2006, MacGarvie 2006). Moreover, foreign-owned subsidiaries have been found to have higher productivity than domestically-owned competitors (Griffith *et al.* 2004). Thus, foreign ownership of Canadian patents may also confer benefits for innovation in Canada by allowing Canadian inventors to access information about advanced innovations abroad.

Although this article is primarily concerned with the relationship between patenting and productivity in Canada, concerns about changes in innovation and slowing productivity growth are not unique to Canada. For example, Bloom, Jones, Van Reenen, and Webb (2020) document a decline in the productivity of research across many sectors and technologies. Kalyani (2022) documents a decline in the use of novel word combinations in the text of patents and associates this with slower productivity growth. Akcigit and Ates (2021) link slower productivity growth to a decline in the diffusion of ideas from leader firms to follower firms, which may be explained by increases in industry concentration. There is some evidence that this rise in industry concentration may be explained by the growth of information technology (IT). Bessen (2020) finds a relationship between adoption of proprietary IT and increases in industry concentration.

Data on Patents and Productivity

One of the major developments in the field of innovation studies in the past two decades is the emergence of new patent datasets and indicators. We use several different data sources in this article. For our primary analyses, we use USPTO data (downloaded from Patentsview.org) for ease of use and interpretation as well as consistency with prior studies. One of the key advantages of USPTO data is that they record both the identity of the organization or individual that owns the patent (the assignee) as well as the name(s) and address(es) of the inventor(s).[8] This fact is important for understanding trends in

8 Country coding of inventors and assignees was exhaustively checked to remove errors from sources such as: (a) apparent data entry or file format errors, e.g., city listed as "Chongqing, Canada"; or (b) potential confusion between, e.g., the US state of California, and the country of Canada – both of which have the code "CA" on USPTO documents.

the location of invention and ownership as studied by prior authors (e.g. Trajtenberg 1999, Greenspon and Rodrigues 2017, and Gallini and Hollis 2019). Screening out inventions that do not result in a US patent may also control for patent quality. Prior studies have suggested that Canadian firms are more likely to patent at the USPTO than at the Canadian Intellectual Property Office (CIPO) (Greenspon and Rodrigues 2017; Eckert, *et al.* 2022), and that patents filed by Canadian inventors in the USPTO and the CIPO are of higher quality than those filed in CIPO only (Eckert, *et al.* 2022).

Although we rely on the USPTO data for most of our analyses, we supplement it with additional data from other patent offices in several cases. We use data from WIPO on the total number of patent applications filed by applicants from a given country across all patent offices worldwide, which we call "worldwide" patents. This helps address potential "home bias" problems in USPTO data. US and Canadian inventors disproportionately file applications in the USPTO relative to other offices, and thus may be over-represented in USPTO data (de Rassenfosse *et al.* 2013).[9] Higher-quality inventions will be patented in more locations, and the worldwide application count will incorporate this fact. However, inventions filed in more than one location will be counted more than once. To address this, we use data on two patent family measures from OECD.Stat, described below. A "family" is the collection of patents filed in patent offices around the world which claim (approximately) the same invention.[10] Worldwide counts of patent families may thus be better measures of the number of inventions across countries, since multiple patent documents can relate to the same invention. Use of family counts can also minimize home bias problems. These variables have the advantage of not constraining attention to inventions patented in the United States alone, and allow us to obtain a broader picture of the full extent of Canadian patenting.[11]

Looking at the countries in which applications are filed for a given invention also permits some degree of screening on the quality of the invention. We use data on "triadic" patent families, families with patents granted by the USPTO that were also filed at the European Patent Office (EPO) and the Japanese Patent Office (JPO), from the OECD. Research has suggested that "triadic" patent families are a better measure of high-quality innovations (OECD 2009:71). We therefore include tri-

9 To be precise, we use indicator 1, "Total patent applications (direct and PCT national phase entries)", "Total count by applicant's origin" from the WIPO IP Statistics Data Center (https://www3.wipo.int/ipstats/ips-search/patent).

10 Technically speaking, a family is the set of patent documents (applications or granted patents) that share the same priority document. The OECD data on patent families draws on the DOCDB definition in the PATSTAT database (Dernis and Khan 2004:8).

11 The WIPO patent dataset classifies a patent as originating in a country based on the residence of the first-named applicant.

12 Plant (2017) argues that triadic patent counts are the "gold standard" patent indicators, and points out that Canada is at the bottom of a list of peer countries in counts of triadic patents. However, overall applications at the JPO have declined since 2000 (World Intellectual Property Indicators 2020, p.14), making triadic patents

adic patent family counts as a robustness check in some of our analyses.[12]

An alternative is to count only patent families protected in two or more patent offices and at least one of the world's top five patent offices (known as IP5 patent families). Note that the data on triadic and IP5 patent family counts (both produced by the OECD) are based on the priority year, and are fractional counts by inventor location (i.e. if half of a patent's inventors are located in one country and half in another, the patent is counted as half a patent in each country). OECD data on patent families are however only available starting in 1985.

We also make use of WIPO data on the country of citizenship of inventors. USPTO inventors can be identified by their addresses, but patents filed under the PCT list the nationality of inventors (until 2012). This allows us to measure how many Canadians invented patents outside of Canada, and how many citizens of other countries invented patents in Canada. Miguelez and Fink (2013) and Ivus (2014) provide in-depth analysis of this data and how it can be used to measure flows of inventors. We make use of data on the number of patent applications from a country which have immigrant or emigrant inventors (in other words, those whose citizenship does not match their country of residence) relative to the number of patent applications filed by nationals (inventors residing in their country of citizenship), in the first year the patent application was filed in any patent office (the priority year).

It is important to note that these data do not count the actual numbers of immigrant and emigrant inventors; rather, they count the number of patent applications by migrant inventors. Thus, a migrant inventor can be counted more than once if they are listed on multiple patent applications. If Canadian migrant inventors have substantially different rates of inventive productivity, this could cause us to under- or overstate Canadian migration. Moreover, if the listed nationality of an inventor changes after migration, the migration event will not be recorded in this data. The migration data also includes information on applications for patents that were never granted. Finally, we assume that the percentage of migrant inventors in PCT applications is similar to the percentage in applications filed directly with the USPTO.

USPTO patent data have been assigned to the following technological categories: chemical, computers and communications, drugs and medical, electrical and electronic, mechanical, and others (Hall *et al.* 2002). We compute the percentage of patents assigned in the "computers and communications" field by country and application year. USPTO patents have both assignees (the owner of the patent) and inventors, and locations of both are listed in the patent document. In our primary measures based on USPTO patents, we attribute patents to a country if it has at least one inventor with an address in that country. We compute the percentage of patents

somewhat difficult to interpret because they show a decline for most countries after 2000, where other patent indicators have been rising.

with any inventor from a particular country and an assignee from another country and call this the percentage of foreign-assigned patents.

To measure the value or importance of patents, we make use of a standard indicator – the number of forward patent citations – which have been shown to be positively correlated with market value at the firm level (Hall *et al.* 2005, Bloom *et al.* 2013). We also draw on new text-based novelty measures originally compiled by Arts *et al.* (2021). These metrics use text from the title, abstract, and claims of the corpus of US patents to these measures identify the "technical novelty" of a given patent. For instance, one such measure is *new_bigram* which captures the number of two-word combinations that the focal patent uses that had not previously been used. Arts *et al.* (2021) validates and makes available a suite of metrics to capture the technical novelty of a patent. Finally, we use data from Penn World Tables version 10.0 (Feenstra *et al.*, 2015) for country-level information on TFP, GDP per capita and per hour worked, and population.[13] Data on the ratio of gross domestic spending on R&D to GDP come from the OECD Science, Technology and R&D Statistics and are measured in purchasing power parity adjusted USD constant prices with 2015 as a base year.[14]

To construct data at the sector level we match counts of patents by 4-digit IPC codes to ISIC industries using the concordance described in Lybbert & Zolas (2014).[15] This procedure uses keywords from patent text and industry descriptions to create a probabilistic mapping.[16] We use this concordance to match patent data with labour productivity (per hour worked) statistics from the OECD Stan database and R&D statistics from the OECD ANBERD database. Our final sector-level dataset consists of the industries listed in Table 1.[17]

Although it should in principle allow a more fine-grained analysis of the relationship between patenting and productivity, the sector-level data has several limitations. It should be noted that, although the mapping between patents and industries is designed to identify the patent classes most related to technologies in a particular industry, this mapping is imperfect. Classes

13 The TFP variable is rtfpna, a TFP index normalized within each country to equal 1 in 2017. GDP per capita is output-side real GDP (rgdpo), at chained PPPs (in mil. 2017 US dollars), divided by population. GDP per hour is rgdpo divided by the product of average hours worked per worker (avh) and total employment (emp)."

14 Data come from https://data.oecd.org/rd/gross-domestic-spending-on-r-d.htmindicator-chart (downloaded October 2021).

15 R&D and productivity data are not available for all industry groupings in all years. To improve the match with patent data, we often aggregate two-digit ISIC codes into wider industry ranges. We consider the first-listed IPC code for each patent at the time of issue. The final list of industries is found in Table 1.

16 The concordance maps IPC codes to ISIC sections pertaining to "Manufacturing," "Electricity, gas, steam and air conditioning supply," "Water supply; sewerage, waste management and remediation activities," and "Construction."

17 We exclude resource-based industries D01T03 (agriculture, forestry and fishing) and D05T09 (mining and quarrying) as well as D45 and above (wholesale and retail trade, transport, and service industries). The coke and refined petroleum products industry (D19) is a significant outlier in terms of labour productivity for Canada and Denmark relative to the rest of the world, and we exclude this industry in some specifications.

are assigned to patents based on the nature of the technology, not the industry of use, and the mapping between patents and industries is probabilistic rather than definitive (Lybbert and Zolas 2014).

Most importantly, some patents are "general purpose" inventions that may be used across multiple industries, and inventions relating primarily to one industry may have productivity spillovers for other industries. For example, innovations in computing have the potential to increase productivity across all sectors, but this type of innovation will not be captured by the country-industry regressions displayed here. Moreover, the panel of industries and countries measures labour productivity rather than TFP, and is unbalanced, with varying availability of productivity and R&D data across country-industries and years.[18]

With these caveats in mind, we use the country-industry-year dataset to examine the roles of specific industries. A more thorough analysis of the relationship between patenting and productivity at the country-industry level can be found in Berkes *et al.* (2022), who analyze a sample of 36 countries between 2000 and 2014. In OLS regressions similar in spirit to ours, they find no significant relationship between patenting and productivity at the country-sector level, but a small positive and significant relationship after instrumenting patents with pre-existing knowledge spillovers across countries and industries combined with technological shocks to specific countries.

Each patent is assigned to a year based on the year of application of the patent (rather than the grant year). We do this because the year of application most closely relates to the development of the invention, while grants can arrive with a lag. The Triadic and IP5 measures based on patent families are based on the priority year.

In the analysis that follows, we construct a stock of each explanatory variable: for example, patents (and variables that capture novelty and foreign assignment), R&D, migration. This is to account for the fact that we expect these variables to take time to impact productivity and do so in a way that is dependent on past values of the variable. We construct these variables with a simple depreciation method using a standard δ =15 per cent discount rate (e.g., Hall 1990; Bessen 2009), such that within a country,

18 Notably, for the 10,672 potential observations (23 countries X 16 industries X 29 years), R&D information is available for 6,052 observations, productivity data are available for 6,250 observations, and both are available for 4,103 observations in the raw data. We then interpolate missing values of R&D using a time trend within country-industry and present regressions with and without controls for R&D investment, but do not interpolate the productivity data since it is the dependent variable.

19 To be precise, we use the following formula:

$$\text{stock}(x_t) = \sum_{k=0}^{10} x_{t-k}(1-\delta)^k$$

This is our preferred method of calculating depreciated stocks as it relies on fewer assumptions and allows for simpler and more transparent calculations. In the Appendix Table A-1, we also confirm that our baseline results in Table 2 are robust to using contemporaneous flows or the stock calculation method proposed by Hall 1990. For industry level data, we use a 5-year depreciation, to minimize the number of observations that are excluded from the analysis in the presence of missing data.

Table 1: Summary Statistics

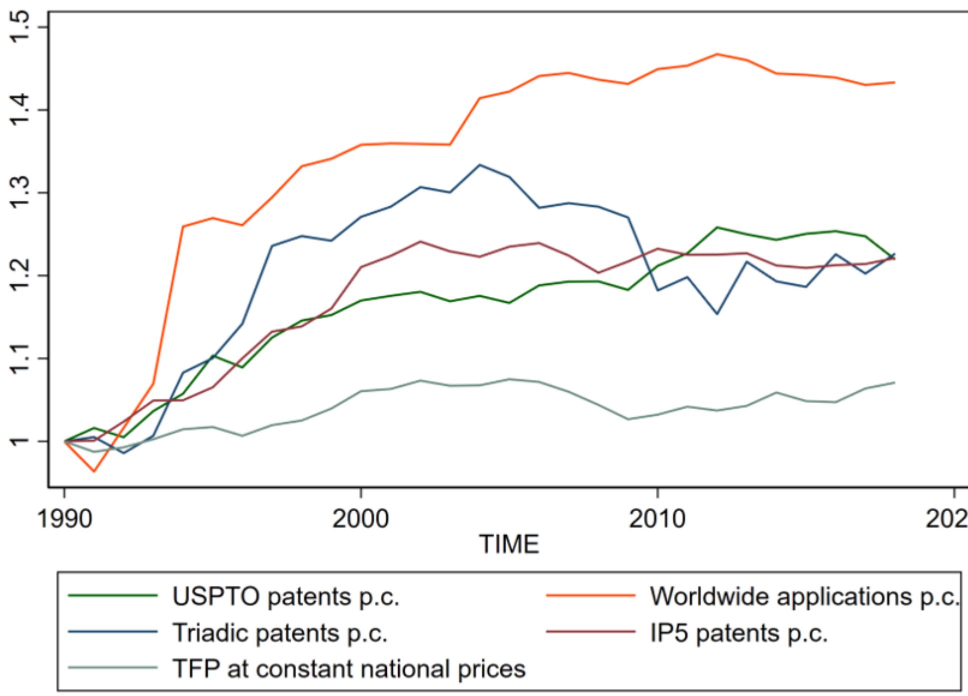
Variable	Obs	Mean	S.D.	Min	Max
Country-level means for 1990-2018*					
Year	667	2004	8.38	1990	2018
TFP	667	0.95	0.08	0.661	1.149
GDP per capita	667	42230.30	13517.03	13819.28	94650.81
GDP per hour worked	667	51.09	16.54	12.18	129.03
Depreciated stock measures					
R&D /GDP(%)	588	11.759	4.107	4.299	24.449
USPTO patents per million pop	667	730.68	526.28	28.70	2634.91
Triadic patents per million pop	552	247.30	181.94	17.97	803.06
Worldwide applications per million pop	580	6551.00	6006.97	375.14	28747.05
IP5 patents per million pop	552	810.32	534.53	71.09	2796.63
% patents in computing/communications fields	666	0.22	0.127	0.000	0.55
Mean forward cites per patent	666	19.45	8.80	4.17	48.37
Mean new bigrams	666	1.46	0.71	0.17	4.58
% USPTO patents assigned to foreign entity	666	0.32	0.18	0.01	0.72
Immigrant/National patents*	529	0.19	0.28	0.00	3.26
Emigrant/National patents*	529	0.17	0.24	0.00	2.53

Country-sector-level data (mean values for all countries over the period 1990-2018)

Industry	Labor Productivity	R&D/GDP (%)	USPTO patents per capita**
Food products, beverages and tobacco	51.98	0.11	19.80
Textiles, wearing apparel, leather and related products	32.01	0.03	11.09
Wood, paper, printing and reproduction of recorded media	39.22	0.07	21.10
Coke and refined petroleum products	2503.71	0.04	3.16
Chemical and pharmaceutical products	101.07	0.75	101.82
Rubber and plastic products	48.04	0.09	17.03
Other non-metallic mineral products	50.05	0.05	22.42
Basic metals and fabricated metal products, except machinery and equipment	46.73	0.02	34.15
Computer, electronic and optical products	58.37	1.54	251.49
Electrical equipment	54.97	0.19	28.89
Machinery and equipment n.e.c.	54.27	0.43	44.21
Motor vehicles, trailers and semi-trailers	46.68	0.61	14.32
Other transport equipment	87.25	0.25	7.40
Furniture, other manufacturing and repair and installation of machinery and equipment	40.83	0.11	24.01
Electricity, gas and water supply; sewerage, waste management and remediation activities	133.81	0.05	30.47
Construction	41.25	0.06	18.96

Note: Countries are Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Ireland, Israel, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Republic of Korea, Singapore, Sweden, Switzerland, United Kingdom, United States. Labour productivity is measured in US dollars per hour worked, R&D/GDP is industry R&D spending as a percentage of aggregate GDP, and USPTO patents are measured per million residents. R&D/GDP and USPTO patents are reported in percentages as stock variables.

Chart 1: Canadian TFP and Patents per Capita, 1990-2018 (1990=1)



Note: USPTO patents are the count of patents filed by at least one inventor with a Canadian address with the US Patent and Trademark Office. "Triadic" patent families granted by the USPTO and also filed at the European Patent Office (EPO) and the Japanese Patent Office (JPO) (source: OECD 2022). Worldwide applications s count all applications filed in offices worldwide, direct and national PCT entries (source: WIPO IP Statistics Data Center). IP5 patents are patent families filed in two or more offices and at least one of the world's top five patent offices (source: OECD). All patent counts are by application year or priority date and normalized by population. TFP is a Total Factor Productivity index at constant national prices (source: rtfpna in Penn World Tables). All series are normalized by their value in 1990 and are shown as flows, rather than stocks.

the stock of a variable x in year t is constructed as a weighted sum of the previous 10 years.[19] Table 1 shows summary statistics for the 16 country and country-industry panels.[20]

Divergence between Patenting and TFP growth

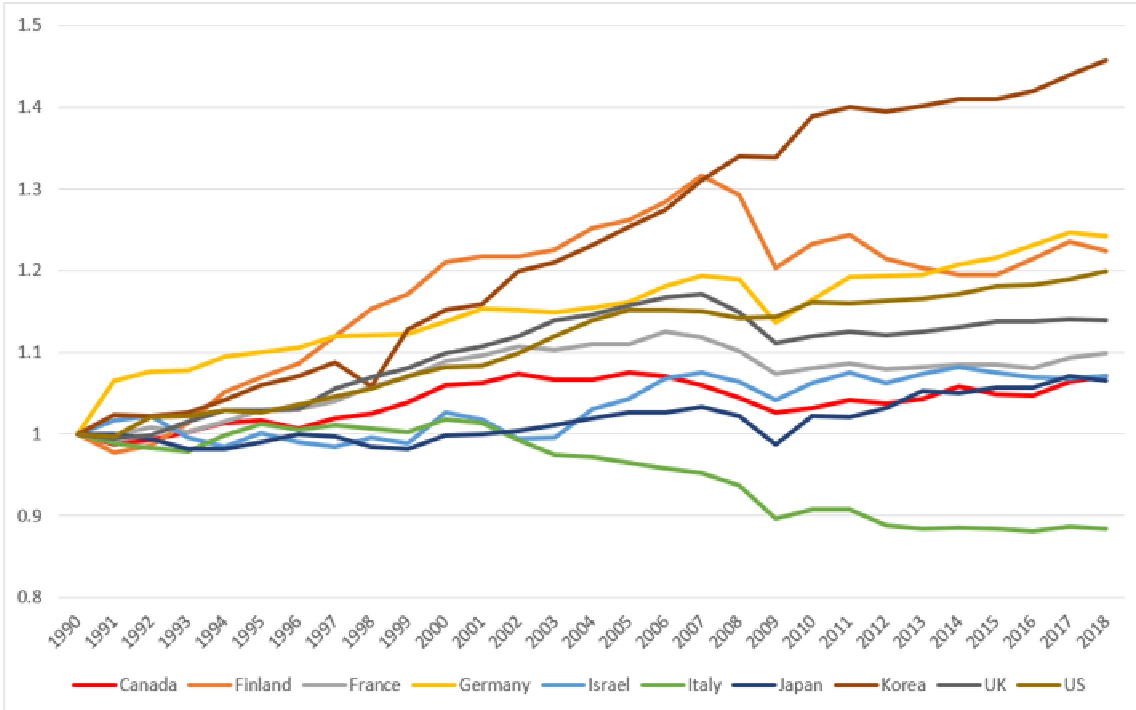
Chart 1 displays the growth in patent applications by Canadian residents (per million population), according to the USPTO, triadic and IP5 patent family counts, and worldwide patents.[21] These series show a dramatic increase in the propensity to patent by Canadians in the last three decades.[22] However, annual TFP at the national level has not kept pace. Sim-

20 There are no patents with an inventor for Iceland in 1990, so per patent measures are missing for this observation.

21 Chart 1 shows yearly flows, rather than patent stocks.

22 The dip in triadic patents observed after the mid-2000s is also observed in the triadic patent counts of other countries and the OECD as a whole. Canadian triadic patents as a share of all OECD countries actually rose from 1.1 per cent of all OECD triadic patents in 2000 to 1.3 per cent in 2020.

Chart 2: Normalized TFP at Constant National Prices, G7-plus countries (1990 = 1)



Source: Data on TFP index (rtfpna) from Penn World Tables 10.0 (Feenstra *et al.*, 2015), indexed to 1990 values for each country.

ilar to the relationship between business R&D expenditure and patenting identified by Greenspon and Rodrigues (2017), we see a divergence between patenting and productivity.

Chart 2 compares TFP growth across a sample of G7-plus countries over the period from 1990 to 2018, with each country's TFP normalized relative to its value in 1990. Among the selected group of countries, only Italy displays slower cumulative productivity growth than Canada.

To understand the relationship between patenting and productivity growth at the country level, we analyze panel data on countries and years from 1990-2018, with regression results in Table 2. Fixed effects for country and year are included in all regressions. This allows us to answer two questions: 1) what is the overall relationship between the growth of patenting and the growth of TFP during this period, after holding constant country-specific and aggregate temporal variation in TFP and patenting? and 2) Is the relationship between TFP and patenting growth weaker in Canada than in other countries? To answer the latter question, we incorporate an interaction between the (natural logarithm of) the stock of per capita number of patents filed by Canadian inventors and a dummy variable for Canada. If the coefficient on this interaction term is negative and statistically significant, this implies that the relationship between productivity and patenting is weaker in Canada than in the other countries in the sample.

Columns 1-3 of Table 2 include TFP

Table 2: Regression Results - The Relationship between the Growth in Patenting and Productivity

	(1)	(2)	(3)	(4)	(5)	(6)
	Full sample, R&D only	+ Patents	+ Can X pats	+ Patents peer countries	Peer countries, no R&D	TFP yr>99
R&D/GDP	0.0931***	-0.0257	-0.0268	-0.00408		-0.0142
	(0.0224)	(0.0267)	(0.0267)	(0.0273)		(0.0468)
Patents		0.0989***	0.0980***	0.0985***	0.0466***	0.108***
		(0.0164)	(0.0164)	(0.0233)	(0.0178)	(0.0295)
Can X Patents			-0.0604***	-0.0538***	-0.0504***	-0.106***
			(0.0118)	(0.0105)	(0.00968)	(0.0357)
Sum of coefs:			0.038*	0.045*	-0.004	0.002
Observations	685	685	685	588	667	419

	(7)	(8)	(9)	(10)	(11)	(12)
	GDPpc	GDPph	TFP G7+	GDPpc G7+	GDPph G7+	TFP (pop weights)
R&D/GDP	-0.309***	-0.255***	0.00151	-0.117	-0.0764	-0.0393
	(0.0729)	(0.0739)	(0.0447)	(0.0831)	(0.0565)	(0.0382)
Patents	0.388***	0.336***	0.164***	0.270***	0.215***	0.0823***
	(0.0696)	(0.0678)	(0.0326)	(0.0503)	(0.0598)	(0.0317)
Can X Patents	-0.131***	-0.188***	-0.0624***	-0.0584**	-0.139***	-0.0676***
	(0.0292)	(0.0236)	(0.0145)	(0.0256)	(0.0195)	(0.0160)
Sum of coefs:	0.257***	0.147**	0.101**	0.211***	0.076	0.015
Observations	588	588	260	260	260	588

Note: Regression coefficients and Newey-west standard errors (lag of 2 years). Data are panel data on countries and years from 1990-2018. Fixed effects for country and year included in all regressions. Columns 1-3 include countries spending more than 1% of GDP on R&D on average during the sample period; columns 4-8 and 12 also exclude China, Russia, the Czech Republic, Estonia, Hungary, and Slovakia. Columns 9-11 include only the "G7 Plus" group of G7 countries plus Israel, Finland and South Korea. Column 12 weights by country population. The dependent variable in Columns 1-6, 9 and 12 is the natural logarithm of output-side real GDP per chained PPPs in mil 2017 USD. The dependent variable in Columns 7-10 and 11 is the logarithm per capita output-side real GDP per chained PPPs, rounded (source: TFP data per PPP 2017 USD, Penn World Tables). The independent variables are the natural logarithm of the stock of R&D as a share of GDP, the natural logarithm of the country's patent stock per capita, and a dummy variable for Canada interacted with the patent variable. The patent stock is based on counts of USPTO patents with inventors located in the country. The "sum of coef's" is the linear combination of the coefficient on "Patents" + the coefficient on "Can X Patents". (***/**/*): significant at the (1/5/10)% level.

regressions for the broad set of countries for which we were able to obtain data on TFP and R&D/GDP during our sample period. To identify a peer set of countries, we select countries that spend at least 1 per cent of GDP on R&D on average during our sample period. In order to restrict attention to countries with economies and innovation ecosystems more similar to Canada's, we exclude current or former planned economies China, Russia, the Czech Republic, Estonia, Hungary and Slovenia in remaining analyses. Columns 9-11 further restrict attention to the "G7

23 Although Trajtenberg includes Taiwan, we do not because data on Taiwan was not available in all our data

plus" group of G7 countries plus Israel, Finland and South Korea (following Trajtenberg 1999).[23] Column 12 reproduces the specification in Column 4 after weighting by country population.

The measures of normalized income and productivity that serve as dependent variables in these regressions are taken from the Penn World Tables. The dependent variable in Columns 1-6, 9, and 12 is the natural logarithm of TFP at constant national prices (2017=1). The dependent variable in columns 7 and 10 is the natural logarithm of per capita output-side real GDP at chained PPPs in mil. 2017 USD. The dependent variable in columns 8 and 11 is the natural logarithm of output-side real GDP per hour worked. The independent variables are the natural logarithm of R&D as a share of GDP, the natural logarithm of the country's patents per capita, and a dummy variable for Canada interacted with the patent variable. To account for heteroskedasticity and potential autocorrelation, in all regressions we calculate Newey-West standard errors with a lag of 2 years.

These regressions show that, although increases in patenting are associated with increases in productivity during this period, the elasticity of productivity with respect to patenting is low (around 0.1 per cent), and significantly lower for Canada than for other countries in the sample (in Column 4, the implied patent elasticity for Canada is 0.045 compared to compared to 0.099 for the rest of the sample). [24] The patent elasticity is higher for GDP per capita and GDP per hour worked (0.39 per cent and 0.34 per cent, respectively, for countries other than Canada), but once again, the elasticity of normalized GDP with respect to patents per capita is significantly lower for Canada. Table 3 shows that this negative and significant interaction effect is similar whether we use USPTO patents per capita, Triadic patent families per capita, worldwide applications per capita, or IP5 patent families per capita. In general, using USPTO patents as our measure, we find a positive relationship between changes in patenting and changes in the output measures, but a significantly smaller relationship for Canada than for other countries in the sample, and the estimated relationship between patenting and output for Canada is not statistically distinguishable from zero at the 5 per cent level in most specifications).[25]

Chart 3 displays the patents interaction effect for Canada in comparison to other countries (without controlling for R&D/GDP). Looking at panel D, only Italy, Luxembourg, and Japan have patent interaction coefficients below Canada's, implying that the correlation between productivity and patenting is higher in all but a few countries.

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sources. The main results are however robust to including Taiwan.

24 We calculate the Canada-specific elasticity of TFP with respect to patents by summing the coefficient on patents (0.0985) with the Canada X patents interaction (-0.0538).

25 The sum of the Patents and the Patents X Canada coefficients is significantly negative at the 5 per cent level in Table 3, Column 1, panel A and panel B, when controlling for R&D/GDP. This may reflect the difficulty of separately estimating the effects of R&D investment from patenting when these two variables are highly correlated.

Table 3: Regression Results by Patent Family

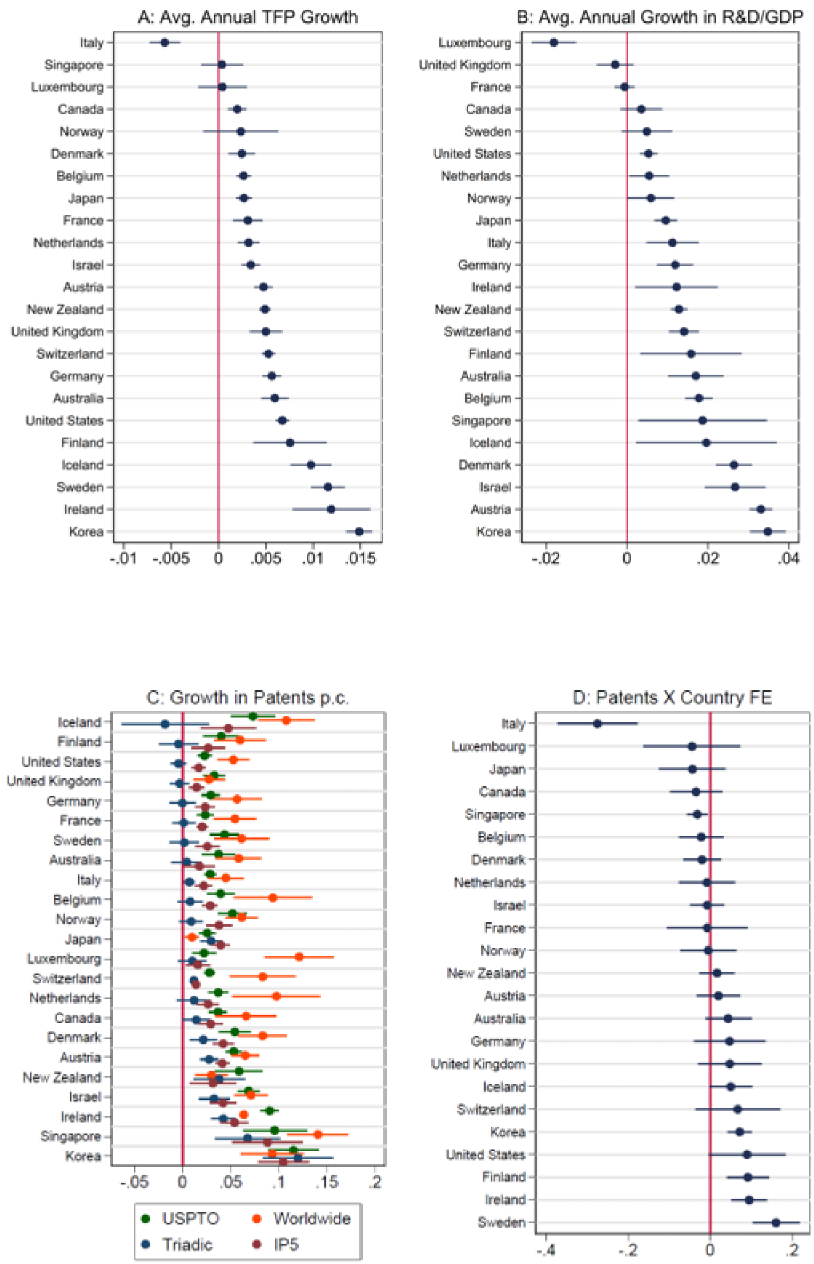
	(1) TFP	(2) TFP	(3) GDP pc	(4) GDP pw	(5) TFP G7	(6) TFP pop wt
Panel A: Triadic patent families (OECD)						
R&D/GDP	0.0806***		-0.0814	-0.0406	0.117***	0.0473
	(0.0269)		(0.0625)	(0.0616)	(0.0418)	(0.0463)
Patents	-0.00653	0.0363*	0.134**	0.128***	0.0583***	0.0113
	(0.0288)	(0.0213)	(0.0541)	(0.0554)	(0.0215)	(0.0314)
Can X Patents	-0.0707***	-0.0651***	-0.167***	-0.246***	-0.0912***	-0.0735**
	(0.0229)	(0.0243)	(0.0776)	(0.0739)	(0.0368)	(0.0342)
Sum of coefs.	-0.077***	-0.029	-0.033	-0.118	-0.033	-0.062
Observations	514	552	514	514	228	514
Panel B: Worldwide applications (WIPO)						
R&D/GDP	0.0500**		-0.0612	-0.0474	0.131***	0.0541*
	(0.0203)		(0.0430)	(0.0421)	(0.0272)	(0.0305)
Patents	0.0112	0.0238*	0.0785***	0.0742***	0.0413**	0.0305**
	(0.0120)	(0.0123)	(0.0253)	(0.0197)	(0.0195)	(0.0134)
Can X Patents	-0.0389***	-0.0433***	-0.0805***	-0.110***	-0.0613***	-0.0520***
	(0.00564)	(0.00598)	(0.0130)	(0.0122)	(0.00687)	(0.00698)
Sum of coefs.	-0.028***	-0.019*	-0.002	-0.036*	-0.020	-0.022*
Observations	530	580	530	530	230	530
Panel C: IP5 patent families (OECD)						
R&D/GDP	0.0392		-0.161*	-0.136	0.0396	0.0250
	(0.0332)		(0.0849)	(0.0826)	(0.0605)	(0.0551)
Patents	0.0492	0.0584*	0.240***	0.252***	0.114***	0.0300
	(0.0306)	(0.0307)	(0.0862)	(0.0801)	(0.0371)	(0.0420)
Can X Patents	-0.0682***	-0.0658***	-0.194***	-0.253***	-0.0695***	-0.0773***
	(0.0182)	(0.0191)	(0.0484)	(0.0460)	(0.0251)	(0.0247)
Sum of coefs.	-0.019	-0.007	0.046	-0.001	0.045	-0.047
Observations	514	552	514	514	228	514

Note: Regression coefficients and Newey-west standard errors (lag of 2 years). Data are panel data on countries and years from 1990-2018. Fixed effects for country and year included in all regressions. Columns 1-4 in each panel include all countries listed in note on Table 1. Column 5 in each panel includes the "G7 plus" group of G7 countries plus Israel, Finland and South Korea. Column 6 in each panel weights by population. In each panel, the dependent variable in Columns 1-2 and 5-6 is the natural logarithm of TFP at constant national prices (2017=1). The dependent variable in column 3 is the natural logarithm of per capita output-side real GDP at chained PPPs in mil. 2017 USD. The dependent variable in column 4 is the natural logarithm of output-side real GDP per hour worked (source for TFP and GDP data: Penn World Tables). The independent variables are the natural logarithm of the stock of R&D as a share of GDP, the natural logarithm of the country's patent stock per capita, and a dummy variable for Canada interacted with the patent variable. Panel A uses "Triadic patent families," the number of patent families per capita from a country granted by the United States and also filed in Japan and the European patent offices. Panel B uses all patent applications filed worldwide, by applicant's origin (source: WIPO IP Statistics Data Center). Panel C uses "IP5 patent families," patent families filed at two or more offices and at least one of the five largest patent offices, by priority year (source for IP5 and triadic patents: OECD.Stat). (***/**/*): significant at the (1/5/10)% level.

The coefficient on the number of patents in Table 2 implies an elasticity of approximately 0.1 per cent, implying a relatively small increase in productivity growth when the rate of patenting increases. This may partly reflect the fact that analysis at the sectoral or national level will average firm-specific effects of patenting, which makes it difficult to trace the relationship between patenting and productivity. However, it does not explain why the relationship between patenting and productivity would be substantially weaker for Canada than for other countries.

Potential Explanations for the Patenting-productivity Divergence

Chart 3: Regression Results by Country



Note: Regression coefficients and Newey-west standard errors (lag of 2 years). The chart displays the coefficients and 95 per cent confidence intervals for regressions on panel data on countries and years from 1990-2018. Panel A: coefficients on Country X year interactions when dependent variable is the natural logarithm of TFP. Panel B: coefficients on Country X year interactions when dependent variable is the natural logarithm of R&D/GDP. Panel C: coefficients on Country X year interactions when dependent variable is the natural logarithm of annual patents per capita (USPTO, WIPO or Triadic definition) by application year. Panel D: coefficients on stock of USPTO patents per capita interacted with the country fixed effects, controlling for year and country effects.

ICT patenting and industry mix

We investigate whether the Canada gap in the relationship between patenting and productivity can be explained by Trajtenberg's (1999) observations that Canadian patenting was not keeping pace with the growth of ICT. Has this phenomenon persisted, and can it explain the gap? ICT patents as a share of all patents invented in Canada have increased substantially in the last two decades. Much of the total growth in patenting at the USPTO since 1990 can be explained by a growth in ICT patenting spurred partly by changes in the USPTO's treatment of software patents. Computing and communication inventions as a share of total patents have risen from less than 10 per cent of total to nearly half of all patents granted to Canadians.

Chart 4 shows disaggregated technology counts of patents by Canadian applicants, from the WIPO IP statistics database, and displays the top 10 technologies by total patents as of 2020. The rise in computer technology and digital communication from very low levels in the 1980s and 1990s is striking, as is the decline in this sector after 2014. This corresponds to the fortunes of Research In Motion/Blackberry, which filed thousands of patents in the early 2000s before declining after 2010.[26] A plateau in pharmaceutical patent counts after 2000 is apparent, however this is tempered by strong growth in medical technology, which from quite low levels in the 1980s and 1990s became one of the top sectors by the end of the sample period.

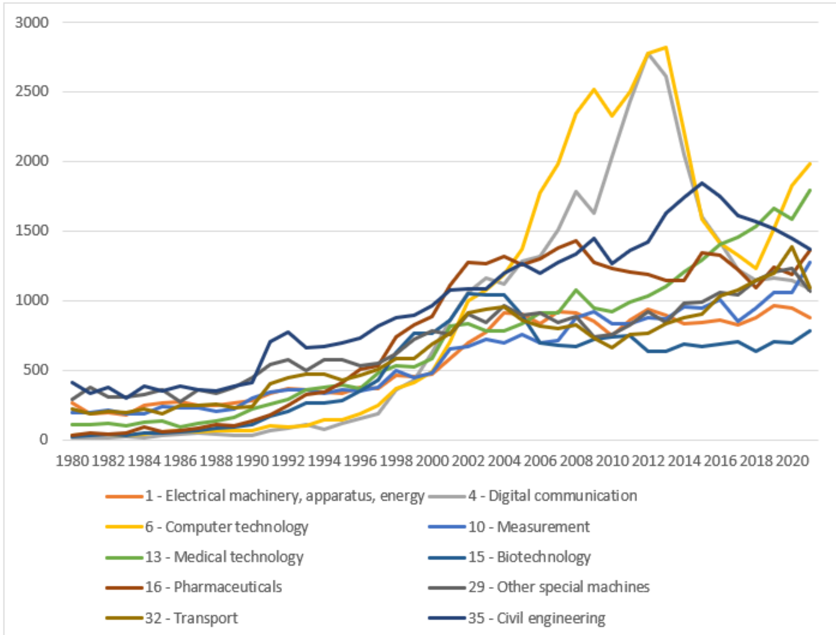
The exclusivity represented by patents can both stimulate innovation, by creating incentives to invest in R&D, and stifle it, if thickets of patents create barriers to entry and raise the cost of cumulative innovation. Many ICT patents could represent strategic patenting by competitors, which can be a drag on firm resources rather than a spur to productivity growth.[27] Moreover, productivity growth in ICT-intensive sectors is notoriously difficult to measure. As described above, recent research has suggested a link between the growth of ICT, rising industry concentration, and declining innovation diffusion. To determine whether the gap between the growth of patenting and of productivity could be explained by trends in ICT patenting by Canadian inventors, we first examine the relationship between productivity and the share of ICT patents at the country level.

Column 1 of Table 4 contains the result of a panel regression at the country level of ln(TFP) on ln(Patents per capita), the R&D to GDP ratio, and Canada X ln(patents per capita), as well as a control for the percentage of patent stock at the country level that are in ICT-related fields (the "computers and communications" field according to the NBER categorization). The Canada X patents interaction remains negative and statistically significant. This shows that adding a variable capturing the

26 The rise and fall of Nortel Networks is also apparent in patent application data in an earlier period (with applications peaking around 2000).

27 Hall and MacGarvie (2010) find that software patents themselves are not independently associated with firm market value after controlling for invention quality.

Chart 4: Patent Publications by Canadian Applicants by Technologies, 1980-2020



Note: This chart displays patent publications (equivalent count) filed by Canadian applicants worldwide by year and technological field, for the top ten technologies as of 2020.
Source: WIPO IP statistics database.

percentage of patents assigned to a country's inventors that are in ICT fields does not reduce the magnitude of the coefficient on Canada X ln(patents per capita). Column 2 drops the control for the natural logarithm of the R&D/GDP, and the coefficient on the Canada X patents interaction remains unchanged.

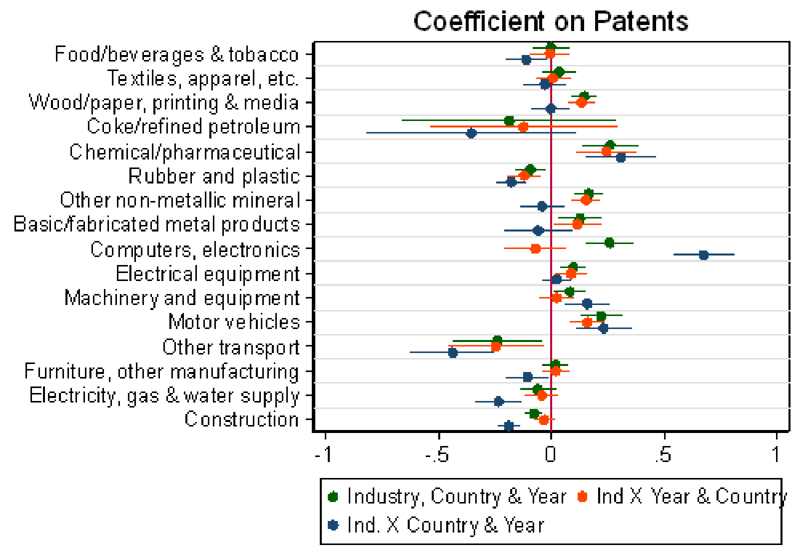
However, these aggregate measures may mask heterogeneity in the impacts of patents across industries. We thus turn to data at the sector level. The right panel of Table 4 and Chart 5 present information on regressions in which a unit of observation is a country-industry-year. Columns 6 and 7 of Table 4 present the industry-level regression of log labour productivity on ln(patent stock) and Canada X ln(patent stock), with and without controls for ln(R&D/GDP). The latter variable is missing for much of the sample, and we chose to omit this variable from the remaining regressions after confirming that its inclusion did not substantially change the main results. Column 8 drops oil refining and column 9 drops oil and ICT, with the significantly negative coefficient on Canada X patent stock persisting.[28]

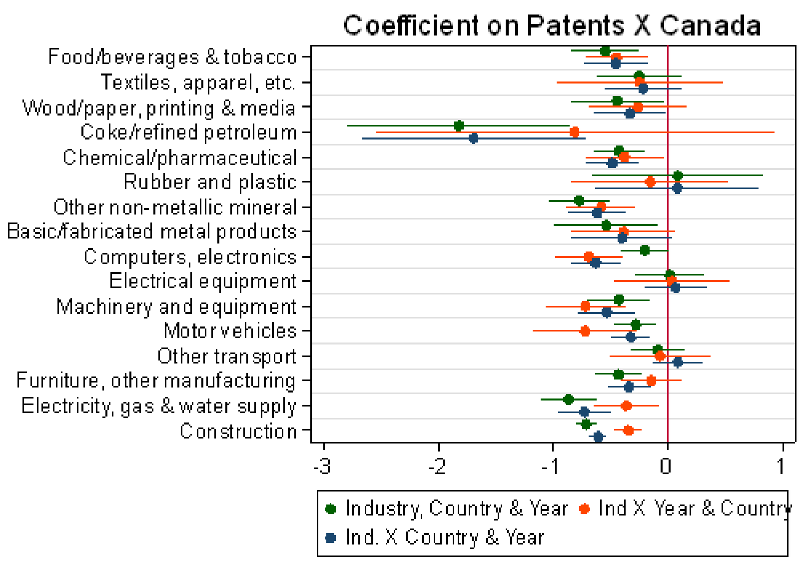
Chart 5 presents results from a regression of log labour productivity on both the patent stock and the Canada X patents

28 We drop the coke and refined petroleum products industry (D19) since it is a significant outlier in terms of labour productivity for Canada and Denmark relative to the rest of the world.

29 In contrast to the country-level TFP data which are normalized within each country, the labour productivity data is measured in US dollars per hour worked. Our fixed effects for country implicitly normalize the labour productivity data relative to other observations within a country.

Chart 5: Industry-specific Relationships between Patenting and Productivity





Note: The top panel displays coefficients and 95 per cent confidence intervals on the patent variable interacted with industry fixed effects, and the bottom panel displays the coefficient on the triple interaction Industry X Patents X Canada. "Industry, Country & Year" refers to a specification with ln(labour productivity) as the dependent variable and industry, country and year fixed effects (as well as a fixed effects for Canada X industry). "Ind. X Year & Country" is the same specification, only with industry interacted with year dummies. "Ind. X Country & Year" controls for industry X country interactions and year fixed effects.

Table 4: Regression Results - Industry-specific Effects

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Country: TFP					Country-industry: Labour Prod.			
	TFP	TFP	TFP	TFP	TFP	W/ R&D	W/o R&D	Drop Oil refining	Drop ICT & Oil
R&D/GDP	-0.00557		-0.00382	0.0125	-0.00422	0.0990***			
	(0.0266)		(0.0274)	(0.0280)	(0.0275)	(0.0122)			
Patents	0.0941***	0.0453**	0.0981***	0.0902***	0.0921***	0.0247	0.0354	0.0461**	-0.00366
	(0.0246)	(0.0180)	(0.0235)	(0.0223)	(0.0235)	(0.0244)	(0.0235)	(0.0202)	(0.0187)
Can X Patents	-0.0635***	-0.0660***	-0.0530***	-0.0573***	-0.0555***	-0.203***	-0.224***	-0.0769***	-0.0899**
	(0.0166)	(0.0160)	(0.0111)	(0.0105)	(0.0107)	(0.0396)	(0.0491)	(0.0268)	(0.0366)
% in ICT	0.0659	0.114							
	(0.0885)	(0.0870)							
Natural resources			0.000778						
			(0.00274)						
Forward citations				-0.00126					
				(0.00112)					
New Bigrams					-0.0178				
					(0.0136)				
Observations	588	666	588	588	588	3158	5670	5328	4994
Country fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Year fixed effects	Y	Y	Y	Y	Y	Y	Y	Y	Y
Industry fixed effects	NA	NA	NA	NA	NA	Y	Y	Y	Y

Note: Regression coefficients and Newey-west standard errors (lag of 2 years). Countries included: see note on Table 1. Columns 6-9 are at the country-sector-year level, for the industries listed in Table 1. Column 8 excludes coke and refined petroleum industry (ISIC D19). Column 9 also excludes computer, electronic and optical products (ISIC D26). The dependent variable in Columns 1-5 is the natural logarithm of TFP at constant national prices (2017=1) and in columns 6-9 it is the natural logarithm of labour productivity at the country-industry level. The independent variables are the natural logarithm of the stock of R&D as a share of GDP, the natural logarithm of the stock of the country's USPTO patents per capita, a dummy variable for Canada interacted with the patent variable, the percentage of patent stock that is in the "computers and communications" technological field, the share of natural resources rents as a share of GDP, the mean stock of forward citations per patents, and the mean stock of number of new bigrams per patent. Because the NBER category classification is available through grant year 2014, we extrapolate forward using the proportion of each IPC code that falls into the "computers and communications" technological field historically. (***/**/*): significant at the (1/5/10)% level.

variable interacted with industry fixed effects. [29] The chart displays three different specifications with fixed effects that control for different sources of variation. The first specification controls for industry, country and year fixed effects. The second controls for global technological trends/shocks in a given industry by adding industry X year effects (and keeping the country fixed effect). The third specification controls for permanent differences across country-industry pairs as well as global trends over time by including country X industry and year fixed effects.

The top panel of Chart 5 displays the coefficients on the industry dummies interacted with the patent variable (which informs us about the relationship between patenting and productivity within an industry). We see that the relationship tends to be positive in the industries known to be reliant on intellectual property as a source of growth. For example, the coefficient on patents is positive, large and significant in the chemical/pharmaceutical industry across all specifications. However, in several industries there is an insignificant or even negative relationship between patenting and productivity. These industries tend to be resource-intensive (e.g. coke and petroleum, electricity/gas/water) or industries not typically associated with strong use of intellectual property (e.g. construction). We suspect that our probabilistic mapping between patent classes and economic activity may be less reliable for industries in which intellectual property plays a less central role. This source of measurement error may explain the insignificant or negative coefficients in those industries.

It is also worth noting that the choice of fixed effects has an impact on the results. Estimates from regressions with controls for Country, Industry, and Year or Country and Industry X Year effects generally suggest a more positive correlation between patents and productivity, while specifications that control for fixed effects at the country-industry level suggest a weaker correlation between patenting and productivity.

This suggests that cross-sectional variation in patenting and productivity across country-industry pairs is an important source of variation for identifying the relationship between patenting and productivity, while the variation within country-industry pairs over time provides less identifying variation. Because productivity in most industries is fairly stable over time, we do not observe strong effects of increases in patenting over time within country-industry groups (except in some with rapid changes in productivity and patenting, like computing and electronics, which we discuss further below). The weaker within-country-industry results may also relate to the difficulty of linking patents to productivity in a specific time and different depreciation rates across industries.

One notable difference across specifications is in the computing and electronics sector. When we control for country and industry or country X industry effects, we estimate a significant positive relationship between patenting and productivity in computing and electronics. In the specification with Industry X year effects, we estimate a positive relationship between patenting and productivity for most manufacturing-related industries, but not computing and electronics. This suggests that the positive coefficient for computing and electronics in the first two specifications was driven by global trends in this sector rather than variation in patenting and productivity across country-industry pairs.

To estimate the effect of patenting in Canada relative to other countries, we include a triple interaction of the industry effects with the Canada dummy and the patent stock variable.[30] These results are displayed in the bottom panel of Chart 5. Although not significantly negative in every industry, the general pattern of coefficients suggests a weaker relationship between patenting and productivity in several sectors. The weaker relationship between patenting and productivity in Canada does not appear to be driven purely by the ICT

30 In the specification with country and industry or country X year and industry X year effects, we also control for the Canada dummy interacted with the industry dummies (which is automatically included in the specification with country-industry fixed effects).

31 We also ran regressions separately for each industry and confirmed a negative and significant coefficient on the Patents X Canada interaction in most industries.

sector.[31] This, together with the results in Table 4, suggests that the Canadian patent productivity paradox is not fully explained by differences in the rate of ICT patenting in Canada.

Another possibility is that Canada's high share of GDP in natural resources explains the disconnect between patenting and productivity. As seen in Chart 5, the gap between Canada and other countries in the estimated relationship between patenting and productivity tends to be large in resource sectors such as coke and refined petroleum. In Table 4, Column 3, we control for the total natural resources rents (the sum of oil, natural gas, coal, mineral, and forest rents) as a percentage of GDP, by country and year.[32] Including this control variable does not materially change the coefficients on patents or Canada X patents, and the variable itself is insignificantly associated with TFP.

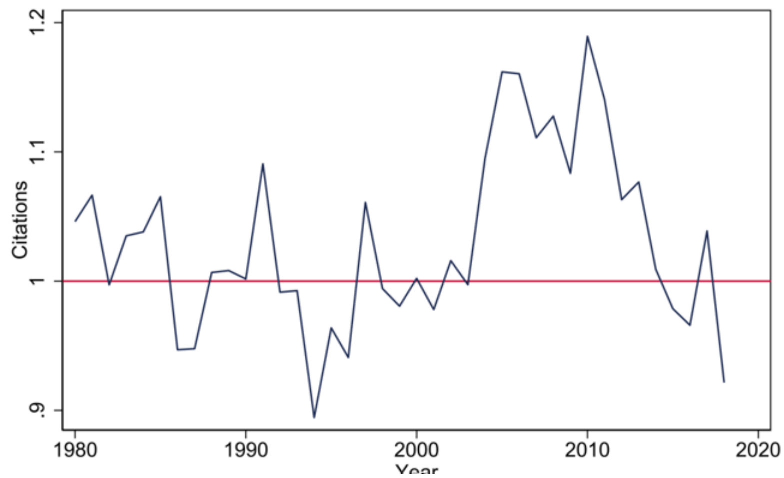
Invention Quality

A second potential explanation for the discrepancy between the growth of patenting and the growth of productivity in Canada is lower invention quality. Trajtenberg (2000) found that Canadian-invented patents were approximately 20 per cent less important than US-invented patents, as measured by the number of forward citations. There is a divergence apparent in Chart 3 between relatively strong growth in Canadian patenting and relatively stagnant R&D spending as a fraction of GDP. This divergence raises the question of whether the increase in Canadian patenting since 1990 reflects a larger number of less important or more derivative inventions.

When inventors file patents, they must cite the preexisting prior art upon which their invention builds (and which is not covered by the application in question). The number of forward citations (or citations received by a patent) have been widely used in the innovation literature as an indicator (albeit an imperfect one) of patent quality or importance. More recently, alternative measures of novelty have emerged based on text analysis of the words in patents (e.g. Arts *et al.* 2021). These measures count the number of patents with novel word combinations (combinations not observed in previously granted patents) and it has been suggested that a decline in patent novelty can explain slowing productivity growth (Kalyani 2022). We begin by comparing the number of forward citations per patent to Canadian patents with the number of forward citations per patent to non-Canadian patents by year of application, in Chart 6. This chart displays the ratio of the mean forward citations per Canadian-invented patent to the mean forward citations per patent to non-Canadian patents. Consistent with Trajtenberg (2000), we find that Canadian patents received fewer forward citations per patent in the 1980s and early 1990s. However, in mid-nineties, the number of citations received by Canadian patents rose considerably to match those received by patents in other countries, and exceed them after 2000 before declining again in recent

32 World Bank, see https://data.worldbank.org/indicator/NY.GDP.TOTL.RT.ZS for more information.

Chart 6: Average Forward Citations to Patents, Canada/Non-Canada



Note:This chart displays the average total forward citations for patents with a Canadian inventor ("Canadian" patents) compared to non-Canadian patents filed at the USPTO, by application year.

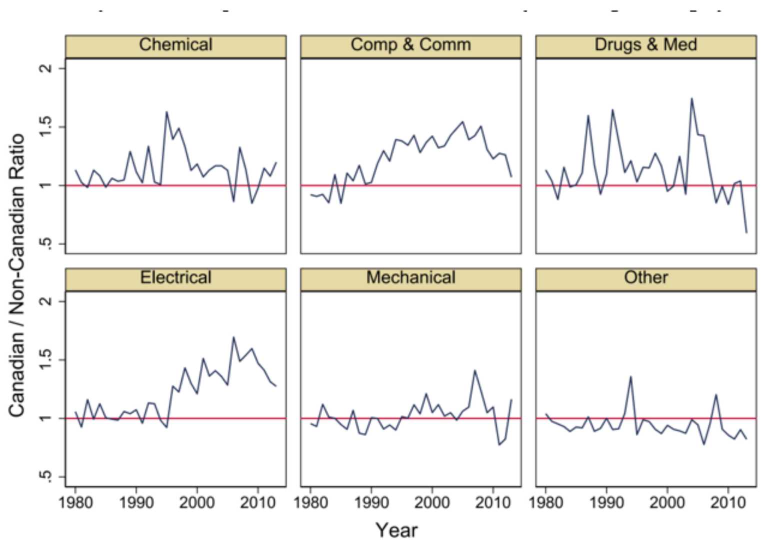
years. It is difficult to interpret data on forward citations to recently granted patents. The application years in the chart correspond to grant lags approximately 2-4 years later (Hall *et al.* 2002 and Popp *et al.* 2003), and recently granted patents take several years to accumulate citations. For this reason, one should be cautious about interpreting the relative decline in the ratio of Canadian to other citations after 2010. However, it does warrant further investigation in future research. Overall, however, this chart does not suggest that Canadian patents are of lower quality on average during our sample period.

Text-based novelty measures based on Arts *et al.* (2021) show a slightly different picture (Chart 7). Across several technological fields (in particular, computers and communications and electrical), Canadian patents appear to use more novel word combinations (bigrams) than patents from other countries. In no field do Canadian patents appear to be consistently less novel than patents from other countries. In the computing and electrical categories, Canadian patents are substantially more novel than patents from other countries after 1990 (according to this measure).

Perhaps not surprisingly, adding measures of invention quality to the TFP regressions does little to enlighten us about the Canadian patent-productivity gap. Results from regressions similar to those in Table 2, but with patent quality measures included as controls, are found in Columns 4 and 5 of Table 4. The coefficients on the mean of forward citations per patent in a country are not statistically significant, and their inclusion in the regression does not materially affect the coefficient on Canada X Patents. The same is true when we include the mean of the number of novel word combinations (new bigrams) in a country's patents.

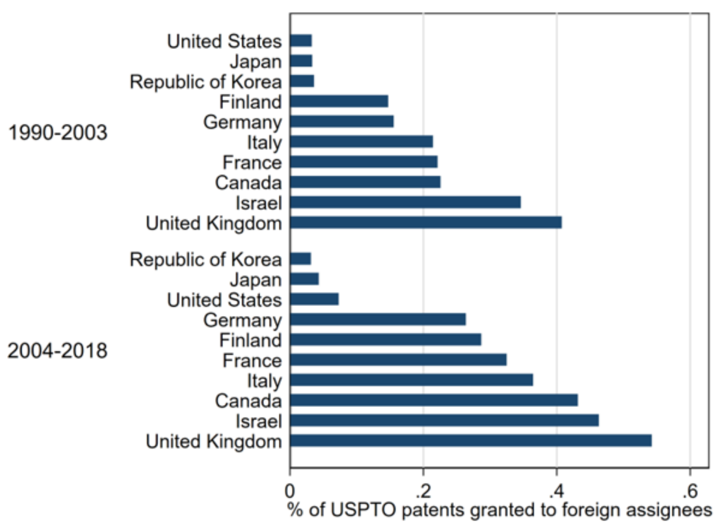
It must be noted that both citation-based and text-based measures of novelty and importance have their limitations. The fact that they appear to be uncorrelated with aggregate productivity after accounting for covariates suggests that they are nuanced measures of invention importance or

Chart 7 : Novelty of Canadian Patents Relative to Other Countries by Technological Category



Note: This chart displays the ratio of Canadian to non-Canadian new bigrams (novel two-word combinations) in patent flows by year and technological category. NBER technology categories are available for patents granted in 2014 and earlier. Source: Arts *et al.* (2021) and authors' calculations.

Chart 8: Foreign Assignment of Patents (G7 plus countries)



Note: Mean percentage of USPTO patents assigned to a foreign entity, by inventor country.

quality that deserve further study. Alternatively, it could be that although these measures have been found to be correlated with market value or productivity in firm-level data (Hall *et al.*, 2009 on citations; Kalyani 2022 on bigrams), the correlation in the cross section across individual firms between measures of patent quality and economic value and impact may be driven by differences that are smoothed away once data are aggregated to the sector or country level. For example, Berkes *et al.* (2022) argue that the relationship between innovation and productivity is affected by attenuation bias due to measurement error or increases in industry concentration, and find a larger impact of innovation on output per worker at the sector level in a two-stage least squares model. Our preliminary analysis of the most readily available and commonly used measures of patent quality thus finds no obvious indication that Canada's slow productivity growth is explained by lower-quality inventions.

Foreign assignment

Because Canadian firms are a small share of the world economy, many Canadian-invented patents will inevitably be assigned to foreign firms. Although the share of patents with a Canadian inventor assigned to Canadian firms has stayed roughly the same, the share of Canada-invented patents assigned to foreign firms has risen (as the share of unassigned patents has fallen). This increase, seen in Chart 8, has been documented by Gallini and Hollis (2019) as well as Greenspon and Rodrigues (2017), the latter of whom stated, "Although increasing the level of innovative activity that takes place in Canada is a crucial policy goal, it is also important for Canadian firms to commercialize these inventions. This inventor-assignee patent gap merits further research and attention because it suggests that Canada may be unable to profit from increases in innovative activity." (p. 66).

While we do not explicitly analyze data on patent filings by Canadian residents at the CIPO, it is worth describing trends in this variable. According to the WIPO IP Statistics Data Center, CIPO patent applications filed by Canadian resident applicants averaged 2,986.9 per year from 1990 to 1999, and rose to 4,710.0 per year from 2000-2009, before declining slightly to 4,377.3 per year from 2010 to 2019. This rate of increase is slower than the rapid increase in patenting by Canadian residents at the USPTO. This may reflect greater innovation among export-oriented firms (Eckert *et al.* 2022), or a greater representation of Canadian residents among inventors on patents held by multinationals (consistent with trends described above in the share of foreign-assigned patents).

Does the rise in foreign-assigned patenting explain Canada's TFP gap? Column 1 of Table 5 shows that the percentage of the stock of patents with foreign assignees is negatively associated with productivity and controlling for this variable partially mitigates the weaker correlation between patenting and productivity in Canada, as the Canada X Patents coefficient falls to -0.028 (significant at the 10 per cent level with a standard error of 0.014). Controlling for this variable has a bigger impact on the Canada-patents interaction in columns 7 (the G7 plus sample) and 9 (the

Table 5: Regression Results - Foreign Ownership and Migration

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Full sample	Full sample, Year<2013					G7 plus	G7 plus, Year<2013	Full sample, pop wt	Year<2013, pop wt
R&D/GDP	-0.00610	0.0256	0.0414	0.0258	0.0400	0.0408	-0.100	-0.0553	-0.0726	-0.0837*
	(0.0262)	(0.0310)	(0.0317)	(0.0314)	(0.0322)	(0.0316)	(0.0642)	(0.0438)	(0.0475)	(0.0464)
Patents	0.102***	0.0690***	0.0827***	0.0697***	0.0783***	0.0820***	0.182***	0.158***	0.0938***	0.105***
	(0.0227)	(0.0247)	(0.0254)	(0.0247)	(0.0249)	(0.0235)	(0.0347)	(0.0279)	(0.0313)	(0.0269)
Can X Patents	-0.0276*	-0.0570***	-0.0317	-0.0576***	-0.0236	-0.0226	-0.00211	0.0251	-0.0274	0.0180
	(0.0141)	(0.0140)	(0.0211)	(0.0150)	(0.0207)	(0.0202)	(0.0298)	(0.0450)	(0.0237)	(0.0402)
% foreign assignees	-0.172***					-0.0879*	-0.408***		-0.219**	
	(0.0506)					(0.0485)	(0.153)		(0.103)	
Immigrant/National patents			0.0250**		0.0276**	0.0208*		0.0574**		0.0305
			(0.0123)		(0.0118)	(0.0123)		(0.0230)		(0.0260)
Emigrant/National patents				0.00132	-0.0120	-0.00855		-0.0182		-0.0416***
				(0.0107)	(0.00891)	(0.00868)		(0.0154)		(0.00866)
Observations	588	452	444	452	444	444	260	200	588	444

Note: Regression coefficients and Newey-west standard errors (lag of 2 years). Data are panel data on countries and years from 1990-2018 in columns 1, 7, and 9, and 1990-2012 in columns 2-6, 8, and 10 (which exclude later years due to missing data on inventor flows). Fixed effects for country and year included in all regressions. Columns 1-6 and 9-10 include the full sample of countries listed in the notes on Table 1. Columns 7-8 include the "G7 plus" group of G7 countries plus Israel, Finland and South Korea. The dependent variable in all columns is the natural logarithm of TFP at constant national prices (2017=1). The independent variables are the natural logarithm of the stock of R&D as a share of GDP, the natural logarithm of USPTO patent stock with inventors located in the country, a dummy variable for Canada interacted with the patent variable, the percentage of the stock of patents assigned to foreign assignees, the natural logarithm of the stock of the number of immigrant and emigrant invented patents per patent invented by nationals. (***/**/*): significant at the (1/5/10)% level

population-weighted regression), where the interaction is no longer significant after controlling for foreign assignment.

There may nonetheless be mixed effects of foreign ownership on productivity. Subsidiaries of foreign firms in the UK have been found to be more productive (Griffith *et al.* 2004) and inward FDI has been found to increase the productivity of domestic firms (Aitken and Harrison, 1999). Foreign-owned R&D-intensive firms often have access to cutting-edge technology developed abroad, and may generate spillovers from R&D activities located in Canada (Javorcik 2004). This may incur benefits including international knowledge diffusion among inventor teams and subsequent spillovers to domestic firms. Patents with inventor teams that are more diverse in terms of nationality may be higher quality (Ferrucci and Lissoni, 2019). On the other hand, there may be few benefits if foreign ownership leads to R&D being shifted out of Canada, for example if inventors of patents owned by foreign parents are transferred to other parts of the company over-

33 We tried including a control for a five-year moving average of the percentage of inventors located in country among patents with an inventor from a given country, by year. We found that this was positively but insignificantly related to productivity in the main specification, and the coefficient fell substantially after controlling for the percentage of domestically invented patents assigned to foreign firms. These control variables have a correlation of -0.86. This suggests that our preferred control – the percentage of domestic patents assigned to foreign firms – is capturing most of the effect of the percentage of inventors located in a country. Of course, this is largely explained by the sizes of these countries. In our sample, Iceland, Canada, Ireland, and Italy have the highest average rates of net emigration per national over the whole sample period (computed as the ratio of emigrant to national patents minus the ratio of immigrant to national patents). The lowest rates of net emigration (or highest rates of net immigration) are in Singapore, Switzerland, the United States, and Luxembourg. Miguelez and Fink (2013) note that the coverage of nationality information in PCT patents has increased over time. There are some outlier values for the migration data for very small countries (e.g. Iceland, Ireland, Luxembourg, New Zealand and Singapore) in the earliest years of our sample. Results are

seas, leading to emigration of highly skilled employees.[33]

Fons-Rosen *et al.* (2018) find that inward FDI increases the productivity of host-country firms when foreign and domestic firms are technologically similar, and that inventor mobility is one of the mechanisms that explains this.

A factor not identified by Trajtenberg (to whom the relevant data were not available), but subsequently flagged by Ivus (2016), is the high rate of net emigration of Canadian inventors (Chart 9). China and India are the only countries with higher rates of total net inventor emigration than Canada (Miguelez and Fink 2013; Ivus, 2016). To attempt to disentangle some of the positive and negative aspects of foreign ownership, we include controls for the natural logarithm of the stock of the number of immigrant inventors per national, and the log of stock of the number of emigrant inventors per national.

As noted previously, this data is only available until 2012. Table 5 displays results based on the full sample period in Column 1 and 9, and sample years restricted to 1990-2012 in all other columns. We find that the log of the stock of immigrant inventors per national is significantly positively correlated with TFP and including it makes the negative coefficient on the Canada X patents interaction small and insignificantly different from zero (Column 3). This suggests that foreign-owned patents may indeed reduce productivity IF they are not accompanied by shifting of inventors to locations inside the country. However, a high rate of foreign-owned patents will not necessarily be harmful if combined with a high rate of inventor immigration.[34]

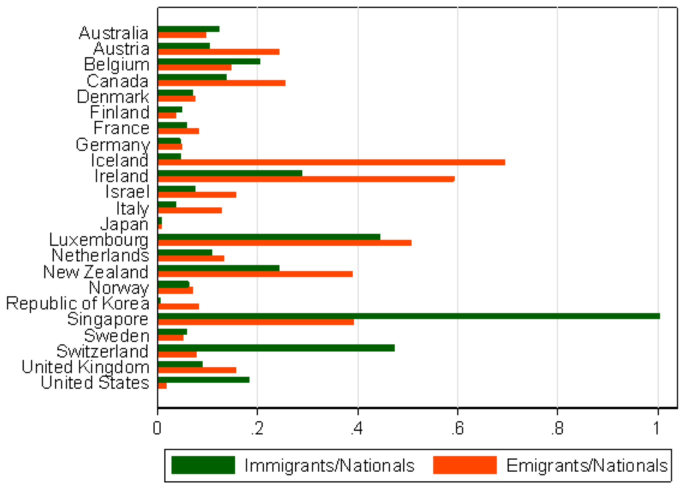
One interpretation of this result is that it is capturing the extent to which MNCs are establishing R&D labs in the country as opposed to Canadian inventors selling their IP to foreign firms that develop it outside the country. This highlights the importance of distinguishing between foreign-owned patents that could potentially lead to productivity spillovers in Canada versus "extractive" foreign-owned patents that primarily benefit firms in other countries.

Caution is warranted in interpreting these panel regressions, which are conditional correlations rather than causal estimates. For example, there is likely to be reverse causality in the relationship between inventor migration and productivity growth, with rapid growth causing immigration to some extent. However, other research has highlighted the importance of retaining and attracting skilled human capital for productivity growth and prosperity (e.g. Kerr 2018). Indeed, Sharpe (2003;28) notes that due to Canada's small size relative to the rest of the world, "what matters for productivity growth is the impor-

robust to dropping these early sample years, as well as to restricting the sample to years after 2003, the period for which Miguelez and Fink report that the data have "excellent" coverage (p. 9).

34 This data is also available by type of applicant: corporate, individual or public/university. We estimated regressions using migration data based on each of these three types of patents and found that the results in Table 5 appear to be primarily driven by immigrant corporate patents, with a small effect of immigrant individual inventors and relatively little relationship between productivity and emigrant or public-sector migrant inventors of both types.

Chart 9 : Ratio of Patents with Immigrant or Emigrant Inventors to Patents Invented by Nationals



Note: Authors' calculations based on data described in Miguelez and Fink (2013). Average ratio of depreciated stock of patents with Immigrant or Emigrant inventors to patents invented by Nationals (inventors residing in their country of citizenship), 1990-2012.

tation of best-practice technologies from other countries and the wide diffusion and adoption of these technologies by Canadian business." To the extent that mobile inventors bring knowledge about best-practice technologies to their destination countries, Canada's low rate of inventor immigration relative to inventor emigration combined with a high rate of foreign-owned patents suggests that it is a net exporter of embodied technological knowledge. More research is needed to disentangle the causal relationships between foreign ownership, inventor migration, innovation and productivity.

Conclusion

In this article, we document a "patent productivity paradox" in Canada: slower growth in productivity than would be predicted by the growth of patenting by Canadian inventors. Guided by prior literature, we investigate three potential explanations. The first of these is that the gap is driven by changing sectoral composition, i.e. acceleration in the rate of ICT patenting that has yet to show up in productivity growth. The second is the possibility that Canadian inventions are of systematically lower quality or economic importance, which is difficult to reconcile with Canada's prominence in academic science. The third is that a combination of high rates of net out-migration by Canadian inventors and the high degree of foreign ownership of Canadian patents limits its local implementation of productivity-enhancing new technologies, and associated knowledge spillovers in Canada. We find no evidence in favor of the first two explanations, but some evidence consistent with the third.

Our results raise questions for future research. For example, how do policies affecting the location of ownership of IP (as distinct from the location of invention) affect productivity and growth? What is the causal relationship between inventor migration and productivity?

It is easy to see how net out-migration of inventors can generate "patents without growth". A patent per se has little impact on productivity and growth. What counts is prompt and effective implementation of the underlying invention in the form of new products and production processes. And without the continued engagement of the inventor this implementation step may be slow, may be ineffective, or may not take place at all. Departing inventors take this deep understanding of their inventions and the challenges and opportunities of implementation of these ideas with them, along with their human capital. If they are not replaced by inflows of immigrant inventors, productivity is bound to stagnate.

The impact of foreign ownership of Canadian inventions on the degree to which they affect productivity growth is less clear. While the scientific and technical employees of foreign-based companies may generate economically significant inventions and ideas while working in Canada, it is their employers who control where, and when, subsequent development and implementation efforts take place, and which markets they will be directed towards. A substantial fraction of inventions with inventors based in Canada may therefore be contributing primarily to productivity growth elsewhere. More research is needed to distinguish between inventions with a domestic development and production footprint, those connected to foreign development through a multinational's internal processes, and those with little continued involvement of the Canada-based inventor.

As a small open economy highly integrated with its trading partners, many patents invented in Canada will inevitably be owned by foreign companies. Rather than seeking to limit the extent of ownership of IP by foreign companies, policymakers could consider the conditions under which foreign ownership is associated with increases in productivity. Our results suggest that the foreign ownership of patents is mainly a problem if it is not accompanied by inventor immigration, which is positively associated with productivity. Confirming prior findings, we show that the growth of patenting has outpaced the growth of R&D, as the percentage of patents assigned to foreign firms has increased (Greenspon and Rodrigues , 2017).

Policy could seek to encourage the location of R&D workers within Canada. For example, Hall (2019) has highlighted the Netherlands' use of lower social charges on science and engineering employment as a way of reducing firms' costs of performing R&D. Research has suggested that Canada's points-based immigration system may have limitations relative to the US employer-sponsored system when it comes to promoting innovation (Blit *et al.* 2020). Recent changes to immigration policy that make it easier for firms to fast-track work visas for skilled workers may represent a

35 According to Silcoff and O'Kane (2023), "The program to fast-track visa applications by skilled foreign workers to work for companies in Canada has brought more than 9,000 people here and is widely considered a success."

step in the right direction.[35] Recognizing the impacts of migration and foreign ownership also suggests close attention by policy makers to the economic incentives for inventors to locate in Canada and "scale up" their inventions (Gallini and Hollis, 2019).

Canada has disproportionately strong academic science. In the most recent WIPO Global Innovation Index (2022), Canada ranked 15th overall but 6th for university quality and 9th for university-industry collaboration.[36] Although world-class universities are a source of well-deserved pride for Canadians, research has documented a "Canadian commercialization discount" in which Canadian universities are less likely to commercialize research than similar counterparts in the United States (Agrawal, 2006). Although efforts to change this have made progress (e.g. via University of Toronto's Creative Destruction Lab), a recent report (Intellectual Property in Ontario's Innovation Ecosystem) identified gaps in expertise in resources at technology transfer offices, and called for clarity on the mandates of these offices and other entities involved in commercialization of university research.

The findings described here also raise questions for future research on the role of tax policy for innovation in the context of global tax competition. Recent policy discussion in Canada has focused on the potential of "patent boxes," or privileged tax rates for IP-related income (Lester, 2022). Research has suggested that IP boxes do not stimulate innovation but rather encourage profit shifting (Hall, 2019; Gaessler *et al.* 2021), and other research has highlighted the impact of tax havens on profit shifting on aggregate productivity (Guvenen et al. 2022). To what extent can tax differences across countries explain the patterns of foreign ownership observed in patent data, and what implications does this have for productivity growth?

Perhaps most importantly, our results raise questions about how policy should target innovation outcomes. Simply increasing the number of patents filed by Canadian inventors may not lead to improvements in economic growth and well-being. Policies should be focused on making sure innovation outputs translate into economic activity in Canada that leads to economic growth.

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36 The top two filers of international patents (via the PCT) in 2021 were the National Research Council of Canada and the University of British Columbia, while the University Health Network and the University of Toronto ranked fourth and fifth in terms of patents filed through the PCT). https://www.wipo.int/ipstats/en/statistics/country$_{p}rofile/profile.jsp?code = CA, accessed 2/1/23$

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Appendix Table A1: Robustness to Alternative Patent Flow/Stock Calculations

Panel A: Annual flows of R&D/GDP and Patents

	(1) Full sample R&D only	(2) + Patents	(3) + Can X pats	(4) + Patents peer countries	(5) Peers, no R&D	(6) TFP yr>99
R&D/GDP	0.0608***	-0.0584**	-0.0613***	-0.0583**		-0.0355
	(0.0207)	(0.0230)	(0.0230)	(0.0254)		(0.0348)
Patents		0.0811***	0.0806***	0.0817***	0.0484***	0.0883***
		(0.0102)	(0.0102)	(0.0167)	(0.0173)	(0.0206)
Can X Patents			-0.0806***	-0.0634***	-0.0537***	-0.129***
			(0.0184)	(0.0135)	(0.0116)	(0.0467)
Observations	800	800	800	649	667	435
	(7)	(8)	(9)	(10)	(11)	(12)
	GDPpc	GDPph	TFP G7	GDPpc G7	GDPph G7	TFP (pop weights)
R&D/GDP	-0.221***	-0.195***	-0.00562	-0.0804	-0.0948	-0.0546
	(0.0640)	(0.0616)	(0.0485)	(0.0735)	(0.0847)	(0.0378)
Patents	0.271***	0.247***	0.108***	0.182***	0.190***	0.0968***
	(0.0462)	(0.0412)	(0.0207)	(0.0318)	(0.0372)	(0.0177)
Can X Patents	-0.163***	-0.214***	-0.0532***	-0.0590**	-0.149***	-0.0826***
	(0.0383)	(0.0347)	(0.0172)	(0.0239)	(0.0219)	(0.0197)
Observations	649	649	288	288	288	649

Panel B: Stock of Patents (Hall 1990 method)

	(1) Full sample R&D only	(2) + Patents	(3) + Can X pats	(4) + Patents peer countries	(5) Peers, no R&D	(6) TFP yr>99
R&D/GDP	0.0412	-0.0813*	-0.0852*	0.00292		0.00619
	(0.0365)	(0.0447)	(0.0446)	(0.0270)		(0.0429)
Patents		0.0953***	0.0958***	0.0712***	0.0345**	0.0913***
		(0.0175)	(0.0175)	(0.0221)	(0.0145)	(0.0278)
Can X Patents			-0.0649***	-0.0540***	-0.0479***	-0.0755***
			(0.0104)	(0.00848)	(0.00785)	(0.0229)
Observations	685	685	685	588	666	419
	(7)	(8)	(9)	(10)	(11)	(12)
	GDPpc	GDPph	TFP G7	GDPpc G7	GDPph G7	TFP (pop weights)
R&D/GDP	-0.214***	-0.142*	-0.0367	-0.0708	-0.0477	-0.116***
	(0.0727)	(0.0735)	(0.0425)	(0.0803)	(0.0585)	(0.0443)
Patents	0.224***	0.184***	0.166***	0.196***	0.156**	0.116***
	(0.0714)	(0.0653)	(0.0315)	(0.0512)	(0.0670)	(0.0273)
Can X Patents	-0.144***	-0.183***	-0.0742***	-0.0719***	-0.130***	-0.0734***
	(0.0232)	(0.0198)	(0.0106)	(0.0234)	(0.0246)	(0.0128)
Observations	588	588	260	260	260	588

Note: See note on Table 2. Panel A uses the annual flow of patents and RD; Panel B uses the stock of RD and patents calculated according to the methodology in Hall 1990. (***/**/*): significant at the (1/5/10) percent level

Measuring Capital and Multi-factor Productivity: The Role of Asset Depreciation and Initial Capital Stock Estimates

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Abstract

This paper suggests a meaningful way to compare how the depreciation and retirement of assets are estimated in the national accounts of different countries and shows large differences. Applying the same assumptions in the US as in other G7 countries would reduce the US net capital stock by up to 1/3 and increase US GDP by up to 0.5 per cent. The growth rates of capital services and MFP would be less affected. This paper also considers two commonly used methods to estimate initial capital stocks and the impact they may have on measured capital and MFP. They assume that either investment growth rates or capital-stock-to-output ratios are constant over time. The first one is misleading because it fails to account for trends and fluctuations in real-estate investment. The second one works well for the US but may be less reliable for other countries. Overall, this paper calls for a more frequent review of asset depreciation patterns by statistical agencies, and for extending investment series to the maximum extent before relying on crude methods to estimate initial capital stocks.

Capital measurement plays a fundamental role in national accounts, both to assess the economic wealth and the state of infrastructure in a given country, and to better understand the sources of economic and productivity growth. Nevertheless, measuring capital stocks is challenging because it requires estimating initial capital stocks, accessing good-quality data on past investment flows, and cumulating them while accounting for the depreciation and retirement of assets. This statistical process is known as the Perpetual Inventory Method

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(PIM).[2]

Statistical agencies in different countries tend to use very different assumptions regarding the depreciation and retirement of assets. While some existing studies conclude that depreciation patterns may differ across countries, industries and time, the reasons for these differences remain largely unexplained (Erumban, 2008). They may be related to structural factors such as climate, construction techniques (for buildings and structures) and government investment incentives, differences in data sources, or measurement errors as depreciation and retirement patterns used by statistical agencies tend to be based on thin empirical evidence or old research (Bennett *et al.*, 2020).

Unexplained differences in depreciation and retirement patterns across countries may harm the cross-country comparability of capital stocks and macroeconomic indicators relying on the consumption of fixed capital (CFC). This is obviously the case for economic aggregates that are measured net of depreciation, such as net investment (the difference between gross investment and CFC) and net domestic product (the difference between GDP and CFC). In addition, since CFC also enters the calculation of the output and value added of non-market activities, uncertainty around CFC estimates may also affect prominent gross indicators such as GDP.

This article discusses the impact on the measurement of capital and multifactor productivity (MFP) of using different asset depreciation and retirement patterns, and different assumptions to estimate initial capital stocks. Given the limited resources that most statistical agencies allocate to these questions, an important objective of this article is to illustrate the potential impact of mismeasuring capital depreciation and initial capital stocks on headline macroeconomic aggregates.

By using the distribution of cohort depreciation rates[3] for a given asset type across countries as a measure of uncertainty, this article assumes that all available estimates measure the same unobserved cohort depreciation rate, and that all differences across countries may be related to measurement errors. This is an extreme assumption, but it provides a useful upper bound of the uncertainty on capital and MFP measurements.[4] By highlighting this uncertainty, this paper aims at

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2 Detailed descriptions of the PIM and how it is applied in different international databases to measure capital and multifactor productivity (MFP) include (OECD, 2009) and (Gouma and Inklaar, 2023).

3 To avoid any ambiguity, the term depreciation (without any further qualification) is reserved to describe how the value (i.e. the market price) of a single productive asset declines over time due to the shortening of its remaining service life. Depreciation is reflected in the age-price profile of a single asset. Nevertheless, the depreciation process does not consider that assets belonging to the same cohort (i.e. purchased at the same time) may be retired from the productive capital stock at a different age. Cohort depreciation corresponds to the combined effect of (single-asset) depreciation and retirement. It determines how the value of a stock of assets declines over time if depreciation and retirement are not compensated by investment (GFCF) or other positive changes in volume. The terms cohort depreciation, combined depreciation and retirement, and consumption of fixed capital all have the same meaning and are used interchangeably in this paper.

4 Alternatively, a pure Monte Carlo analysis could have been considered. Nevertheless, there is no obvious statistical distribution from which to draw cohort depreciation rates. Therefore, this study relies on the cohort depreciation rates used in different countries as a measure of uncertainty.

encouraging statistical agencies to develop internationally comparable data sources to estimate asset depreciation and retirement patterns, and to review these estimates regularly, including for assets that have been capitalized in national accounts for a long time (e.g. buildings, structures, machinery and equipment). The intention here is not to promote a complete standardization of asset depreciation and retirement patterns across countries, but to ensure that differences are well justified.

Another practical issue that statistical agencies face when estimating capital stocks and CFC is the estimation of initial capital stocks at a given date in the past in order to initialize the PIM. This article reviews two commonly used methods to estimate initial capital stocks. They assume either that investment growth rates or capital stock-to-output ratios are constant over time. By showing the limits of these methods, we aim at encouraging statistical agencies to use national sources and extend their investment series to the maximum extent before relying on any crude assumption on investment growth or capital stock-to-output ratios.

The national accounts produced by the US Bureau of Economic Analysis (BEA) are used as a laboratory to analyse the sensitivity of capital and MFP measurement in this paper. The reason is that the BEA produces the longest and most detailed investment series in OECD countries, which allows applying the assumptions of other countries and test their impact on US capital and MFP measurement.

This article focuses on produced assets that are included in the asset boundary of the 2008 System of National Accounts (SNA) and the US National Income and Product Accounts (NIPAs). This excludes some produced intangible assets such as brands, and firm-specific human and organizational capital, as well as non-produced assets such as land and subsoil assets. While such assets are important for MFP measurement (Corrado, Hulten and Sichel, 2009; Brandt, Schreyer and Zipperer 2017), they are either short lived (intangibles), not subject to an accumulation and depreciation process (land), or their depreciation (consumption) can be directly measured without resorting to imputed depreciation and retirement patterns (subsoil assets). Therefore, they are less relevant than assets in the SNA/NIPA asset boundary.

In theory, the sensitivity of capital and MFP measurement to alternative depreciation patterns and different methods to estimate initial capital stocks may depend on the composition of investment in each country. Nevertheless, it looks sufficiently similar across OECD countries to consider that the sensitivity of capital and MFP measurement in the United States is relevant for other advanced economies as well (OECD, 2023).

This paper extends a previous sensitivity analysis by Inklaar (2010), who focused on the sensitivity of capital services to the type of assets considered and to the measurement of capital user costs. First, it analyses the effect of changing depreciation/retirement patterns and/or initial capital stocks, which Inklaar (2010) did not consider but acknowledged as potentially important factors. Second, it discusses the sensitivity not only of capital services, but also of net capital stocks,[5] CFC and MFP. Third, it assesses the reliability of different methods to estimate initial capital stocks. Fourth, it compares cohort depreciation rates in Canada, France, Germany, Italy, the United Kingdom and the United States, and therefore extends a recent sensitivity analysis by Giandrea *et al.* (2021) which focused on Canada and the United States.

The rest of this article is organised as follows. Section 1 describes a synthetic way to compare combined asset depreciation and retirement patterns across countries, and the sensitivity of capital and MFP measurement to such patterns. Section 2 discusses two leading methods to estimate initial capital stocks and assesses their impact on capital and MFP measurement. Section 3 concludes. Figure 1 summarizes the organization of the sensitivity analysis and the article.

1. Impact of Changing Asset Depreciation and Retirement Patterns on Capital and MFP Measurement

1.1 Comparison of combined asset depreciation and retirement patterns across countries

Net capital stocks result from successive vintages of investment in productive assets and the combined effect of their depreciation and retirement over time. The depreciation pattern describes how the value of a single asset declines over time as the asset ages. The retirement pattern takes into account that not all assets purchased at the same time (i.e. belonging to the same cohort) are removed from the capital stock at the same age. For this purpose, non-degenerated probability distributions around average asset service lives are usually considered by statistical agencies.

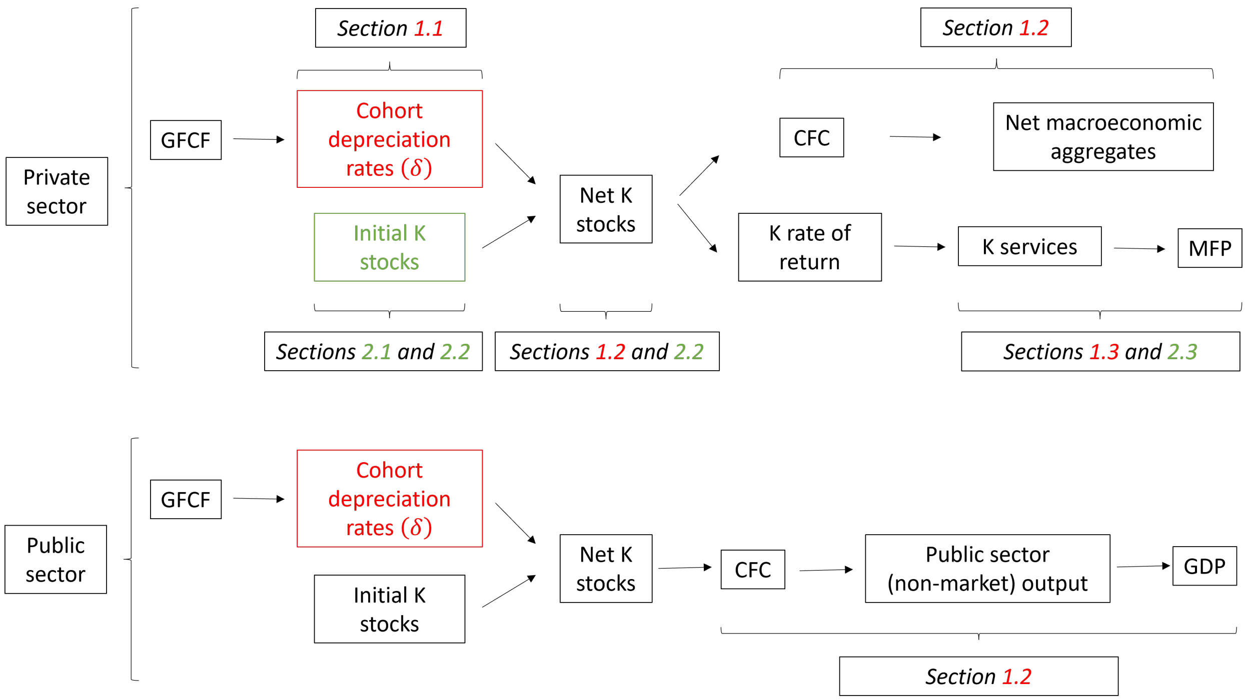
Hulten and Wykoff (1981a) showed how the combination of depreciation and retirement gives rise to convex age-price profiles for cohorts of assets, which can usually be approximated by geometric patterns.[6] The main advantage of geometric patterns is that they are characterized by a single and constant parameter (the geometric cohort depreciation rate). This simplicity led several statistical agencies such as the US BEA and Statistics Canada to rely on geometric patterns to estimate CFC for their national accounts (Fraumeni, 1997; Baldwin *et al.*, 2015).

However, not all countries rely on geometric patterns to summarize the combined effect of depreciation and retirement and estimate net capital stocks. For example, France relies on linear depreciation profiles for single assets and combines them with log-normal retirement patterns. Alternatively, the Netherlands and the United Kingdom estimate net wealth capital stocks using the combined depreci-

5 In this paper, the term "net capital stock" is used as synonymous for "net wealth capital stock". The latter is only used when there is a need to distinguish net wealth and productive capital stocks.

6 Hulten (2008) later summarized this as follows: "The more assets are grouped together, the more the group experience tends to be a geometric-like pattern, regardless of the actual patterns of the individual assets in the group. If the individual patterns are themselves nearly geometric, the group effect is reinforced, but this is not a necessary condition."

Figure 1: Organization of the Sensitivity Analysis and the Article



Note: The red colour indicates a discussion related to cohort depreciation rates, and the green colour a discussion related to initial capital stocks.
Source: Authors' compilation

ation and retirement patterns that they derive from hyperbolic age-efficiency profiles combined with Weibull (for the Netherlands) or truncated normal (for the United Kingdom) retirement functions (Statistics Netherlands, 2019; Office for National Statistics, 2019).[7]

In order to compare countries that rely on different asset depreciation and retirement patterns, this sensitivity analysis follows Cabannes *et al.* (2013) who estimate geometric approximations of combined depreciation and retirement patterns for France. This method combines depreciation and retirement patterns analytically and estimates the geometric function that provides the best fit to the combined pattern in a least square sense.[8]

Table 1 provides average ratios of Canadian, French, German, Italian and UK cohort depreciation rates to the corresponding US parameters for aggregate asset categories. In nearly all cases, the cohort depreciation rates used in Canada, France, Germany and the United Kingdom are higher, or much higher, than those used in the United States. This is especially true for dwellings and non-residential buildings, as

7 The United Kingdom's Office for National Statistics applies this method to all assets except research and development, for which they combine a Weibull retirement distribution with a geometric age-efficiency function. See Appendix B in Pionnier *et al.* (2023) for additional information on the asset depreciation and retirement functions used in G7 countries. https://doi.org/10.1787/92498395-en.

8 Appendix B in the Working Paper version of this article (Pionnier *et al.*, 2023) discusses how these geometric approximations are obtained for France, Germany, Italy and the United Kingdom. https://doi.org/10.1787/92498395-en.

Table 1: Ratios of Cohort Depreciation Rates in Canada, France, Germany, Italy and the United Kingdom, relative to the United States

Asset label	Canada	France	Germany	Italy	United Kingdom
Dwellings	2.0	5.0	2.4	1.6	2.5
Buildings other than dwellings	3.0	2.8	2.1	1.4	3.1
Other structures	2.7	1.1	1.4	1.6	1.7
Transport equipment	1.5	1.5	1.4	1.1	1.3
Computer hardware	1.3	1.2	0.8	1.4	1.2
Telecom. equipment	2.1	1.4	1.6	2.8	1.2
Other machinery and equipment	1.8	1.1	1.5	1.4	1.1
R&D	1.8	1.0	1.0	1.3	1.8
Software & databases	1.0	0.7	0.9	0.9	0.7
Originals	6.3	2.6	2.7	1.4	1.5

Note: Ratios higher than 1.5 are colored in orange font, and ratios higher than 2.0 are colored in red font.

Source: The geometric cohort depreciation rates for Canada and the United States are sourced from Statistics Canada and Giandrea *et al.* (2021). Geometric approximations are used for France, Germany, Italy and the United Kingdom (Cabannes *et al.*, 2013 and Annex B in Pionnier *et al.*, 2023). Ratios are first calculated for detailed assets and then aggregated to the upper level of the asset classification using 2019 net capital stock shares in the US private sector as weights.

well as other (civil engineering) structures in Canada.[9] The Italian depreciation rates are closer to the US rates.

It is worth noting that this proposed comparison is better than relying on Declining Balance Rates (DBRs) to plug the depreciation and retirement patterns of other countries into the PIM used by the BEA. DBRs were first introduced by Hulten and Wykoff (1981b) to provide a simple inverse proportional relationship between geometric cohort depreciation rates (δ) and average asset services lives (T):

$$\delta = DBR/T$$

Nevertheless, DBRs do not have any obvious economic meaning. Pionnier *et al.* (2023): Appendix A[10] shows that they are not universal constants as they depend on the shape of the underlying depreciation and retirement functions used by national statistical agencies. Therefore, DBRs are country specific, and estimating geometric cohort depreciation rates for France, Germany, Italy and the United Kingdom based on the average asset service lives of these countries and the DBRs of the United States would be misleading. By contrast, the geometric approximations to asset depreciation and retirement in this article are only based on national assumptions and summarize all aspects of asset depreciation and retirement in each country.

1.2 Sensitivity of CFC and Net Capital Stocks to Changes in Cohort Depreciation Rates

1.2.1 US private sector

This section analyses the sensitivity of capital measurement to changes in cohort

9 The results for Canada and the United States are in line with Giandrea *et al.* (2021). The present article extends the comparison to France, Germany, Italy and the United Kingdom

10 https://doi.org/10.1787/92498395-en.

depreciation rates. In order to explore the range of possible depreciation patterns, the geometric cohort depreciation rates used by Canada, France, Germany, Italy and the United Kingdom are successively introduced into the US PIM along with the original US GFCF time series to recalculate the CFC and net capital stocks for all assets of the US private sector.[11]

Consistently with the evidence provided in Table 1, Chart 1 shows that the US ratio of CFC to gross value added (GVA) would be significantly higher if the BEA relied on the same cohort depreciation rates as Canada, France, Germany and the United Kingdom (15.9 percent, 15.5 percent, 15.2 percent and 15.2 percent against 14.2 percent, respectively). It would be only slightly higher if the BEA relied on the same cohort depreciation rates as Italy (14.6 percent against 14.2 percent). The main difference with the official US accounts relates to the CFC of residential and non-residential buildings.[12]

Accordingly, Chart 2 shows that the level of US net capital stock would be significantly lower, by up to one third, if the BEA relied on the same cohort depreciation rates as Canada, France, Germany and the United Kingdom, and only slightly lower if it relied on the same cohort depreciation rates as Italy. Here again, differences are mainly related to residential and non-residential buildings.

Nevertheless, the impact of switching to other countries' cohort depreciation rates is more limited on the growth rate of the US net capital stock (at constant prices) than on its level (at current prices). This is because an increase in the depreciation rate of an asset has two opposite effects on the growth rate of its net capital stock. Rewriting the generic capital accumulation equation $K_t = I_t + (1 - \delta)K_{t-1}$ in terms of growth rate $\frac{\Delta K_t}{K_{t-1}} = \frac{I_t}{K_{t-1}} - \delta$ shows that an increase in δ has a direct negative effect as well as an indirect positive effect on $\frac{\Delta K_t}{K_{t-1}}$ because it reduces K_{t-1}. This latter effect is more muted in a period of low investment ($I_t \to 0$). In this case, an increase in δ is more likely to reduce the growth rate of the net capital stock.

As expected, Chart 3 shows that the impact of switching to other countries' (larger) cohort depreciation rates on the growth rate of the US net capital stock has the largest (negative) impact in the period corresponding to the Great Recession and the immediately following years, which is a period of low investment. Nevertheless, on average between 1998 and 2019, the annual growth rate of the US net capital stock hardly changes when using Canadian, French or German cohort depreciation rates, and it is unaffected when using Italian or UK cohort depreciation rates.

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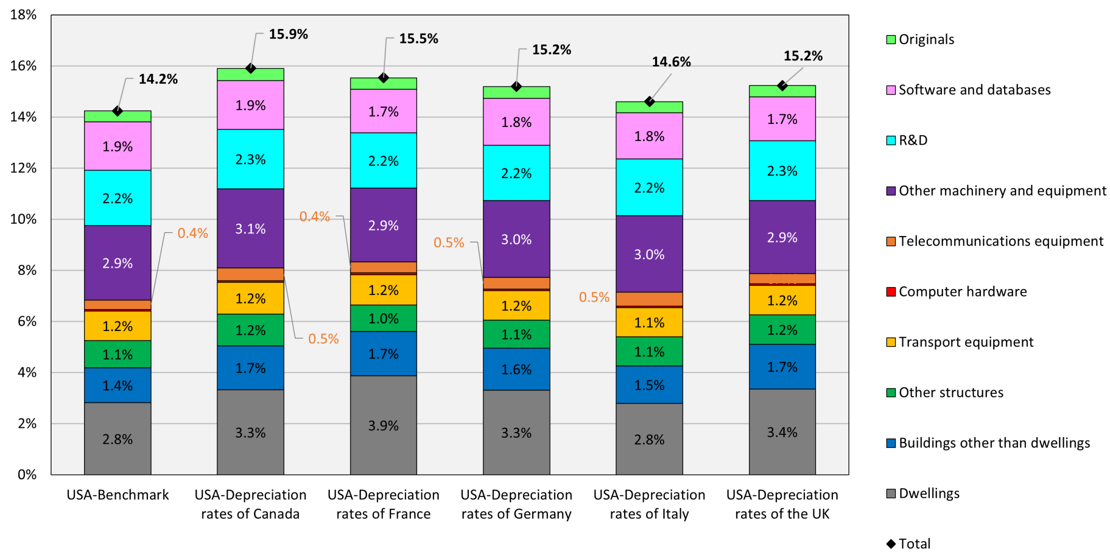
11 For France, this article relies on the geometric approximations provided by Cabannes *et al.* (2013). For Germany, Italy and the United Kingdom, it is based on geometric approximations of the combined depreciation/retirement profiles in each country. The asset classifications used in the five countries are mapped together using information from Cabannes *et al.* (2013), Giandrea *et al.* (2021) and the replies by Statistic Canada, ISTAT and the ONS to the 2019 Eurostat-OECD Questionnaire on the Methodology underlying Capital Stocks (See Appendix C in Pionnier *et al.* (2023)- https://doi.org/10.1787/92498395-en.)

12 Changes in CFC also affect the level of net investment. The impact of changes in cohort depreciation rates on the level of net investment is presented in Pionnier *et al.* (2023).

Chart 1: Sensitivity of Consumption of Fixed Capital to Changes in Cohort Depreciation Rates

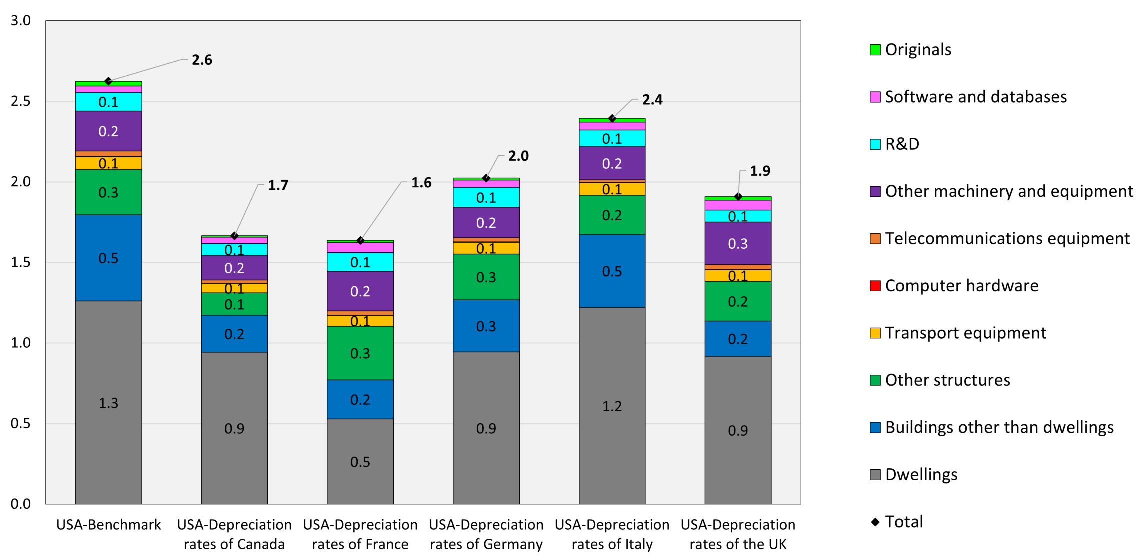
Ratio of consumption of fixed capital to gross value added, US private sector, 2019



Source: Authors' calculations, based on BEA depreciation rates, Cabannes *et al.* (2013), Giandrea *et al.* (2021), information shared by Statistics Canada, DESTATIS (Germany), ISTAT (Italy) and the ONS (United Kingdom). The USA-Benchmark is computed by the authors as described in Pionnier *et al.* (2023).

Chart 2 : Sensitivity of Net Capital Stock Levels to Changes in Cohort Depreciation Rates

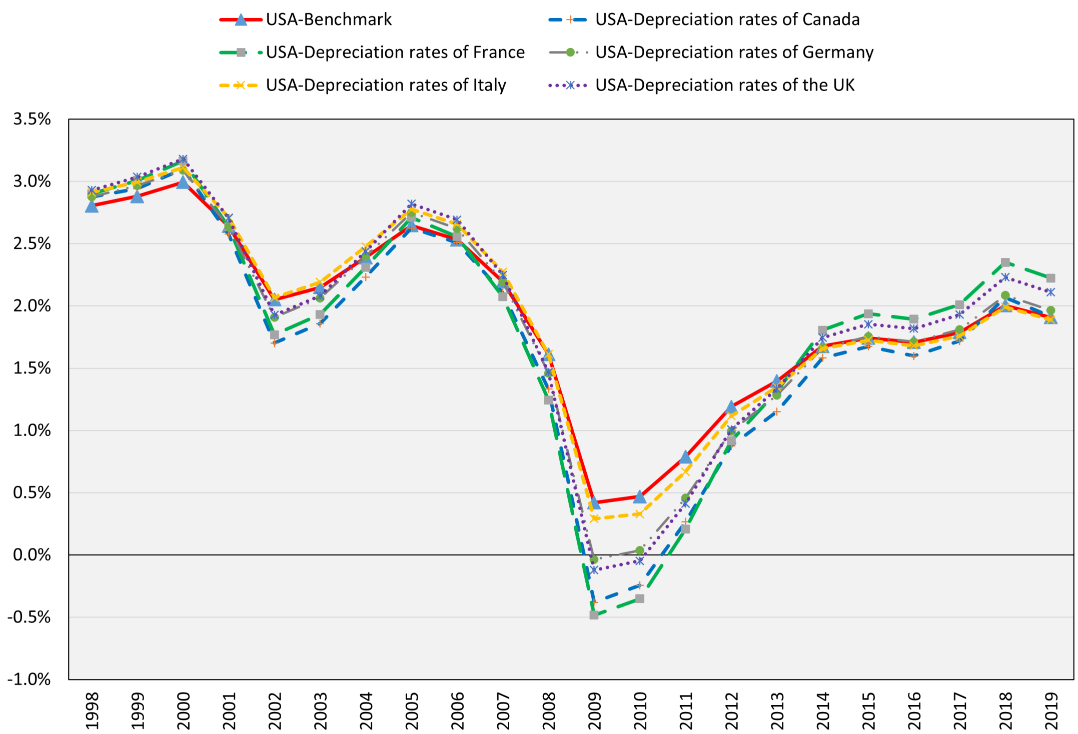
Ratio of net capital stock to gross value added, US private sector, 2019



Source: Authors' calculations, based on BEA depreciation rates, Cabannes *et al.* (2013), Giandrea *et al.* (2021), and information shared by Statistics Canada, DESTATIS (Germany), ISTAT (Italy) and the ONS (United Kingdom). The USA-Benchmark is computed by the authors as described in Pionnier *et al.* (2023).

Chart 3: Sensitivity of Net Capital Stock Growth to Changes in Cohort Depreciation Rates

Constant prices, US private sector, 1998-2019



Source: Authors' calculations, based on BEA depreciation rates, Cabannes *et al.* (2013), Giandrea *et al.* (2021), information shared by Statistics Canada, DESTATIS (Germany), ISTAT (Italy) and the ONS (United Kingdom). The USA-Benchmark is computed by the authors as described in Pionnier *et al.* (2023).

1.2.2 US Government Sector

This section extends the analysis of the previous section to the US government sector. The lack of publicly available detailed GFCF series only allows assessing how changes in cohort depreciation patterns affect the CFC of the government sector as a whole, but not for specific assets.[13] Since the gross output of the government sector is calculated as the sum of intermediate consumption, compensation of employees and CFC (BEA, 2021), any change in CFC affects the gross output and the value added of the government sector and, in turn, nominal GDP.

The level of the US government CFC in 2019 would increase by up to 19 percent if the BEA relied on the same cohort depreciation rates as Statistics Canada (Chart 4). Accordingly, the level of the US GDP in 2019 would be revised upwards by up to 0.5 per cent (Table 2).

13 Detailed GFCF series matching the granularity of depreciation rates used by the BEA would be required for this purpose. With this information, it would also be possible to assess how changes in cohort depreciation rates affect the stock, average age and remaining service life of specific government infrastructure assets such as roads, schools and hospitals.

Table 2: Sensitivity of Government Sector Value Added and GDP to Changes in Cohort Depreciation Rates

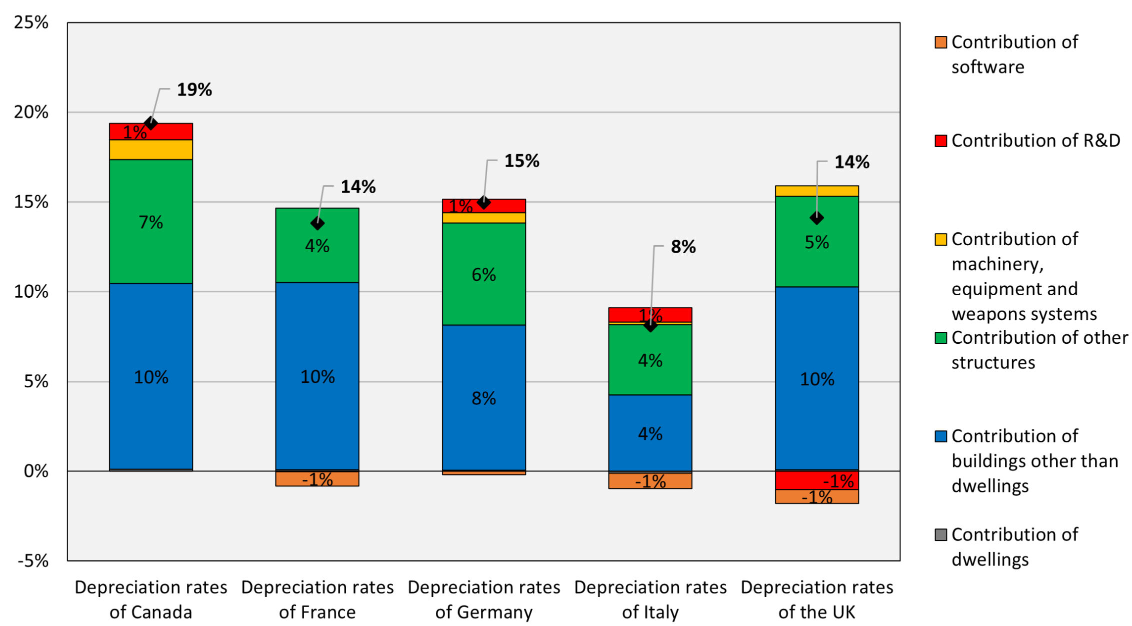
Increase in government sector value added and GDP, 2019

	Depreciation rates of Canada	Depreciation rates of France	Depreciation rates of Germany	Depreciation rates of Italy	Depreciation rates of the United Kingdom
Government sector value added	+4.7%	+3.4%	+3.6%	+2.0%	+3.4%
GDP	+0.5%	+0.4%	+0.4%	+0.2%	+0.4%

Source: Authors' calculations, based on BEA depreciation rates, Cabannes *et al.* (2013), Giandrea *et al.* (2021), information shared by Statistics Canada, DESTATIS (Germany), ISTAT (Italy) and the ONS (United Kingdom). For further info about authors' calculations, see Pionnier *et al.* (2023).

Chart 4: Sensitivity of Government Sector CFC to Changes in Cohort Depreciation Rates

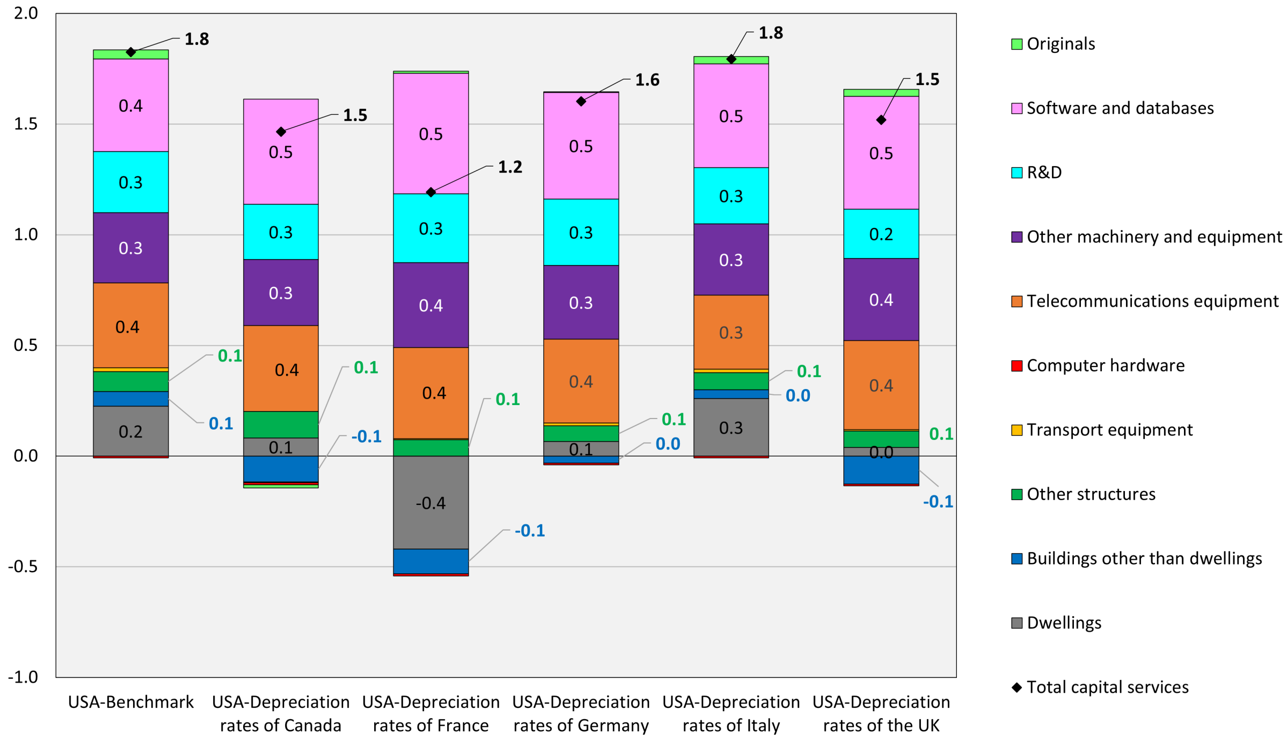
Percentage increase in CFC and contribution of underlying assets, US government sector, 2019



Note: The CFC of the US government sector would increase by 19 percent if the BEA relied on the same depreciation rates as Statistics Canada. Non-residential buildings would contribute to this increase by 10 percentage points.
Source: Authors' calculations, based on BEA depreciation rates, Cabannes *et al.* (2013), Giandrea *et al.* (2021), information shared by Statistics Canada, DESTATIS (Germany), ISTAT (Italy) and the ONS (United Kingdom). Additional information in available in Pionnier *et al.* (2023).

Chart 5: Sensitivity of Capital Services Growth to Changes in Cohort Depreciation Rates

Average annual percentage changes, US private sector, 2006-2012



Source: Authors' calculations.

1.3 Sensitivity of Capital Services and MFP Growth to Changes in Cohort Depreciation Rates

The subsequent analysis of how the capital services and MFP growth depends on cohort depreciation rates focuses on the US private sector. The user costs of capital underlying the calculation of capital services are based on exogenous and time-varying rates of return (Pionnier *et al.*, 2023).

Similarly to what is observed for the evolution of net capital stocks, the average evolution of capital services between 1998 and 2019 is not significantly affected by changes in cohort depreciation rates (Table 3).

The impact of changing cohort depreciation rates is more significant during the Great Recession and the immediately following years. Over 2006-2012, the average growth rate of capital services is 1.8 per cent per year with US and Italian depreciation rates, and declines up to 1.2 percent with French depreciation rates (Table 3, Chart 5). Dwellings and non-residential buildings are the main contributors to these differences, as expected since cross-country differences in depreciation patterns are larger for these assets.

An increase in the depreciation rate of a given asset impacts the growth rate of its capital services via three different channels: it increases the user cost of this asset, decreases the level of its net capital stock, and modifies the growth rate of its net capital stock. The first two channels have opposite effects on each asset's weight in aggregate capital services. Indeed, this weight is the share of each asset's capital services value (defined as the product of a user cost and a capital stock) in the total value of capital services. As already discussed above, an increase in the depreciation rate of an asset also has an ambiguous effect on the growth rate of its net capital stock, and a more negative impact on capital accumulation in a period of low investment. This is why the impact on capital services growth of switching to the higher depreciation rates of Canada, France, Germany and the United Kingdom is more visible in the low investment years following the Great Recession.

Consistently with the results obtained for capital services, US MFP growth rates are only marginally affected by changes in depreciation patterns (Table 3).

2. Impact of Initial Capital Stocks on Capital and MFP Measurement

2.1 Options for Estimating Initital Capital Stocks

In addition to specific assumptions on the depreciation and the retirement of assets, the estimation of capital stocks with the PIM requires investment time series and initial capital stocks to initiate the estimation process. Initial capital stocks matter all the more that the available investment series are short and the corresponding assets have long service lives. Unlike the United States, several OECD European countries, mostly in Central and Eastern Europe, only have investment series going back to the mid-1990s.

There are two main avenues for estimating initial capital stocks. The first possibility is to rely on national sources such as population censuses (giving information on the number of dwellings owned by households) and company accounts (giving information on the fixed assets owned by firms). Nevertheless, company accounts usually value assets at their book value (i.e. at their historical purchase price) and need to be supplemented with information on the date of purchase of all assets, depreciation patterns and price deflators to value the stock of assets at the price of a given year. The second possibility is to rely on stationarity assumptions to backcast investment time series and/or estimate initial capital stocks directly.[14]

Since the use of national sources to estimate initial capital stocks is country-specific and the lessons one may draw for the United States would be difficult to generalize to other countries, the present article focuses on the second possibility (stationarity assumptions). These assumptions may concern the growth rate of investment, in which case they are used to backcast investment time series, or capital stock-to-output ratios, in which case initial capital stocks are derived from the value of output (GDP) at the initial date.

14 In statistics, a (weakly) stationary time series has a mean and a standard deviation that does not vary with time. In the following, it will be assumed that either the growth rate of investment or the capital stock-to-output ratio is constant.

Table 3: Sensitivity of Capital Services and MFP Growth to Changes in Cohort Depreciation Rates

Average annual percentage changes, US private sector, 1998-2019

	USA - Benchmark	USA – Depreciation rates of Canada	USA – Depreciation rates of France	USA – Depreciation rates of Germany	USA – Depreciation rates of Italy	USA – Depreciation rates of the United Kingdom
Sensitivity of capital services Growth to changes in cohort depreciation rates						
1998-2019	**2.8**	**2.7**	**2.7**	**2.8**	**2.9**	**2.8**
1998-2006	3.6	3.4	3.9	3.8	3.7	3.7
2006-2012	1.8	1.5	1.2	1.6	1.8	1.5
2012-2019	2.7	2.8	2.7	2.8	2.8	2.8
Sensitivity of MFP Growth to changes in cohort depreciation rates						
1998-2019	**0.6**	**0.7**	**0.7**	**0.6**	**0.6**	**0.6**
1998-2006	0.7	0.8	0.6	0.7	0.7	0.7
2006-2012	1.5	1.7	1.8	1.6	1.6	1.7
2012-2019	-0.3	-0.3	-0.3	-0.3	-0.3	-0.3

Source: Authors' calculations.

2.1.1 Assuming Constant Investment Growth Rates

A standard procedure to estimate initial capital stocks is to assume that investment in each asset type grows at a constant rate, usually taken equal to the average growth rate observed over a period where the data is available. In this case, denoting the average growth rate of investment in asset type i as g_i and its geometric cohort depreciation as δ_i, the capital stock of asset i at the end of period t can be calculated as follows:

$$K_{t,i} = \sum_{j=0}^{N}(1-\delta_i)^j I_{t-j,i} = I_{t,i}\sum_{j=0}^{N}\left(\frac{1-\delta_i}{1+g_i}\right)^j$$

Provided that $\left|\frac{1-\delta_i}{1+g_i}\right| < 1$ and letting N tend to infinity, the previous formula simplifies to:

$$K_{t,i} = \frac{1+g_i}{g_i+\delta_i} I_{t,i}$$

In this case, the initial capital stock at date t ($K_{t,i}$) can be estimated from investment at date t ($I_{t,i}$) and the two parameters g_i and δ_i.

2.1.2 Assuming Constant Capital Stock-to-output Ratios

Alternatively, it can be assumed that the capital stock-to-output ratio is constant over time. This assumption is based on the Solow (1957) growth model where, on a balanced growth path, capital and output grow at the same rate. Initial capital stocks in the Penn World Tables are estimated in this way (Inklaar and Timmer, 2013; Feenstra *et al.*, 2015).

2.2 Accuracy of Initial Capital Stock Estimates and Impact on Net Capital Stocks at Later Dates

In order to assess the accuracy of ini-

Table 4: Assumptions on Capital Stock-to-output Ratios to Estimate Initial Capital Stocks

Asset category	Capital stock-to-output ratio (total economy)
Structures (residential and non-residential)	2.2
Transport equipment	0.1
Other machinery and equipment	0.3
All other assets (i.e., IT equipment, software, and originals)	0

Note: Inklaar and Timmer (2013) did not cover R&D which, at the time, was considered intermediate consumption (not investment) in the System of National Accounts (SNA).
Source: Inklaar and Timmer (2013, Table 4).

tial capital stock estimates and their impact on net capital stocks at later dates, it is assumed that the US investment time series start in 1950, 1980 or 1995, instead of 1901 as in the BEA national accounts.[15] The above-described assumptions on investment growth rates and capital stock-to-output ratios for specific assets are then used in turn to estimate initial capital stocks.

In the first case, average investment growth rates are estimated for each aggregate asset and industry[16] over the first 20 years where investment series are available.[17] These average growth rates are then used to backcast investment series for each aggregate asset and industry.

In the second case, the asset-specific capital stock-to-output ratios calculated by Inklaar and Timmer (2013) are used. They are reported in Table 4. These are average capital stock-to-output ratios[18] estimated on a sample of 142 countries with asset series starting in 1970 or before. Output corresponds to GDP, and both capital and GDP are measured at current national prices.

For the purpose of this sensitivity analysis focusing on the US private sector, the three capital stock-to-output ratios given by Inklaar and Timmer (2013) have been multiplied by a factor 0.8, corresponding to

15 These cut-off dates are representative of the typical length of publicly available investment series across OECD countries. While according to the 2019 Eurostat-OECD Questionnaire on the Methodology underlying Capital Stocks, many OECD countries rely on unpublished historical investment series to implement their PIM. This is apparently not the case for Central and Eastern European countries, for which investment time series do not seem to available before 1995.

16 More precisely, average investment growth rates are estimated for dwellings, buildings other than dwellings, other structures, transport equipment, computer hardware, telecommunication equipment, other machinery and equipment, R&D, and software and originals, in each aggregate industry shown in Table D.1 of Appendix D in Pionnier *et al.* (2023)- https://doi.org/10.1787/92498395-en.

17 For example, for the scenario where investment series start in 1950, average investment growth rates are estimated over the period 1950-1969 for each aggregate asset industry.

18 Note that the adjustment advocated by Inklaar *et al.* (2019) to account for the slight increase in global capital stock-to-output ratios over time is not implemented in the present article. Since the US ratios in the BEA accounts do not show any trend (Charts 8 and 10), this adjustment would not improve the accuracy of national capital stock estimates for the United States. Similarly, their method to account for the fact that since the United States is close to the cross-country average, this correction is not implemented here. Because of the capital stock estimates for the United States across countries would not improve the accuracy.

19 This ratio is taken from the actual BEA accounts. Nevertheless, this operation does not bias our results because the actual stock-to-stock ratio for the US economy as a whole (0.75) is close to the cross-country average (0.76) calculated by Inklaar and Timmer (2013), which is the key reason why this method works well for the United States. That multiplication by 0.8 simply allows focusing on the US private sector rather than the US economy as a whole.

Table 5: Accuracy of Stationarity Assumptions to Estimate Initial Capital Stocks

Starting date of investment series (D)	Asset	Share of initial capital stock remaining in 2005(%)	Assuming constant investment growth rates		Assuming constant capital stock-to-output ratios	
			Ratio between estimated and BEA stocks at initial date (D)	Ratio between estimated and BEA stocks in 2005	Ratio between estimated and BEA stocks at initial date (D)	Ratio between estimated and BEA stocks in 2005
1950	All structures	23.5	2.0	1.0	1.0	1.0
	Of which: Dwellings	20.5	1.5	1.0	1.0	1.0
	Of which: Other buildings and structures	25.0	2.7	1.0	1.0	1.0
	Transport equipment	0.6	1.0	1.0	1.6	1.0
	Other machinery and equipment	0.8	1.1	1.0	1.1	1.0
	IT equipment, Software and Originals	0.1	0.9	1.0	0.0	1.0
	R&D	0.0	0.9	1.0	not estimated	not estimated
	Total		**1.8**	**1.0**	**1.0**	**1.0**
1980	All structures	48.4	1.3	1.1	1.0	0.9
	Of which: Dwellings	41.3	0.7	0.9	0.9	0.9
	Of which: Other buildings and structures	52.0	2.3	1.3	1.0	1.0
	Transport equipment	5.2	1.8	1.1	1.1	1.0
	Other machinery and equipment	6.5	1.0	1.0	0.8	1.0
	IT equipment, Software and Originals	2.4	1.2	1.0	0.0	1.0
	R&D	1.0	1.0	1.0	not estimated	not estimated
	Total		**1.3**	**1.0**	**0.9**	**0.9**
1995	All structures	72.5	26.1	15.8	1.2	1.0
	Of which: Dwellings	64.7	3.8	2.7	1.1	1.0
	Of which: Other buildings and structures	76.5	59.0	37.1	1.2	1.1
	Transport equipment	24.6	1.2	1.0	1.5	1.0
	Other machinery and equipment	28.2	1.1	1.0	1.0	1.0
	IT equipment, Software and Originals	15.9	1.2	1.1	0.0	0.9
	R&D	11.3	1.1	1.0	not estimated	not estimated
	Total		**20.5**	**13.0**	**1.1**	**1.0**

Note: The shares of initial capital stock remaining in 2005 are calculated as $(1-\delta_i)^{2005-D}$, where δ_i is the geometric cohort depreciation rate of asset i and D the starting date of investment series. These shares only depend on asset-specific cohort depreciation parameters, not on initial capital stock levels. In case depreciation rates are set at a more detailed level, an unweighted unweighted average of the corresponding shares is reported in Table 5. This unweighted average is only reported for homogeneous asset categories (e.g. transport equipment), but not for the whole economy.

private-sector share of the overall US capital stock.[19] Initial capital stocks are then further broken down into assets and industries based on their respective investment shares over the first 20 years where investment series are available. Finally, these initial capital stocks are used as starting points to apply the PIM and estimate net capital stocks at the same level of detail as the BEA.

Table 5 shows the accuracy of both methods to estimate initial capital stocks by comparing their results with the official capital stocks published by the BEA.[20] As expected, initial capital stocks have a long-lasting influence on future capital stock figures for structures and, to a lesser extent, for transport equipment and other machinery and equipment. For example out of the initial capital stocks of structures estimated in 1950, 1980 and 1995, 23.5 per cent, 48.4 per cent and 72.5 per cent, respectively, remain in use in 2005.[21] It is especially for long-lived assets that the accuracy of the method to estimate initial capital stocks is important.

The first conclusion that can be drawn from Table 5 is that the stationarity assumption on investment growth rates to estimate initial capital stocks can be very misleading, especially in the case of structures for which estimated capital stocks in 2005 with investment series starting in 1995 are 16 times higher than the official BEA estimates. This reflects the fact that the growth rate used to backcast investment series before 1995 is much below the actual average growth rate over the past, which leads to excessively large investment estimates before 1995, especially for buildings other than dwellings.

The US private sector exhibits large fluctuations and/or long-term trends in investment growth rates for dwellings and buildings other than dwellings, even when these growth rates are averaged over 20 years (Chart 6). Therefore, using investment growth rates that are based on a specific sample to backcast investment series over long periods in the past may lead to inaccurate results. This issue is magnified if available time series are short, like in the 1995 scenario. Nevertheless, given that more than half of the initial capital stock in structures remains in use after 25 years, a similar issue could have happened in the 1980 scenario. Therefore, relying on the assumption of constant investment growth rates to estimate initial capital stocks of long-lived assets such as structures should be avoided.

By comparison, capital-stock-to-output ratios for the US private sector are much more stable over time than investment growth rates (Chart 7). They are also rel-

20 The BEA capital stock series start in 1947, or even 1925 for some assets, but these estimates are based on unpublished historical investment series. Based on publicly available investment series starting in before 1981, capital stocks for the published BEA assets (residential buildings) cannot be recalculated before 1981. Therefore, the longest-lived BEA capital stock series, rather than the ones that have long record histories, are used in the BEA code.

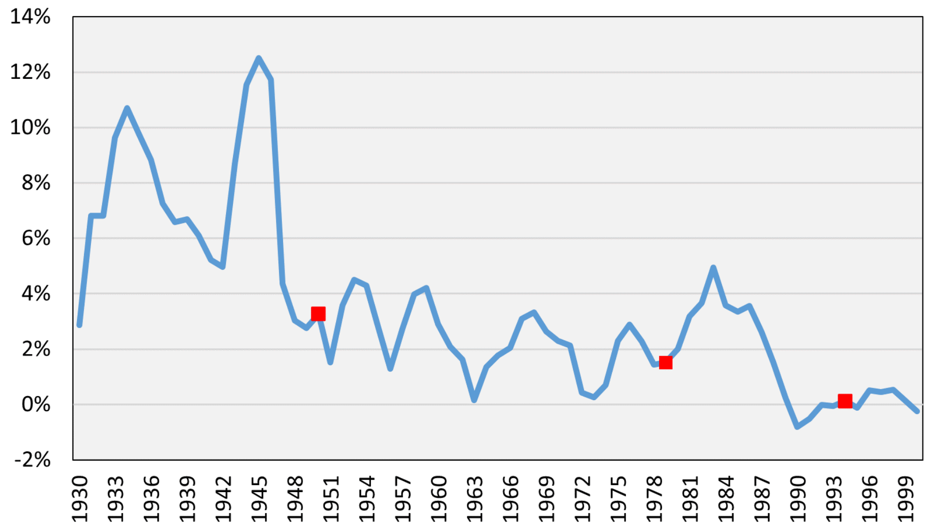
21 These numbers are implied by the BEA geometric cohort depreciation rates. See the note in Table 5.

22 As explained above, the capital stock-to-output ratios estimated by Inklaar and Timmer (2013) are multiplied by a factor 0.8 , in order to focus on the US private sector.

Chart 6: Investment Growth Rates

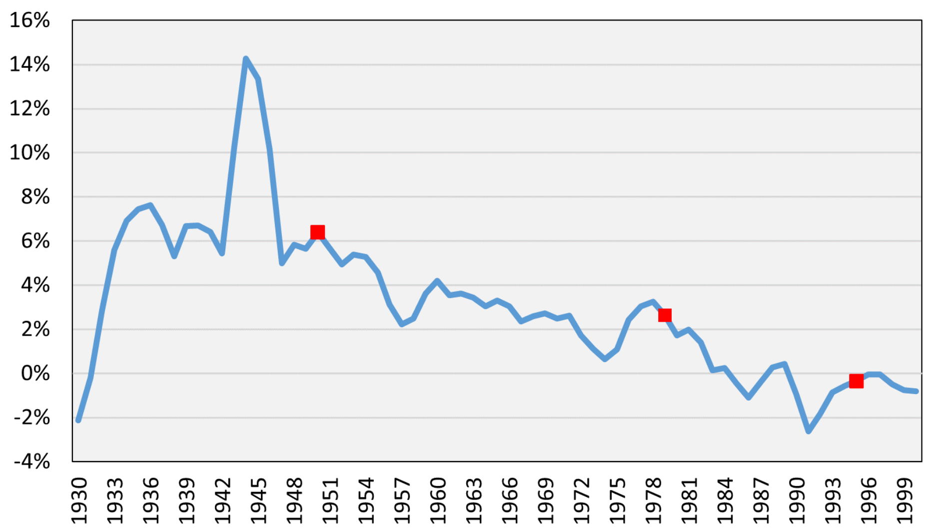
Panel A: Dwellings

20-year forward moving average, Constant prices, US private sector, 1930-2000



Panel B: Buildings Other than Dwellings

20-year forward moving average, Constant prices, US private sector, 1930-2000

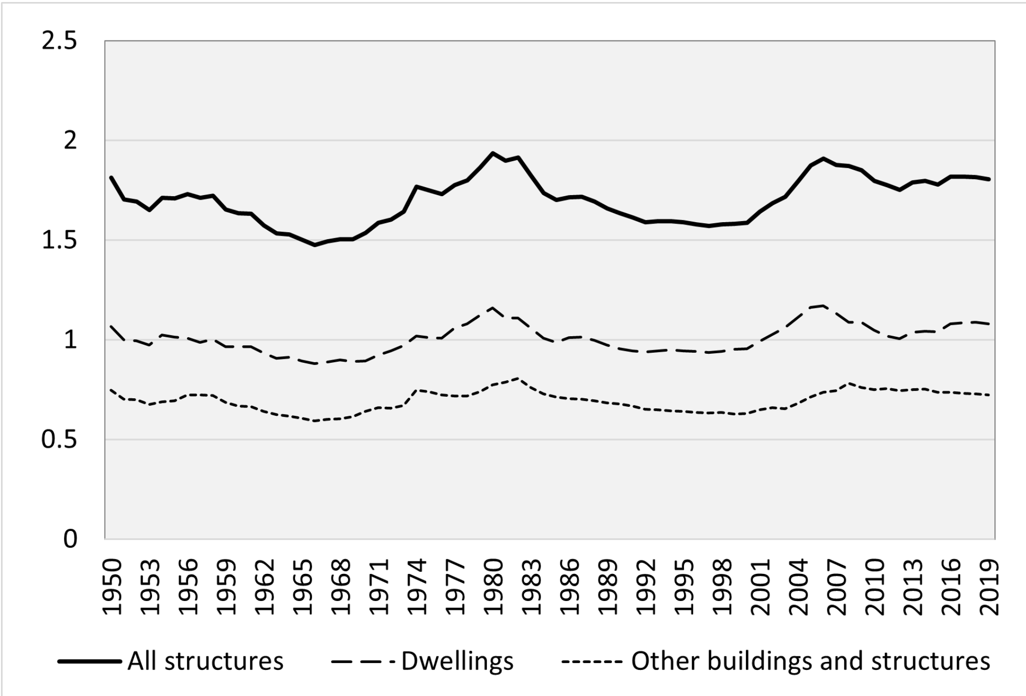


Note: The red dots indicate the 20-year forward moving average investment growth rates that are used to backcast investment time series from 1950, 1980 and 1995 backwards, respectively.
Source: Authors' calculations, based on BEA Fixed Assets Accounts.

Chart 7: Capital-stock-to-output Ratios

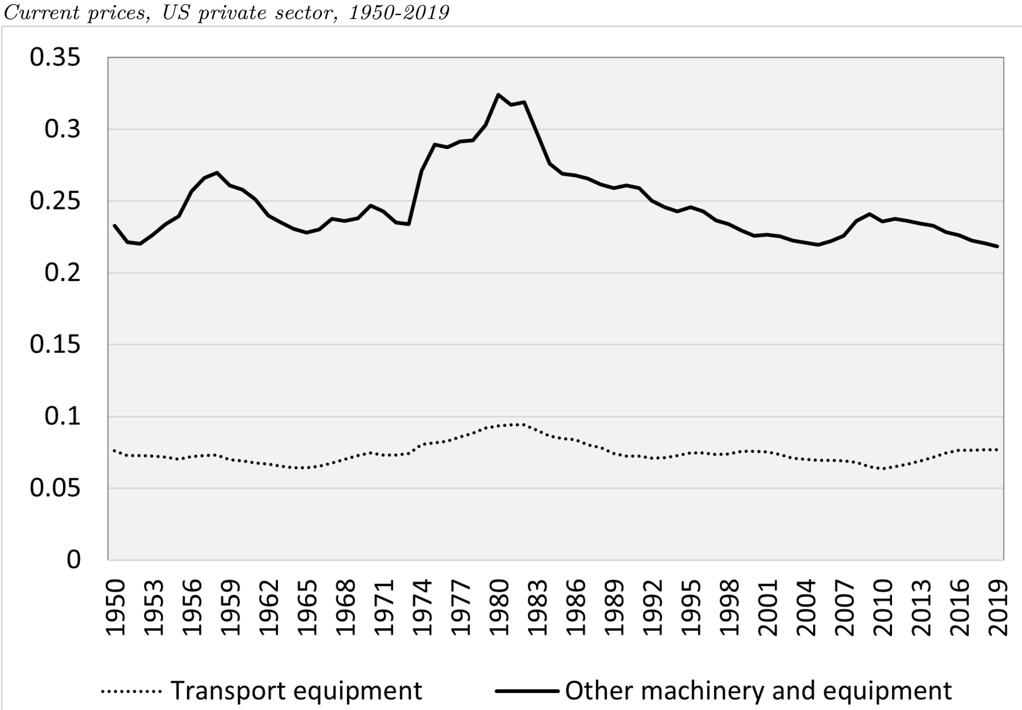
Panel A: For Structures

Current prices, US private sector, 1950-2019



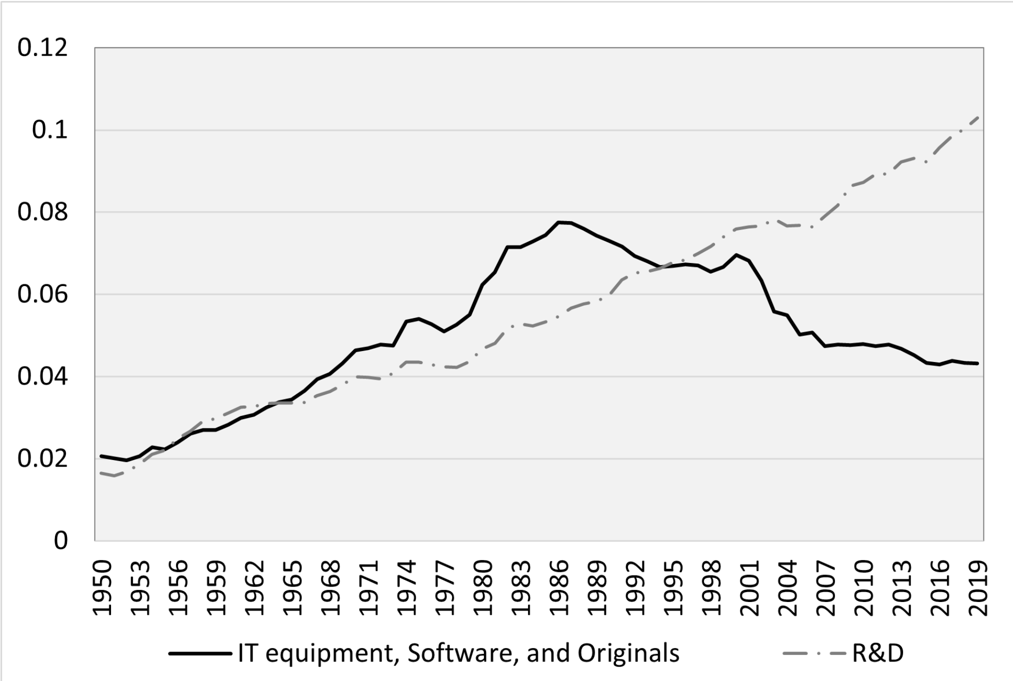
Panel B : For Transport Equipment, and Other Machinery and Equipment

Current prices, US private sector, 1950-2019



Panel C : For IT Equipment, Software, Originals and R&D

Current prices, US private sector, 1950-2019



Source: Authors' calculations, based on BEA Fixed Assets Accounts.

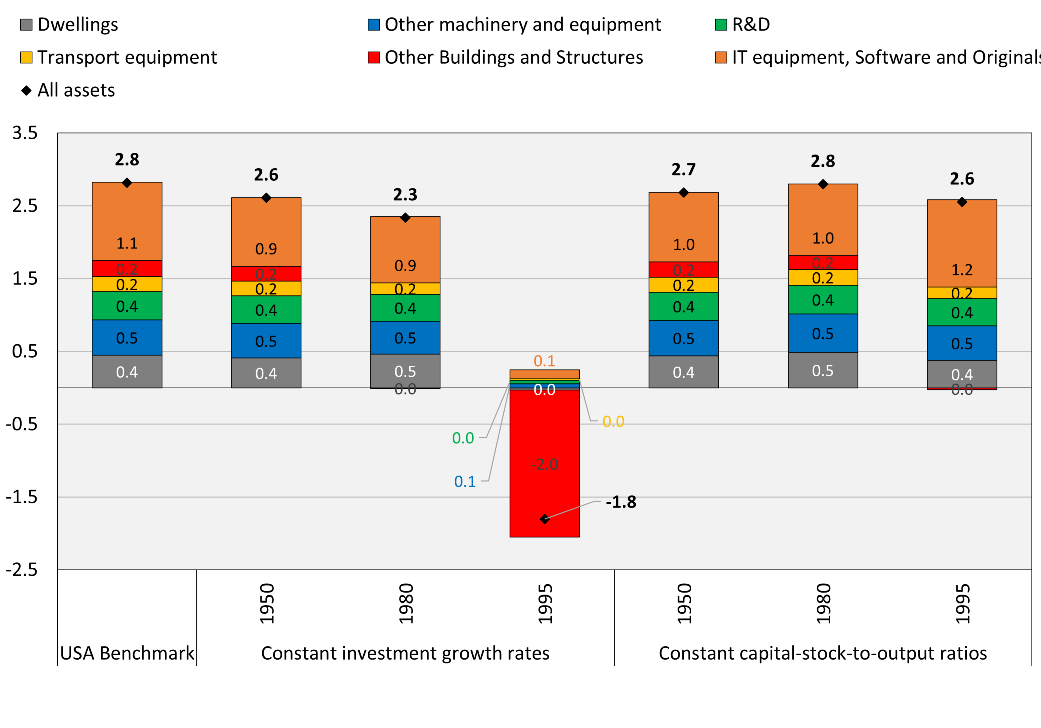
atively close to the cross-country averages estimated by Inklaar and Timmer (2013).[22] Assuming zero initial net capital stocks for IT equipment, software and originals as Inklaar and Timmer (2013) looks reasonable given the actual values for these ratios and the short service lives of these assets. Overall, estimates of net capital stocks in 2005 are in the +10/-10 per cent range around official values reported by the BEA for all main asset categories and under all scenarios (investment series starting in 1950, 1980 or 1995) when capital-stock-to-output ratios are used to estimate initial capital stocks. Nevertheless, given the dispersion of capital-stock-to-output ratios across countries (Inklaar and Timmer 2013, Figure 1), the same method may give less reliable results for other countries than the US. Exploring this issue is left for further research.

2.3 Sensitivity of Capital Services and MFP Growth to Initial Capital Stock Estimates

With short investment series, assuming constant investment growth to estimate initial capital stocks may lead to very inaccurate estimates of capital services growth (Chart 8). This reflects to a large extent the difficulty to estimate initial capital stocks for real-estate assets when assuming a constant investment growth rate. Long investment series are required to mitigate this problem. By contrast,estimating initial capital stocks by assuming constant capital-stock-to-output ratios gives rela-

Chart 8: Sensitivity of Capital Services Growth to Initial Capital Stocks

Average annual percentage changes, US private sector, 1998-2019



Note: This figure shows the sensitivity of capital services growth to initial capital stock estimates. Two different methods (relying on stationarity assumptions on investment growth rates or capital-stock-to-output ratios) and three possible starting dates for investment series (1950, 1980 and 1995) are considered.
Source: Authors' calculations.

Table 6: Sensitivity of MFP Growth to Initial Capital Stocks

Average annual percentage changes, US private sector, 1998-2019

	USA-Benchmark	Constant investment growth rates			Constant capital-stock -to-output ratios		
		1950	**1980**	**1995**	**1950**	**1980**	**1995**
1998-2019	**0.6**	**0.6**	**0.7**	**3.0**	**0.6**	**0.6**	**0.7**
1998-2006	0.7	0.8	0.8	3.3	0.7	0.7	0.7
2006-2012	1.5	1.6	1.6	3.4	1.6	1.6	1.6
2012-2019	-0.3	-0.3	-0.2	2.5	-0.3	-0.3	-0.3

Note: This table shows the sensitivity of MFP growth to changes in initial capital stock estimates. Two different methods (Assuming constant investment growth rates or capital-stock-to-output ratios) and three possible starting dates for investment series (1950, 1980 and 1995) are considered.
Source: Authors' calculations.

tively accurate estimates of US capital services growth, including when only short investment series are available. Nevertheless, the same caveat as for the estimation of net capital stocks holds. Indeed, the findings in this article are limited to the United States, for which the average capital-stock-to-output ratios estimated by Inklaar and Timmer (2013) on a large cross-section of countries work reasonably well. Considering the dispersion in capital-stock-to-output ratios across countries, this method may give less reliable results for other countries than the United States.

Similar results apply for MFP growth, but with attenuation due to the weighting of capital services growth (by roughly one third) in the calculation of MFP growth. MFP growth estimates only stand out as inaccurate when initial capital stocks are estimated in 1995, by assuming constant investment growth before that date (Table 6).

3. Conclusion

The measurement of capital stocks in an economy typically implies estimating initial capital stocks at a given date, and cumulating and depreciating investment flows over time. This article discussed the sensitivity of capital and MFP measurement to changes in the depreciation and retirement patterns of assets, and to the way initial capital stocks are estimated.

In order to capture differences in combined depreciation and retirement patterns across countries, this article focused on geometric approximations of cohort depreciation patterns. This allowed comparing the asset depreciation and retirement patterns used by national accountants in the United States and Canada, as well as France, Germany, Italy and the United Kingdom, where functional forms for asset depreciation and retirement differ from those used in Canada and the United States.

The sensitivity analysis in this article has two main characteristics. First, the distribution of cohort depreciation rates across countries for a given asset is used as a measure of uncertainty. This assumes that country-specific depreciation rates provide different estimates of the same unobserved depreciation rate, and that all differences across countries may be related to measurement errors. This extreme assumption ultimately provides a useful upper bound of the uncertainty on capital and MFP measurement.

Second, the US national accounts are used as a laboratory to analyse the sensitivity of capital and MFP measurement. Since the composition of investment is relatively similar across advanced economies, the sensitivity of capital and MFP measurement in the United States is relevant for other advanced economies as well.

Applying the same geometric cohort depreciation rates in the United States as in Canada, France, Germany or the United Kingdom would reduce the net capital stock of the US private sector by up to one third. Through an increase in the CFC of the government sector, this would also increase U.S. GDP by up to 0.5 per cent. This largely reflects the faster depreciation of buildings in the national accounts of Canada, France, Germany and the United Kingdom. Switching to Italian depreciation rates, which are closer to those used in the United States, would have a more limited impact.

Compared to the absolute levels of net capital stocks and CFC, the growth rates of net capital stocks, capital services and MFP are less sensitive to changes in depreciation and retirement patterns, no matter which country's depreciation rates are used.

This article also assessed the accuracy of two commonly used methods to estimate initial capital stocks and their impact on capital and MFP measurement. These methods involve stationarity assumptions on either investment growth rates or capital-stock-to-output ratios. While the estimation method of initial capital stocks is innocuous for rapidly depreciating assets, it has a more significant impact for long-lived assets. The US example shows that real-estate assets may exhibit large trends and fluctuations in investment growth. Since the same may be true in other countries, estimating initial capital stocks of real-estate assets by assuming constant investment growth rates over time should be avoided. On the contrary, relying on average capital-stock-to-output ratios in a large cross-section of countries works reasonably well to estimate initial capital stocks in the US private sector. Nevertheless, given the wide dispersion in capital-stock-to-output ratios across countries, this result may not be universally true and relying on the cross-country average of capital-stock-to-output ratios may give less reliable results for other countries than the United States.

Overall, the empirical evidence in this paper calls for a more frequent review of the methods used by statistical agencies to estimate asset depreciation and retirement patterns, including for assets that have been capitalised for a long time in national accounts (e.g. buildings, structures, machinery and equipment). The aim of this recommendation is not to standardize depreciation and retirement patterns across countries, but to ensure that differences reflect country-specific factors rather than statistical assumptions or measurement errors. The results also call for a careful use of stationarity assumptions to estimate initial capital stocks, especially for long-lived assets. Before relying on any stationarity assumption, statistical agencies should extend investment time series as much as possible based on historical vintages of national accounts, and use the information on capital stocks provided by population censuses, company accounts and administrative sources whenever possible.

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Capacity Utilization and Production Function Estimation: Implications for Productivity Analysis

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Abstract

During business cycles and disruptions of global value chains, capacity utilization has important implications for explaining variations in productivity and for evaluating the effectiveness of a certain investments such as R&D and ICTs. Unfortunately, data on capacity utilization is not easily available, especially at the firm level. This article develops and evaluates a methodology for measuring capacity utilization at the micro level. Unlike the literature using ad-hoc proxies (for example, the ratio of energy use to capital stock) or ex-post return to capital which is endogenous to productivity shocks, the new measure is practical and easily implemented. Importantly, it is based on the theory of the firm in terms of profit-maximizing and price-taking and is exogenous to productivity shocks. Using Canadian micro data, this article shows that the developed new measure under the assumption of capital being not adjustable in the short term explain well the variations in firm productivity. It also finds that controlling for capacity utilization may be essential in evaluating the economic impact of certain investments such as in ICT.

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A firm installs machines and hires workers to meet expected demand for its products. The maximum production level under normal economic conditions of the firm's operating practice with respect to the use of installed machines and the deployment of workers is the production capacity of the firm (Klein and Long, 1973). In reality, however, the operation of the firm may often not be at its capacity as the realized demand for its products may be lower/higher than expected or there is a shortage of necessary parts due to a disruption of global value chains. If actual demand is lower than expected or there is a shortage in necessary inputs, a firm may have to reduce its production. This leads to underutilization of production capacity as it is difficult or costly to adjust the installed capacity in a short-term. Similarly, if actual demand is higher than expected, the firm may want to increase production by operating overtime, resulting in capacity utilization higher than normal.

The variation in capacity utilization has important implications for production function estimation or measured productivity. If productivity is simply an indicator for how much output is produced by a unit of all inputs, including all workers and all installed capital, then measured productivity is not affected and capacity utilization is not an issue. However, if productivity is used as an indicator for technological change or production efficiency, which is often the case, then measured productivity under the full capacity utilization assumption may be misleading, particularly during shorter periods of time when the firm has not been able to adjust input levels to match demand. In this case, the appropriate measure should only include the actually-used inputs – the unutilized portion of production capacity should be excluded from the calculation. Thus, it has become important to adjust for capacity utilization in estimating productivity function.

Capacity utilization may also indirectly affect the estimation of the economic performance of policy programs or certain investments such as R&D and ICTs. Without controlling for capacity utilization, econometric analyses may incorrectly estimate the economic impact of policy programs or investments. Thus, controlling for capacity utilization is also important for evaluation and development of industrial policies.

Capacity utilization is commonly measured as a ratio of the actual level of output to a sustainable maximum level of output (Corrado and Mattey, 1997). Unfortunately, despite several decades of research and a well defined definition, how to actually measure capacity utilization is still debated. Importantly, data on capacity utilization is not readily available for economic analysis and research at the firm level or at the industry level for service industries. This opens the door for various proxies for capacity utilization. Measures based on both inputs and output have been put forward. For input-based measures, the proxies includes uses unemployment rates by Solow (1957), an index of electric motor utilization by Jorgenson and Griliches (1967), the ratio of energy costs to capital stock by Burnside *et al.* (1995), the growth of materials by Basu (1996), and hours worked per worker by Basu and Fernald (2001) and Basu *et al.* (2006). For output-based measures, the most popular and traditional one is actual output divided by potential/capacity output (Berndt and Fuss, 1989; Statistics Canada, 2022 for non-manufacturing goods industries). Following Berndt and Fuss (1986) and Hulten (1986), more recently, Baldwin *et al.* (2013) and Gu and Wang (2013) suggest a measure based on ex-post return to capital, and propose capacity utilization as the ratio of the ex-post return to the ex-ante expected return on capital.

However, these measures have limitations. The input-based proxies are unsatisfactory due to lacks a theoretical framework (Berndt and Fuss, 1986). They tend to capture the utilization of labour/energy utilization rather than capital utilization, which is the most difficult to adjust in the short term. Also, these proxies can be different across different groups of firms or industries, and can change over time even in normal economic conditions (for example, from input substitution effect due to relative price changes). These measures are found to be poor indicators for capacity utilization in Canada, and are unable to significantly remove the cyclical fluctuations in productivity growth (Baldwin *et al.* 2013).

Output-based measures are also questionable as the ex-post return to capital is endogenous to productivity. Ex-post income to capital is measured as output net of labour and intermediate inputs costs. Firms are often price takers for labour and intermediate inputs. Most of the gains (or loss) from positive (or negative) productivity improvements accrue to capital, which leads to over estimation (under estimation) of capacity utilization. An over- or under-estimation may be problematic if the measure is used to adjust variation in productivity or for assessing the economic performance of some economic policy instruments. The practice will also lead to the endogeneity problem in estimating production functions when capacity utilization enters regressions as an explanatory variable.

The objective of this article is to use the theory of the firm, which assumes that firms are profit maximizing and price-taking in both output and input markets, to develop a practical methodology under the Cobb-Douglas production function for estimating capacity utilization.[2] Unlike output-based measures in the literature, the theory-based measure is also exogenous to productivity shocks. Using econometric analyses, we validate the new methodology by its effectiveness in explaining variations in productivity performance of firms over business cycles. We also provide evidence on the importance of controlling for capacity utilization in assessing the economic performance of investments in R&D and ICTs during business cycles.

It is important to note that the main objective of this study is not to replace the valuable data development programs on capacity utilization at statistical agencies around world. Instead, it is to provide a practical way for researchers to estimate capacity utilization at the firm level or at

2 The project also contributes to the data development at Statistics Canada by estimating capacity utilization at the micro level.

the industry level for services industries, which currently have no capacity utilization estimates at least in Canada.

Following the introduction section, this article develops a methodology to estimate capacity utilization at the firm level, together with two hypotheses. In the data section, it briefly describes the micro data, which is used to evaluate the developed methodology. This is followed by a discussion of the measured capacity utilization under two different hypotheses. It then tests and evaluates the two hypotheses, by associating the measured capacity utilization with output, labour, investments, and official capacity utilization at the sector or industry level. It also shows whether or not controlling for capacity utilization is important in measuring productivity and in evaluating the economic impact of investments in R&D and ICTs. Finally, it concludes.

Methodology

We assume that a firm uses two inputs for its production: one input is fully adjustable (for example, combined labour and intermediate inputs) and the other is not adjustable in the short term (for example, capital). In formulation, firm i at time t maximizes profit from its production as follows:

$$\begin{cases} \max \pi_{it} = P^Y_{it} Y_{it} - P^C_{it} C_{it} - P^F_{it} V_{it} \\ \text{s.t. } Y_{it} = A C^{\alpha}_{it} V^{\beta}_{it} \end{cases} \quad (1)$$

Where π, Y, C, and V denote profit, output, un-adjustable input, and adjustable input, respectively; P^Y, P^C, and P^V are the prices corresponding to Y, C, and V. Note that A is a production efficiency parameter, and α and β are the output elasticities with respect to inputs C and V.

Assume that the firm is a price taker in both output and in inputs markets. From the first order conditions of the maximization problem of equation (1), we obtain

$$\frac{V^*_{it}}{C^*_{it}} = \frac{\beta P^C_t}{\alpha P^V_t} \quad (2)$$

where V^*_{it} and C^*_{it} represent the optimal levels of the adjustable and un-adjustable inputs for a given output Y_{it} for firm i at time t.

Equation (2) is the input ratio of the adjustable input to the un-adjustable input. It captures the substitution effect between the two inputs due to a relative change in input prices.

We define capacity utilization as the extent to which a firm uses its installed productive capacity. Thus, for firm i at time t, it equals

$$U_{it} = \frac{C^*_{it}}{C_{it}} \quad (3)$$

where C_{it} is the total installed production capacity for firm i at time t.

By this definition, we implicitly assume that a firm will install production capacity to meet expected demand in the medium- or long-term while actual use of the installed capacity is based on the short term (or yearly) demand.

This is an input-based measure of capacity utilization. The optimal level of C^*_{it} for a realized demand can be smaller or larger than the installed C_{it}. If actual demand is lower than expected, a firm may have to adjust its operation, leading to under-utilization of installed production capacity.

In contrast, if actual demand is higher than expected, the firm may want to increase production by operating overtime, resulting in capacity utilization higher than normal. Substituting (2) into (3), we derive capacity utilization as:

$$U_{it} = \frac{\alpha}{\beta} \frac{P_{it}^{V} V_{it}^{*}}{P_{it}^{C} C_{it}} \tag{4}$$

The measure has a desirable property. It is exogenous as it is not influenced by the production efficiency parameter (A), which is affected by productivity shocks, in equation (1).[3] During normal business operation under the Cobb-Douglas production function, the capacity utilization measure equals 1. When there is a negative (positive) shock to the demand condition, the capacity utilization measure is below (above) 1 as C_{it} is larger (smaller) than C_{it}^{*}.

It is important to note that in the context of this study, the price of the installed capacity, C_{it}, should not be determined endogenously, that is, the compensation for C_{it} should not be equal to the output value $P_{it}^{V} Y_{it}$ minus the cost of the adjustable input $P_{it}^{V} V_{it}^{*}$. It should be exogenously determined, which will be discussed further when we introduce our hypotheses.

For an empirical analysis, the output elasticity parameters α and β can be obtained by estimating the production function. Alternatively, they can be estimated by income shares as they are equivalent to income shares when inputs are paid the value of their marginal products (Hulten, 2009). Accordingly, we derive the firm-specific ratio of the two elasticity parameters for firm i as the firm sample average, that is,

$$\begin{aligned} \frac{\alpha_i}{\beta_i} &\approx \frac{1}{T_i} \sum_{t=1}^{T_i} \frac{\alpha_{it}}{\beta_{it}} \\ &= \frac{1}{T_i} \sum_{t=1}^{T_i} \frac{\left(P_{it}^{Y} Y_{it} - P_{it}^{V} V_{it}^{*}\right) / P_{it}^{Y} Y_{it}}{P_{it}^{V} V_{it}^{*} / P_{it}^{Y} Y_{it}} \\ &= \frac{1}{T_i} \sum_{t=1}^{T_i} \frac{P_{it}^{Y} Y_{it} - P_{it}^{V} V_{it}^{*}}{P_{it}^{V} V_{it}^{*}} \quad (5) \end{aligned}$$

where T_i is the total number of yearly observations for firm i.

Under this model, the average capacity utilization over time will be one. The model is then used to test two hypotheses.

Hypothesis 1: Labour and intermediate inputs are fully adjustable, and capital cannot be adjusted in the short term.

In this case, like intermediate inputs, employment can be adjusted in the short term and labour hoarding is insignificant.[4] Under this hypothesis, the adjustable input F is both labour and intermediate inputs and the un-adjustable input is capital, that is, in formulation:

$$U_{it}^{K} = \frac{\alpha^{K}}{\beta^{LM}} \frac{P_{it}^{LM} V_{it}^{LM*}}{P_{it}^{K} C_{it}^{K}} \tag{5}$$

The combined labour-intermediate input for firm i at time t is calculated as a weighted sum of labour and real interme-

3 Note also that firms are price-taking in labour and intermediate inputs and the price of capital is determined by the long-term return to capital, which will be discussed later.

4 To reflect the full adjustment in labour input, employment here should ideally be measured in hours worked. In the empirical analysis of this study, we have only data on the number of employees."

diate inputs in the Törnqvist index as follows:

$$\Delta \ln(V_{it}^{LM*}) = \overline{\phi}_{it}\Delta \ln(L_{it}^{*}) + (1-\overline{\phi}_{it})\Delta \ln(M_{it}^{*}) \quad (6)$$

where $\overline{\phi}_{it}$ is the average share of labour cost in the total cost of labour and intermediate inputs between t and $t-1$.

Firm-level price data are not easily available. Fortunately, for our estimation of capacity utilization, we do not have to obtain firm-level price data for all inputs. According to equation (6), $P_{it}^{LM}Y_{it}^{LM*}$ is equal to the sum of the labour compensation $P_{it}^{L}L_{it}^{*}$ and the nominal value of intermediate inputs $P_{it}^{M}M_{it}^{*}$, that is,

$$P_{it}^{LM}Y_{it}^{LM*} = P_{it}^{L}L_{it}^{*} + P_{it}^{M}M_{it}^{*}$$

and

$$P_{it}^{K}C_{it}^{K} = P_{it}^{K}K_{it}$$

is the cost of installed capital. To estimate the cost of installed capital, we need to estimate the price of capital, P_{it}^{K}. As capital investment is in the long term and also to avoid the volatility in return to the investments in the short term we approximate P_{it}^{K} by the average return to capital over the whole sample period. [5]

$$P_{it}^{K} \approx P_{i}^{K} = \frac{1}{T_i}\sum_{s=1}^{T_i}\frac{P_{is}^{Y}Y_{is} - P_{is}^{L}L_{is} - P_{is}^{M}M_{is}}{K_{is}}. \quad (7)$$

The ratio of the output elasticity of the adjustable input to the output elasticity of the un-adjustable input can also be estimated by

$$\frac{\alpha_i^K}{\beta_i^{LM}} \approx \frac{1}{T_i}\sum_{t=1}^{T_i}\frac{P_{it}^{Y}Y_{it} - P_{it}^{L}L_{it} - P_{it}^{M}M_{it}}{P_{it}^{L}L_{it} + P_{it}^{M}M_{it}} \quad (8)$$

Hypothesis 1 has been developed under the assumption that both labour and intermediate inputs are fully adjusted in the short term. If the assumption that labour is fully adjustable in the short term is violated and there is labour hoarding when demand is lower than expected is significant, then installed capacity should also include labour. Although it will be rejected later on, we develop our second hypothesis by going to extremes and assuming that like capital, labour is not adjustable.

Hypothesis 2: Intermediate inputs are fully adjustable and both labour and capital are not adjustable in the short-term.

Thus, in this case, installed capital cannot be adjusted in the short term and labour hording is significant. They together form the installed capacity, C^{LK}. In contrast, intermediate inputs are fully adjustable, and $V^* = M^*$.

Under this hypothesis, the capacity utilization firm i at time t is:

$$U_{it}^{LK} = \left(\frac{\alpha^{LK}}{\beta^{M}}\right)\left(\frac{P_{it}^{M}V_{it}^{M^*}}{P_{it}^{LK}C_{it}^{LK}}\right) \quad (9)$$

The combined labour-capital input for firm i at time t can be calculated as a

5 The micro data we have are for 2000-2017. Also, the measure is firm-specific. Alternatively, for a general ex-ante user cost of capital, we can use a standard rate of return to capital for all firms. For example, Diewert (2001) suggests that a constant real interest rate of 4% per year plus the actual rate of consumer price inflation may be used for the user cost of capital.

weighted sum of labour and capital input in the Törnqvist index as follows:

$$\Delta \ln \left(C_{it}^{LK} \right) = \bar{w}_{it} \Delta \ln \left(L_{it} \right) + (1 - \bar{w}_{it}) \Delta \ln \left(K_{it} \right) \tag{10}$$

where $\bar{w}_{it}$ is the average share of labour cost in the total cost of labour and capital at time $t-1$ and t. $\Delta \ln \left(C_{it}^{LK} \right), \Delta \ln \left(L_{it} \right)$, and $\Delta \ln \left(K_{it} \right)$ are log difference of C^{LK}, L, and K between t and $t-1$, respectively.

For this hypothesis, $P_{it}^{M} V_{it}^{M^*} = P_{it}^{M} M_{it}^{*}$ and $P_{it}^{LK} C_{it}^{LK} = P_{it}^{L} L_{it} + P_{it}^{K} K_{it}$. P_{it}^{LK} is the price of installed capacity. As capacity investments are in the long term and also to avoid the volatility in return to the investments in the short term, in this article, we approximate P_{it}^{LK} by the average return to installed capacity over the whole sample period: [6]

$$P_{it}^{LK} \approx P_{i}^{LK} = \frac{1}{T_i} \sum_{s=1}^{T_i} \frac{P_{is}^{Y} Y_{is} - P_{is}^{M} M_{is}}{C_{is}^{LK}} \tag{11}$$

$$\frac{\alpha_i^{LK}}{\beta_i^{M}} \approx \frac{1}{T_i} \sum_{t=1}^{T_i} \frac{P_{it}^{Y} Y_{it} - P_{it}^{M} M_{it}}{P_{it}^{M} M_{it}} \tag{12}$$

Thus the new method in estimating capacity utilization is an input-based measure, which utilizes all information on labour, capital and intermediate inputs. As such, it is exogenous to output and productivity shocks.

Micro Data

The empirical analysis for evaluating the proposed measure of capacity utilization is based on micro data in Canada, covering total business sector from 2000-2017. The micro data file is from National Accounts Longitudinal Microdata File (NALMF), which is an administrative data file created by the Economic Analysis Division at Statistics Canada. The NALMF makes use of administrative tax records (T2 and PD7), T4 data, and information from the Business Register (BR), and the Survey of Employment, Payrolls and Hours (SEPH).[7] The T2 data includes corporations that file a T2 tax return with the Canada Revenue Agency (CRA). The T4 data, PD7 and SEPH include corporations and unincorporated firm that hire employees.

From the NALMF dataset, we extract for each firm, gross output, physical capital stock, intermediate inputs, R&D stock, and ICT capital stock. R&D stock is derived using the perpetual inventory method (PIM).

NALMF also has data on foreign ownership and firm birth year. These data are originally from Business Register (BR). BR is the central repository of information on businesses in Canada. Used as the principal frame for the economic statistics program at Statistics Canada, it maintains a complete, up-to-date and unduplicated list

6 The micro data we have are for 2000-2017. Also, the measure is firm-specific. Alternatively, for a general ex-ante user cost of capital, we can use a standard rate of return to capital for all firms. For example, Diewert (2001) suggests that a constant real interest rate of 4 per cent per year plus the actual rate of consumer price inflation may be used for the user cost of capital.

7 When a firm files its tax return, PD7 is the statement of account for payroll deduction containing the total number of employees and the gross payrolls. For an employee, T4 is the statement of remuneration paid by an employer, containing employment earnings.

on all active businesses in Canada that have a corporate income tax (T2) account, are an employer or have a goods and services tax account. The BR information on foreign ownership is combined with an updated foreign ownership information from Industrial Organization and Finance division (IOFD) at Statistics Canada.

Output and intermediate inputs in the NALMF database are in nominal dollars. To ensure comparison over time, it is necessary to deflate the nominal variables. Deflators at the firm level are not available so detailed industry deflators based on the KLEMS database are used.[8]

We end up with 12.3 million observations for the whole sample period (Table 1). The number of observations gradually increased for most of the non-manufacturing industries from 2000 to 2017, and it decreased for most of the manufacturing industries. This reflects the general change in the industrial structure of the Canadian economy, moving into a more service oriented economy.

Measured Capacity Utilization

Using the micro data, we estimate capacity utilization using our developed methodology under the two hypotheses. To reflect the importance of each firm in an industry group, capacity utilization for the industry is the average of capacity utilization of all firms in the industry, weighted by their output. Table 2 is the measured capacity utilization under hypothesis 1 (or CU1) for selected years, which assumes that only capital input is not adjustable in the short term. The years are the beginning and the ending points of our data, or they are associated with the two significant economic downturns in Canada.[9] In general, the measured capacity utilization is consistent with the movement in real GDP, that is, capacity utilization was high when the Canadian economy was performing well while it was low in economic downturns, especially in the 2008-2009 global financial crisis. Over the data period, the annual correlation between the measured capacity utilization (level) and real GDP growth for the business sector was highly significant at 0.49.

Chart 1 illustrates the movement of capacity utilization for industry groups for the analysis period. In general, capacity utilization decreased over time, mainly driven by non-manufacturing industries. The capacity utilization of the non-manufacturing goods-producing industry group is more volatile than manufacturing and services, with standard deviation being 0.18, 0.09 and 0.10, respectively. The high volatility in capacity utilization in the non-manufacturing goods-producing industry group can be partly explained by the high volatility of commodity price and economic activities in the mining sector.

The measured capacity utilization also captures well the change in economic condi-

8 For a description of the KLEMS database for Canada, see Baldwin *et al.* (2007).

9 Over the sample period 2000-2017, Canada only experienced one recession due to the great financial crisis, with real GDP declining 2.9 percent in 2009. Unlike the United States, Canada did not enter recession in 2001. However, due to our export industries heavily depending on the U.S. economy, Canada's real GDP growth slowed significantly from an average of 2.9 percent per year in 1990-2000 to 1.8 percent in 2001, with many manufacturing and information related services industries being hit hard.

Table 1: Number of Firms (Observations by Industry in Sample, between 2000-2017)

Industry	2000	2009	2017	**Total 2000-2017**
Forestry and logging	5855	4449	3709	86221
Fishing, hunting and trapping	1836	2137	2311	38237
Support activities for agriculture and forestry	2642	2827	3016	51081
Crop and animal production	4944	5124	4675	89940
Oil and gas extraction	1071	1616	1235	26005
Mining and quarrying	725	676	605	12145
Support activities for mining and oil and gas extraction	3820	6523	5473	101892
Utilities	445	588	545	10124
Construction	73654	104003	122712	1807629
Total manufacturing	48985	46042	42890	834814
Food	4657	4285	4568	80049
Beverage and tobacco	433	531	1106	10862
Textile and product mills	1524	1088	858	20641
Clothing, leather and allied product	3178	1818	1303	37665
Wood product	3269	3000	2709	54477
Paper	604	498	362	8990
Printing	4450	3859	3096	69113
Petroleum and coal	188	134	161	2680
Chemical	1616	1548	1528	28271
Plastics and rubber	2036	1896	1781	34499
Non-metallic mineral	1688	1651	1475	29194
Primary metal	543	552	467	9444
Fabricated metal	7386	7335	6800	131063
Machinery	4710	4615	4212	82774
Computer and electronics	2066	1796	1529	32167
Electrical equipment	1018	1017	1004	18275
Transportation equipment	2011	1800	1621	32747
Furniture	3342	3672	3352	64037
Miscellaneous manufacturing	4266	4947	4958	87866
Wholesale trade	44964	47292	42383	823391
Retail trade	77681	84197	85365	1512108
Transportation and warehousing	29958	42657	59588	775239
Information and cultural industries	8674	10434	10894	185604
Finance, insurance, real estate, and company management	58225	68136	62587	1154877
Professional, scientific and technical services	70947	106856	122517	1833234
Administrative, waste management	26892	37186	38999	635512
Arts, entertainment and recreation	10145	13698	13302	234670
Accommodation and food services	44444	53697	62411	973437
Other services except public administration	43452	62825	60446	1072343
Total business sector	559359	700963	745663	12258503

Source: Authors' own compilations based on the micro dataset for this study.

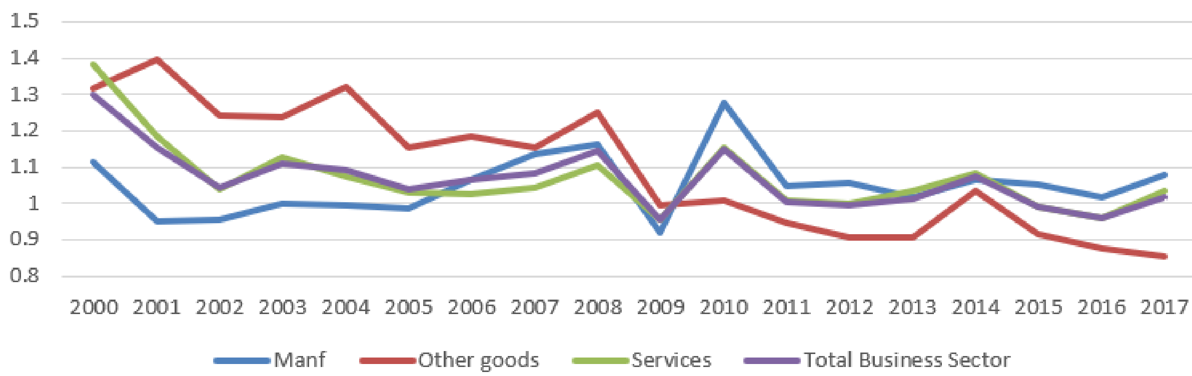
Table 2: Capacity Utilization When Only Capital Cannot Be Adjustable in the Short Term (Hypothesis 1, CU1)

Industry	2000	2001	2009	2017	**Average 2000-2017**
Forestry and logging	1.44	1.23	0.90	0.91	1.06
Fishing, hunting and trapping	1.63	1.40	0.89	1.03	1.09
Support activities for agriculture and forestry	1.48	1.33	1.00	0.97	1.08
Crop and animal production	1.42	1.26	2.36	1.01	1.18
Oil and gas extraction	0.79	1.49	1.08	0.79	1.12
Mining and quarrying	0.96	0.88	1.25	0.68	1.05
Support activities for mining and oil and gas extraction	1.42	1.28	0.91	0.88	1.07
Utilities	1.69	1.64	0.58	0.48	0.91
Construction	1.49	1.28	1.02	0.97	1.11
Total manufacturing	1.11	0.95	0.92	1.08	1.05
Food	1.24	1.14	1.00	0.94	1.01
Beverage and tobacco	1.18	0.92	0.68	0.96	0.97
Textile and product mills	1.19	1.04	1.01	0.91	1.01
Clothing, leather and allied product	1.34	1.25	1.02	0.91	1.05
Wood product	1.15	1.10	0.79	1.01	0.99
Paper	0.90	0.78	0.73	1.09	1.07
Printing	1.07	0.99	1.09	1.02	0.97
Petroleum and coal	1.11	0.92	0.84	0.97	1.12
Chemical	0.97	0.84	0.86	1.46	1.03
Plastics and rubber	1.35	0.96	0.89	0.91	0.96
Non-metallic mineral	1.09	1.14	0.91	0.95	1.02
Primary metal	1.06	0.96	1.00	0.85	1.05
Fabricated metal	1.31	1.08	0.96	0.93	1.03
Machinery	1.19	1.17	1.00	0.92	1.04
Computer and electronics	1.48	0.85	1.57	1.04	1.06
Electrical equipment	1.52	0.88	1.05	1.11	1.08
Transportation equipment	0.90	0.83	0.75	1.14	1.02
Furniture	1.28	1.30	0.84	0.92	0.99
Miscellaneous manufacturing	1.29	1.13	1.04	0.92	1.07
Wholesale trade	1.35	1.16	0.98	1.00	1.06
Retail trade	1.18	1.10	0.94	1.07	1.02
Transportation and warehousing	2.13	1.66	0.90	0.92	1.09
Information and cultural industries	0.96	0.90	0.97	0.74	1.05
Finance, insurance, real estate, and company management	1.48	1.18	0.92	1.09	1.08
Professional, scientific and technical services	1.28	1.20	1.00	1.06	1.16
Administrative, waste management	1.35	1.26	1.03	1.07	1.09
Arts, entertainment and recreation	1.43	1.18	0.79	0.93	1.10
Accommodation and food services	1.21	1.09	1.05	0.97	1.02
Other services except public administration	1.51	1.31	0.96	1.05	1.06
Total business sector	1.30	1.15	0.96	1.02	1.07

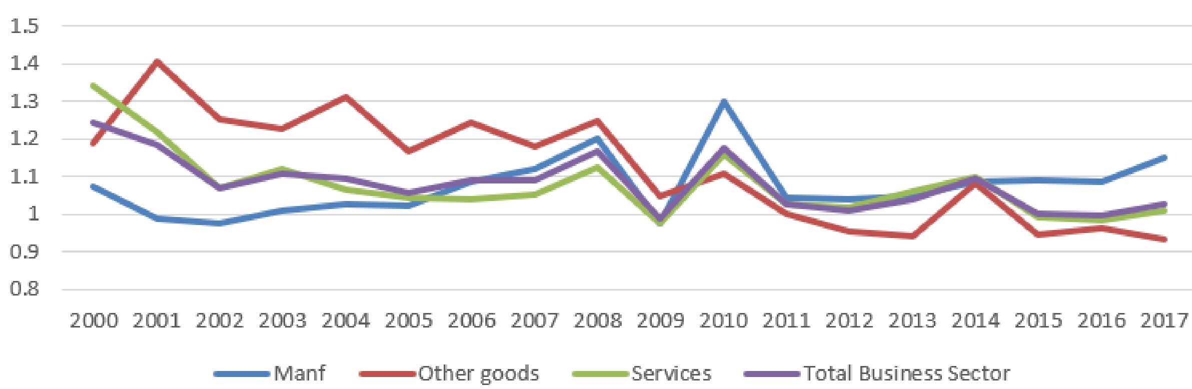
Note: The years selected are the peaks and troughs of real GDP line in Canada. The capacity utilization at the industry level is aggregated from the firm level, weighted by gross output.
Source: Authors' own compilations based on the micro dataset for this study.

Chart 1 : Capacity Utilization

Panel A: When Only Capital Cannot Be Adjustable in the Short Term (Hypothesis 1, CU1) for Aggregated Industry Groups



Panel B: When Both Labour and Capital Input Cannot Be Adjustable in the Short Term (Hypothesis 2, CU2) for Aggregated Industry Groups



tion at the industry level, although the general annual correlation between real GDP growth and the measured capacity utilization was 0.13 at the industry level, as shown later on in Table 5.[10] For the 2001 U.S. recession, which was mainly due to the collapse of the dotcom bubble and the 9/11 attacks, Canada's export-orientated manufacturing sector, especially computer and electronics and electrical equipment, was significantly affected (Table 2). We observe that the capacity utilization for total manufacturing declined 15 percent, from 1.11 in 2000 to 0.95 in 2001. The decline was more

10 The lower correlation at the industry level than at the aggregate business sector may be due to the fact that the variation in real GDP growth across industries was mainly driven by other industry-specific factors other than capacity utilization.

dramatic for the computer and electronics and electrical equipment manufacturing industry, from 1.48 to 0.85. For the great financial crisis, the negative economic impact was deeper and widespread across industries. Consistent with the development, we observe that 33 out of the 38 industries experienced a significant decline in capacity utilization. In 2009, The industries with the largest decline in capacity utilization were oil and gas extraction, petroleum and coal, primary metal, machinery, and finance, insurance and real estate.

Table 3 and Chart 1 is the measured capacity utilization under hypothesis 2 (or CU2), which assumes that both labour and capital input are not adjustable in the short term. The industry variation and movement pattern of CU2 is generally similar to that of CU1, with a correlation of 0.94 at the industry level and 0.98 for the total business sector.

The Evaluation of the Measured Capacity Utilization

How well does our estimated capacity utilization capture the actual capacity utilization? In this section, we assess them by correlating our measures with the official measure of capacity utilization and with economic growth.

Against Official Capacity Utilization for the Goods Producing Industries

Statistics Canada regularly releases capacity utilization statistics for the non-agriculture goods producing industries. In its recent practices, two approaches are followed for estimating capacity utilization rates at Statistics Canada (Statistics Canada, 2022). For manufacturing industries, the rates are directly calculated using survey data from the Monthly Survey of Manufacturing (MSM). In the survey, a plant is asked at what percentage of its capacity it has been operating, with capacity being defined as maximum production attainable under normal conditions. For other non-agriculture goods producing industries, the rates are calculated as the actual output-to-capital ratio divided by the potential output-to-capital ratio. The latter is the de-trended output-to-capital ratio, derived from actual output-to-capital ratio using the Hodrick-Prescott filter (HP filter). As discussed before, the capacity utilization estimates using output-to-capital ratio are endogenous to productivity shocks as they reflect the change in productivity.

The official rates are reported in Table 4. For a comparison between our measured capacity utilization and the official one, the official capacity utilization is normalized to the average of CU1 and CU2 for manufacturing over 2000-2017.

The movement pattern of the official capacity utilization is in general similar to that of our measures, although the correlation between our measures and the official measure at the industry level for 2000-2017 is only modest at 0.18 for CU1 and 0.17 for CU2. In consistent with CU1 and CU2, the largest decline in 2001 were computer and electronics and electrical equipment. For the Great Financial Crisis, in 2009, the decline was widespread across all industries.

Chart 2 illustrates the movement of the official measure and our measured capacity utilization for the total manufacturing

Table 3: Capacity Utilization When Both Labour and Capital Input Cannot Be Adjustable in the Short Term (Hypothesis 2, CU2)

Industry	2000	2001	2009	2017	**Average 2000-2017**
Forestry and logging	1.15	1.09	1.02	0.97	1.06
Fishing, hunting and trapping	1.31	1.17	0.99	0.98	1.07
Support activities for agriculture and forestry	1.18	1.20	1.05	1.01	1.11
Crop and animal production	1.44	1.29	2.38	1.07	1.21
Oil and gas extraction	0.77	1.60	1.05	0.98	1.17
Mining and quarrying	0.86	0.98	1.07	0.76	1.08
Support activities for mining and oil and gas extraction	1.27	1.18	1.27	1.02	1.11
Utilities	1.66	1.65	0.82	0.68	1.04
Construction	1.26	1.22	1.05	0.98	1.09
Total manufacturing	1.07	0.99	0.97	1.15	1.07
Food	1.10	1.10	1.01	1.02	1.02
Beverage and tobacco	1.01	1.04	0.86	1.15	1.02
Textile and product mills	1.07	1.02	1.05	1.05	1.02
Clothing, leather and allied product	1.17	1.13	1.03	0.93	1.03
Wood product	1.06	1.09	0.90	1.10	1.02
Paper	0.93	0.79	0.75	1.12	1.12
Printing	1.28	1.36	0.94	1.02	1.04
Petroleum and coal	1.40	1.10	0.95	0.96	1.18
Chemical	0.91	0.88	0.93	1.58	1.09
Plastics and rubber	1.10	1.11	0.96	1.02	1.02
Non-metallic mineral	1.00	1.08	0.96	0.98	1.03
Primary metal	0.91	0.96	1.04	0.93	1.07
Fabricated metal	1.15	1.01	1.00	0.98	1.02
Machinery	1.06	1.08	1.07	1.02	1.05
Computer and electronics	1.61	0.88	1.62	1.18	1.12
Electrical equipment	1.17	0.92	1.07	1.06	1.07
Transportation equipment	0.90	0.91	0.80	1.20	1.02
Furniture	1.09	1.24	0.92	0.98	1.00
Miscellaneous manufacturing	1.17	1.06	1.10	0.98	1.06
Wholesale trade	1.27	1.16	1.01	1.04	1.07
Retail trade	1.14	1.15	0.97	1.05	1.03
Transportation and warehousing	2.18	1.75	0.94	0.97	1.11
Information and cultural industries	1.00	1.03	1.01	0.74	1.07
Finance, insurance, real estate, and company management	1.45	1.24	0.95	1.00	1.08
Professional, scientific and technical services	1.23	1.15	0.99	1.01	1.16
Administrative, waste management	1.21	1.19	1.04	1.10	1.07
Arts, entertainment and recreation	1.34	1.14	0.83	0.97	1.11
Accommodation and food services	1.16	1.13	0.99	0.96	1.02
Other services except public administration	1.29	1.21	0.98	1.04	1.05
Total business sector	1.24	1.18	0.99	1.02	1.08

Note: The years selected are the peaks and troughs of real GDP line in Canada. The capacity utilization at the industry level is aggregated from the firm level, weighted by gross output.
Source: Authors' own compilations based on the micro dataset for this study.

Table 4: Official Capacity Utilization for the Non-Agriculture Goods Producing Industries

Industry	2000	2001	2009	2017	Average 2000-2017
Forestry and logging	1.11	1.11	0.88	1.11	1.13
Oil and gas extraction	1.13	1.08	0.98	1.04	1.06
Mining and quarrying	1.13	1.13	0.83	1.01	1.06
Construction	1.15	1.17	1.07	1.16	1.17
Food	1.08	1.08	1.09	1.05	1.06
Beverage and tobacco	1.05	1.05	0.96	1.00	0.99
Textile and product mills	1.10	1.04	0.86	1.02	0.99
Clothing, leather and allied product	1.09	1.04	0.87	1.10	0.99
Wood product	1.13	1.09	0.81	1.10	1.09
Paper	1.22	1.18	1.09	1.16	1.18
Printing	1.06	1.02	0.97	0.99	0.97
Petroleum and coal	1.23	1.26	1.04	1.19	1.14
Chemical	1.06	1.07	0.94	1.05	1.05
Plastics and rubber	1.12	1.11	0.90	1.01	1.07
Non-metallic mineral	1.06	1.07	0.90	0.87	1.03
Primary metal	1.21	1.15	1.01	1.06	1.13
Fabricated metal	1.12	1.06	0.86	0.94	1.04
Machinery	1.11	1.04	0.93	1.01	1.06
Computer and electronics	1.29	0.96	1.11	1.05	1.10
Electrical equipment	1.23	1.01	0.99	1.01	1.03
Transportation equipment	1.18	1.14	0.89	1.12	1.12
Furniture	1.13	1.07	0.92	1.01	1.06
Miscellaneous manufacturing	1.11	1.07	1.01	0.99	1.07
Total Manufacturing	1.14	1.09	0.96	1.04	1.07

Source: Statistics Canada Table 16-10-0109-01.
Note: Official capacity utilization is normalized to the average of CU1 and CU2 for manufacturing over 2000-2017.

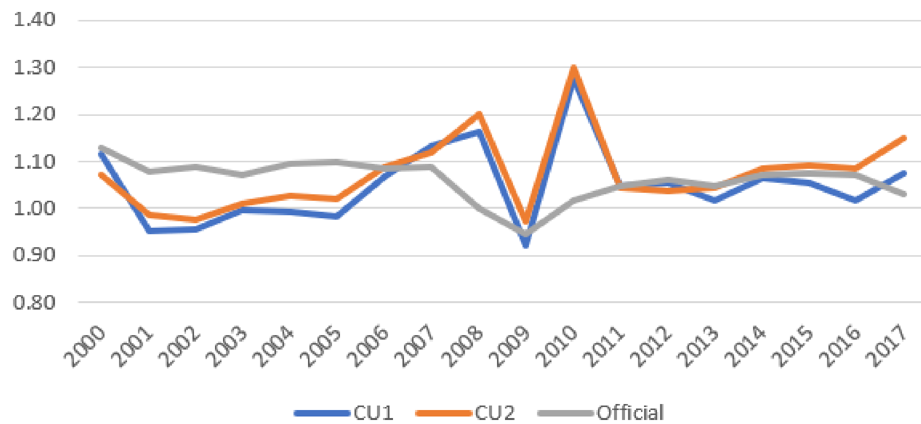
sector. The three measures are broadly similar. For example, during the economic downs in 2001 and 2008-2009, all measures fell substantially. However, our measures are more volatile than the official measure.

Correlation with Output, Employment, and Investment Growth

Measured capacity utilization should generally reflect the change in business conditions. To provide some evidence, we also associate the measured capacity utilization indicators with growth in output (value added), employment (number of employees and hours worked), and investment (total investment and investment in machinery & equipment), which is done at the industry level.

In Table 5, we report the correlations for 38 goods and services industries. All correlations are positive. In general, the associations of CU1 with output, employment and investment growth are better than with CU2 at the manufacturing or the business sector level. This suggests that CU1 may be a better measure for capacity utilization than CU2. It should be noted, however, that a higher correlation of a CU measure with output may not necessarily indicate that the CU measure is a better measure of true capacity utilization as output is determined by many factors besides the use of installed capacity. On the other hand, a higher correlation of a CU measure with inputs directly related to installed capacity may indicate that the CU measure a better measure. This is case for CU1 for

Chart 2: Comparison to the Official Capacity Utilization Manufacturing



Note: Official capacity utilization is normalized to the average of CU1 and CU2 for manufacturing over 2000-2017.

the manufacturing sector as its correlations with growth in total investment and investment in M&E are significantly higher than for CU2. However, at the detailed industry level, we do not observe large differences between CU1 and CU2 as the correlations with output growth, employment growth, and investment growth are generally similar for CU1 and CU2.

In Table 5, we also include the correlations for official CU, which are only available for 22 goods producing industries. The correlation results are mixed for the CU measures. Despite a similar broad trend as shown in Chart 2, the correlations between our CU measures and the official CU is negative, especially for CU2. The correlation of capacity utilization with growth in output and employment/hours worked is higher for official CU than for CU1 or CU2. But, for the manufacturing sector, the correlations with growth in total investment and investment in M&E are significantly higher for CU1 than official CU or CU2.

Correlation is a simple indicator for possible relationship between two variables, without controlling for the effects from other factors. To validate our CU measures related to productivity estimation and the role in evaluation of policy instruments, we need to isolate the effects of other factors. To this end, in the remaining two sections, we conduct an econometric analysis.

Capacity Utilization and Measured Multifactor Productivity

In this section, we assess the role of controlling for capacity utilization in explaining variations of measured productivity. To this end, we compare the smoothness of measured productivity with and without controlling for capacity utilization. We use the mean square error to measure smoothness. The basic production regression model with capacity utilization is:

$$\ln(Y_{i,t}) = \alpha_0 + \alpha_L \ln L_{i,t} + \alpha_K \ln K_{i,t} + \alpha_M \ln M_{i,t} + \beta_1 \ln U_{i,t} + \sum_{j=2}^{s} \beta_j Z_{i,j,t} + \varepsilon_{i,t} \tag{14}$$

where $Y_{i,t}$ is gross output; $L_{i,t}$, $K_{i,t}$, and

Table 5: Industry-Year Correlation between Measured Capacity Utilization and Economic Performance Indicators, 2000-2017

Aggregate Manufacturing Sector

	CU1	CU2	OCU	VA	L	H	I	ME
CU Under Hypothesis 1 (CU1)	1.00							
CU Under Hypothesis 2 (CU2)	0.94	1.00						
Official CU (OCU)	-0.08	-0.24	1.00					
Value Added Growth (VA)	0.38	0.25	0.65	1.00				
Employment Growth (L)	0.17	0.09	0.63	0.89	1.00			
Hours Worked Growth (H)	0.30	0.21	0.62	0.91	0.98	1.00		
Total Investment Growth (I)	0.52	0.38	0.31	0.69	0.59	0.63	1.00	
M&E Investment Growth (ME)	0.44	0.36	0.37	0.60	0.55	0.59	0.93	1.00

Aggregate Business Sector

	CU1	CU2	VA	L	H	I	ME
CU Under Hypothesis 1 (CU1)	1.00						
CU Under Hypothesis 2 (CU2)	0.98	1.00					
Value Added Growth (VA)	0.49	0.44	1.00				
Employment Growth (L)	0.40	0.36	0.84	1.00			
Hours Worked Growth (H)	0.37	0.32	0.82	0.95	1.00		
Total Investment Growth (I)	0.52	0.53	0.70	0.65	0.68	1.00	
M&E Investment Growth (ME)	0.44	0.40	0.72	0.71	0.71	0.94	1.00

Goods and Service Industries (38 industries)

	CU1	CU2	VA	L	H	I	ME
CU Under Hypothesis 1 (CU1)	1.00						
CU Under Hypothesis 2 (CU2)	0.94	1.00					
Value Added Growth (VA)	0.13	0.10	1.00				
Employment Growth (L)	0.11	0.12	0.63	1.00			
Hours Worked Growth (H)	0.11	0.12	0.66	0.97	1.00		
Total Investment Growth (I)	0.08	0.10	0.22	0.22	0.22	1.00	
M&E Investment Growth (ME)	0.04	0.06	0.22	0.23	0.23	0.80	1.00

Non-Agriculture Goods Industries (22 industries)

	CU1	CU2	OCU	VA	L	H	I	ME
CU Under Hypothesis 1 (CU1)	1.00							
CU Under Hypothesis 2 (CU2)	0.94	1.00						
Official CU (OCU)	0.18	0.17	1.00					
Value Added Growth (VA)	0.15	0.12	0.40	1.00				
Employment Growth (L)	0.12	0.14	0.32	0.63	1.00			
Hours Worked Growth (H)	0.12	0.14	0.33	0.64	0.98	1.00		
Total Investment Growth (I)	0.10	0.14	0.20	0.06	0.10	0.11	1.00	
M&E Investment Growth (ME)	0.03	0.07	0.21	0.03	0.09	0.09	0.79	1.00

Note: There is no official capacity utilization estimates for service industries.
Source: Authors' own compilations based on Statistics Canada Table 16-10-0109-01 and the micro dataset for this study.

$M_{i,t}$ are the inputs representing labour, capital and intermediate inputs, respectively ; U_{it} is capacity utilization; Z_i is a set of control variables such as foreign ownership, firm age, and industry-year specifics; and $\varepsilon_{i,t}$ is an error term.

In the regression, we control for firm age as it takes time for new entrants young firms to learn their markets, establish supplier and distribution networks and develop scale. Thus, they are generally less efficient than established firms. To reflect this, we introduce a dummy for young firms, which takes 1 for firms being not more than 5 years and 0 otherwise. This is based on Liu and Tang (2017). They show that entrants take about 5 years to become as productive as incumbents.

We also control for foreign ownership as it is well established that foreign controlled firms in Canada are on average more productive than Canadian controlled firms in Canada. Finally, we introduce industry-year dummies to capture any effect at the industry level, including technological progress and changes in competition.

Estimation and Discussion

To ensure robust results, each regression model is estimated by two different methodologies. First, we assume robust standard error when ordinary least square estimation (OLS) is used. Robust standard error is a common and effective way to deal with heteroscedasticity, minor problems associated with the lack of normality, or some observations that exhibit large influence. Second, we estimate the model with firm fixed effects, which concerns only within-firm variation and ignores between-firm changes. The design aims to control for individual firm fixed effects. It also corrects potential miss-specifications of the regression model due to missing time-invariant variables, and addresses the endogeneity problem when a component of the productivity shock is fixed over time at the firm level. To ensure robust results, each regression model is estimated by two different methodologies.

Our sample contains many small firms. The data for small firms tend to be noisy. So we limit our estimation to firms with average number of employees being 10 or more.[11]

The regression results based on the whole sample for firms with average number of employees being 10 or more are reported in Table 6. In general, the results based on OLS assuming robust standard error and those with firm fixed effects are fairly similar. As expected, labour, capital, intermediate inputs, and foreign ownership are found to be positive and statistically significant while young firms are found to be less productive.

Important for this article are the estimates related to capacity utilization. For CU1, the coefficients are positive and sta-

11 The possibility that the effect of capacity utilization in economic downturns differs from that in normal times as production capacity is mostly underutilized. To capture this, we divide our sample into two groups: normal times and downturn times. The down times contains two economic downturns: the dotcom bust 2001-2002 and the Great Financial Crisis 2008-2009. The normal times is the rest years in our sample 2000, 2003-2007, and 2010-2017. However, the estimation results with the two sub-samples are fairly similar to those with the whole sample.

Table 6: The Estimation of the Production Function With and Without CU

	Robust standard error			Firm Fixed effects		
	Without CU	With CU1	With CU2	Without CU	With CU1	With CU2
Labour (in log)	0.249***	0.247***	0.241***	0.265***	0.250***	0.241***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Tangible Capital (in log)	0.049***	0.055***	0.042***	0.040***	0.112***	0.016***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Intermediate inputs (in log)	0.706***	0.701***	0.717***	0.605***	0.564***	0.644***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Foreign ownership dummy	0.100***	0.098***	0.095***	0.217***	0.213***	0.200***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Young firm dummy	-0.033***	-0.033***	-0.031***	-0.034***	-0.036***	-0.032***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Capacity utilization		0.034***	-0.071***		0.088***	-0.062***
		(0.000)	(0.000)		(0.000)	(0.000)
Industry-year dummies	Yes	Yes	Yes			
Year dummies				Yes	Yes	Yes
Firm-fixed effects				Yes	Yes	Yes
Number of observations	2978996	2978996	2978996	2978996	2978996	2978996
R-square	0.95	0.95	0.95			
R-square, within				0.85	0.86	0.85
R-square, between				0.94	0.94	0.94

Note: P-values are in parenthesis. "***" denotes significance at the 1% level.

tistically highly significant, indicating that firm production and capacity utilization are positively correlated, that is, higher capacity utilization means higher production. We also observe that with CU1, the relationship between output and capital stock becomes stronger. This suggests that after controlling for capacity utilization, output is more sensitive to capital stock. So, CU1 serves the purpose.

In contrast, the results on CU2 are surprising. First, the coefficient is negative. Second, after controlling for CU2, the relationship between output and capital (or labour) becomes weaker. Thus, after controlling for the effects of other factors, CU2 has a negative relationship with output, which cannot be explained in an economic sense. For those reasons, we reject hypothesis 2.

In the remaining of this paper, we continue to validate the importance of controlling for capacity utilization for CU1.

Productivity Dispersion Before and After Controlling for Capacity Utilization

Firms with lower capacity utilization are likely to be less productive when the measured productivity is estimated with all installed capacity. Controlling for capacity utilization reduce productivity dispersion and the productivity gap between frontier firms and laggards. In Table 6, we report the mean square error (MSE) of multifactor productivity (MFP) by industry, with or without controlling for capacity utilization (CU1).

According to Table 7, without controlling for capacity utilization, productivity dispersion varies significantly across indus-

Table 7: Mean Squared Error of Measured MFP With and Without Capacity Utilization

Industry	2000-2017			2001-2002, 2008-2009		
	Capacity U			Capacity U		
	No	Yes	A/B	No	Yes	C/D
	A	B		C	D	
Forestry and logging	1.08	1.00	1.07	1.12	1.06	1.05
Fishing, hunting and trapping	1.94	1.87	1.04	1.21	1.15	1.05
Support activities for agriculture and forestry	1.14	1.10	1.04	0.91	0.86	1.06
Crop and animal production	4.24	4.15	1.02	3.41	3.41	1.00
Oil and gas extraction	5.06	4.95	1.02	5.16	5.11	1.01
Mining and quarrying	2.52	2.52	1.00	2.10	1.91	1.10
Support activities for mining and oil and gas extraction	2.14	2.12	1.01	2.53	2.52	1.01
Utilities	4.03	3.94	1.02	4.71	4.89	0.96
Construction	1.22	1.16	1.05	1.24	1.19	1.04
Food	0.75	0.74	1.01	0.59	0.57	1.03
Beverage and tobacco	1.06	1.00	1.07	0.45	0.44	1.03
Textile and product mills	0.70	0.67	1.04	1.62	1.52	1.06
Clothing, leather and allied product	0.76	0.74	1.04	1.14	1.08	1.05
Wood product	0.49	0.48	1.02	0.54	0.54	1.00
Paper	0.35	0.33	1.04	0.09	0.09	1.00
Printing	0.63	0.62	1.01	0.54	0.56	0.96
Petroleum and coal	1.09	1.13	0.96	1.53	1.64	0.93
Chemical	1.04	1.02	1.02	0.53	0.52	1.01
Plastics and rubber	0.64	0.61	1.05	0.42	0.42	1.01
Non-metallic mineral	0.47	0.44	1.06	0.31	0.31	1.02
Primary metal	0.48	0.46	1.05	0.20	0.20	0.99
Fabricated metal	0.78	0.75	1.04	0.98	0.93	1.05
Machinery	1.01	0.97	1.03	1.04	1.02	1.01
Computer and electronics	1.28	1.21	1.06	1.45	1.39	1.04
Electrical equipment	0.82	0.77	1.06	0.44	0.45	0.98
Transportation equipment	1.43	1.34	1.07	0.35	0.34	1.01
Furniture	0.48	0.46	1.05	0.24	0.24	1.01
Miscellaneous manufacturing	0.66	0.65	1.02	0.74	0.73	1.02
Wholesale trade	1.00	0.96	1.04	0.93	0.92	1.02
Retail trade	0.51	0.48	1.05	0.43	0.41	1.04
Transportation and warehousing	0.92	0.90	1.02	0.91	0.90	1.00
Information and cultural industries	2.70	2.59	1.04	2.78	2.64	1.05
Finance, insurance, real estate, and company management	8.82	8.47	1.04	7.82	7.58	1.03
Professional, scientific and technical services	3.77	3.59	1.05	3.70	3.52	1.05
Administrative, waste management	3.06	2.94	1.04	2.96	2.85	1.04
Arts, entertainment and recreation	1.68	1.62	1.03	1.44	1.40	1.03
Accommodation and food services	0.58	0.55	1.06	0.62	0.60	1.03
Other services except public administration	1.18	1.14	1.04	1.19	1.14	1.04
Total	2.28	2.18	1.04	2.16	2.09	1.04

Source: Authors' own compilation based on results from columns (1) and (2) in Table 5 with robust standard error and under CU1 tries from 0.35 in the paper manufacturing industry to 8.82 in finance, insurance, real estate and company management. After, controlling for capacity utilization, the dispersion was significantly reduced, about 4 per cent on average. The reduction is mostly significant in forestry and logging, beverage and tobacco, and transportation equipment.

In Table 7, we also single out productivity dispersion in economic downturns 2001-2002 and 2008-2009. Interestingly, the productivity dispersion during downturns is very similar to average for the whole sample period. We also observe that the reduction in dispersion after controlling for capacity utilization in downturns is very similar to that for the whole sample period. Notably, the largest reduction during downturns is in mining and quarrying.

Capacity Utilization and the Economic Performance of Investments in R&D and ICTs

In this section, we use the micro database to demonstrate whether or not controlling capacity utilization is important in evaluating the economic impact of investments in R&D and ICTs. Our basic regression model is following:

$$\ln(Y_{i,t}) = \alpha_0 + \alpha_L \ln L_{i,t} + \alpha_K \ln K_{i,t} + \alpha_M \ln M_{i,t} + \beta_1 \ln U_{i,t} + \sum_{j=2}^{s} \beta_j Z_{i,j,t} + \varepsilon_{i,t}, \tag{15}$$

The regression model above extends regression model (14) by adding two variables: R&D intensity and ICT intensity, which are defined as the ratios of R&D stock to capital and ICT stock to capital, respectively. Basically, here we would like to see if firms with high R&D and ICT investments are doing better in productivity than firms with lower R&D and ICT investments.

The estimation results with or without controlling for capacity utilization (CU1) is reported in Table 8. The estimation shows that controlling for capacity utilization substantially improves the significance of ICT on firm performance. Under the OLS estimation, ICT being insignificant in the absence of capacity utilization becomes highly significant with the presence of the capacity utilization. Under the estimation with fixed effects, the estimated coefficient on ICT doubles after introducing the capacity utilization variable. The effect of R&D on firm performance is highly significant. However, the size of the effect is not influenced by the presence of capacity utilization. This may be because ICT investments are more related to installed capacity than R&D investments.

Conclusions

Firms invest production capacity to meet expected long-term demand. This is often a long process as design, equipment purchase, and installation take time. In other words, capacity cannot be changed in a short time. However, in reality, production in a particular year often deviates from expected, and thus the use of production capacity may not be at the capacity level. When actual demand is more than expected, firms may choose to use overtime

Table 8: The Estimation of the Production Function With and Without CU

	Robust standard error		Firm Fixed effects	
	Without CU	With CU1	Without CU	With CU1
Labour (in log)	0.248***	0.246***	0.266***	0.251***
	(0.000)	(0.000)	(0.000)	(0.000)
Tangible Capital (in log)	0.047***	0.054***	0.039***	0.112***
	(0.000)	(0.000)	(0.000)	(0.000)
Intermediate inputs (in log)	0.705***	0.700***	0.604***	0.562***
	(0.000)	(0.000)	(0.000)	(0.000)
Foreign ownership dummy	0.103***	0.101***	0.217***	0.213***
	(0.000)	(0.000)	(0.000)	(0.000)
Young firm dummy	-0.033***	-0.033***	-0.034***	-0.035***
	(0.000)	(0.000)	(0.000)	(0.000)
Capacity utilization		0.034***		0.090***
		(0.000)		(0.000)
R&D Intensity (in log)	0.009***	0.009***	0.003***	0.003***
	(0.000)	(0.000)	(0.000)	(0.000)
ICT intensity (in log)	-5.8e-5	1.9e-4***	0.002***	0.004***
	(0.316)	(0.001)	(0.000)	(0.000)
Industry-year dummies	Yes	Yes		
Year dummies			Yes	Yes
Firm-fixed effects			Yes	Yes
Number of observations	2978996	2978996	2978996	2978996
R-square	0.95	0.95		
R-square, within			0.85	0.86
R-square, between			0.94	0.94

Note: P-values are in parenthesis. "***" denotes significance at the 1% level.

and the use of capacity will be above the normal. Similarly, when demand is lower than expected or when necessary parts are in shortage due to disruptions of global value chains, say, caused by such as the current COVID-19 pandemic, production will be reduced, leading to under utilization of production capacity.

The issue is that productivity is often estimated under the assumption of full production capacity, that is, installed capacity is always used for whatever level of production. Given inputs are not actual used fractions, this leads to under- or overestimation of productivity. To produce a reliable productivity measures, we need to control for capacity utilization in estimating productivity. Unfortunately, capacity utilization is not available at the firm level. To bridge the data gap, this study developed a methodology in estimation capacity utilization at the firm level. The methodology is based on the theory of the firm in terms of profit-maximizing and price-taking. Unlike some proxies used in the literature, it is exogenous to productivity shocks. Importantly, it is fairly practical to estimate.

We tested two hypotheses, and showed that the hypothesis that labour and intermediate inputs are fully adjustable in the short term and capital cannot be adjusted in the short term is more appropriate. Controlling for capacity utilization based on the hypothesis increased the relationship between capital and output. It also reduced variation in measured productivity across firms, lessened the divergence in productivity between frontiers and laggards. Finally, we found that ICT investments that are insignificant in firm performance before controlling for capacity utilization became highly significant after controlling for capacity utilization.

With micro data being increasingly available, research using micro data to measure productivity or to evaluate policy programs has become increasingly common. The approach to analysis often relies on the estimation of a production function. This study showed that to produce a more reliable estimate, it is important to controlling for capacity utilization in estimation. It leads to more reliable productivity estimates or correct conclusion about the effect of some investments on firm performance, which has important implications for policy developments.

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Measuring Productivity: The Response of National Statistical Institutes to the OECD's Productivity and Capital Manuals

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Abstract

In 2001, the Organization for Economic Cooperation and Development issued its Productivity Manual, alongside its Capital Manual (the latter was updated in 2009). These Manuals set out a detailed guide for National Statistical Institutes (NSIs) on how to expand their national accounts to incorporate a production account using the KLEMS methodology. In many cases full acceptance of these proposals might well require changes to national accounts methodology, for instance the adoption of double deflation, and also a considerable statistical effort, such as incorporating data on wages and employment into the national accounts in a consistent way. This article summarizes the response of some leading NSIs to this challenge and assesses how far they have succeeded in meeting it.

In 2001, the Organization for Economic Cooperation and Development (OECD) issued its Productivity Manual whose full title is "Measuring Productivity – Productivity Manual: Measurement of Aggregate and Industry-Level Productivity Growth" (OECD, 2001).[2] In addition to much else, this contained a chapter devoted to the measurement of capital input. This chapter was later enlarged into a second manual devoted entirely to capital, now in its second edition: "Measuring Capital: OECD Manual 2009" (OECD, 2009). Though not credited on the title pages, the principle author of both manuals was Paul Schreyer. The two manuals will be considered together in what follows.

Given the nature of the OECD as an

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2 The Productivity Manual is summarized in Schreyer(2001).

organization, these manuals do not have the force of law. Their publication did not commit the member states to implementing the recommendations contained in them. So they have less force than the prescriptions of the System of National Accounts (SNA). And they have even less force than the rules laid down by Eurostat for implementing the System of National Accounts in the European Union, the European System of Accounts (Eurostat, 2013), which are legally binding on member states unless derogations are negotiated. Nonetheless the OECD's recommendations in the productivity area carry considerable weight since they were arrived at by a consensual process involving many experts, both from National Statistical Institutes (NSIs) and from academia, and are generally agreed to represent best practice. The purpose of this article is firstly to summarise and critically review the OECD's approach to productivity measurement and secondly to assess how much progress National Statistical Institutes have made in implementing the OECD's recommendations.

In the next section I first discuss the general framework adopted in the Manuals for productivity measurement which is frequently called the KLEMS approach. Here I summarize what seem to me to be the principle recommendations. Then in section 2 I sketch out the KLEMS approach in algebraic terms before turning in section 3 to what the OECD sees as the main measurement issues to be addressed before the framework can be implemented. Section 4 considers some limitations and omissions in the OECD approach. In section 5 I examine the response of selected National Statistical Institutes (NSIs) in their own productivity statistics. How close are they to fulfilling the "vision" of the Manuals? This entails examining first an NSI's own productivity handbook (where one exists) to check compatibility with the OECD's recommended methods and secondly seeing how closely its published productivity statistics conform to the OECD's standards. Section 6 concludes.

The OECD's Approach and Recommendations

The Productivity Manual sets out its objectives as follows:

"1.1. Objectives 1. The main objectives of this manual are to:

- Provide an accessible guide to productivity measurement for those involved in constructing and interpreting productivity measures, in particular statistical offices, other relevant government agencies and productivity researchers.
- Improve international harmonization: *although there is no strong prescriptive element in the manual*, it contains indications about desirable properties of productivity measures. Hence, when countries have a choice in constructing new measures or developing a system of indicators, the manual may provide guidance. [Emphasis added]
- Identify desirable characteristics of productivity measures by reference to a coherent framework that links economic theory and index number theory. Desirable properties have to be assessed against the reality of data availability or the costs of producing statistics. Broad trends can often be discerned with tools that do not live up to full theoretical standards as long as they are interpreted with the necessary

caution. However, the user has to be aware of simplifications that occur in the practice of productivity measurement."

These objectives are expanded on in the next subsection:

"2. The manual is focused in four ways:

- First, the manual focuses on measures of productivity growth rather than on the international comparison of productivity levels. Although there may be few conceptual differences between growth and level comparisons (the former compares different points in time, the latter different points in space), there are practical differences between the two. In particular, productivity level comparisons between industries have to address the tricky issue of currency conversion. . . . Productivity growth measurement avoids this question and constitutes a useful starting point, given its frequent use in analysis and policy formulation.

- Second, the manual focuses on the measurement of productivity at the industry level. This is a natural choice given that much of the underlying methodology relies on the theory of production and on the assumption that there are similar production activities across units of observation (firms or establishments). Because industries are defined as "a group of establishments engaged in the same, or similar, kinds of activity" (Commission of the European Communities, OECD, IMF, United Nations, World Bank, 1993, *System of National Accounts 1993*, paragraph 5.40 – SNA 93), the industry level is an appropriate level of analysis. At the same time, an important part of the manual is also devoted to issues of aggregation across industries and the link to economy-wide or sector-wide measures of productivity growth.

- Third, the manual does not cover productivity measures of production activities beyond the production boundary of the System of National Accounts, in particular households' production. Within the SNA production boundary, emphasis is given to productivity measures of those industries that are characterized by a large share of market producers, leaving aside those activities where non-market producers dominate in many OECD countries. These activities pose specific problems of productivity measurement, due to the difficulty or impossibility of observing and/or defining market prices or output. Reference will be made when appropriate but an in-depth treatment of the output measurement in each of these industries would go beyond the scope of the present manual.

- Fourth, the manual focuses on non-parametric methods of productivity measurement. This choice has been made because the manual's primary audience is statistical offices and other, regular producers of productivity series. Econometric methods, as opposed to non-parametric approaches to productivity measurement are a tool that is much more frequently used in the context of individual, academic research projects." I interpret these objectives as saying that productivity measures should be consistent with the SNA, which

3 The revised Capital Manual is consistent with the 2008 SNA where, for the first time, the concept of capital services was officially recognized; indeed the revision was undertaken in order achieve consistency with the new SNA.

at the time was the 1993 version[3], and should start at the industry level. There is no explicit recommendation as to the number of industries into which the economy should be broken down, though the implication is the more the better (provided quality can be maintained). Consistency with the SNA means that household production (unpaid cooking, cleaning, child-care, and house maintenance and repair undertaken by householders) will not be included since there is no household production industry, these activities being outside the production boundary. There is no such barrier to including the public sector, in particular health, education, social security, law enforcement and defence, since these activities form part of GDP even when done on a non-profit basis and when the outputs are not sold in the market, as is predominantly the case in OECD countries. But the Manual recognizes that international comparisons of productivity growth rates in the public sector are vitiated by the varying degree to which real output is measured appropriately; obviously, an "output equals inputs" approach which has been widespread in the past in the public sector and is still common today makes measured productivity growth meaningless (Atkinson, 2005).

The Productivity Manual also identified a number of "challenges for statisticians:

"17. From the perspective of productivity measurement, there are at least four areas with a specific need for further research and development of data and statistics:

- *Price indices for output measures* by industry, in particular for high-technology industries and difficult-to-measure but economically important services such as the financial sector, health care and education.
- Measurement of hours worked by industry, as labour is the single most important factor of production. Currently, there are many problems associated with the accurate measurement of hours worked, in particular when disaggregated by industry. Specific challenges in this context include successfully combining information from the two main statistical sources, enterprise and household surveys, and measuring labour input and compensation of self-employed persons. A cross-classification of hours worked by productivity-relevant characteristics of the workforce (education, experience, skills, etc.) would also be highly desirable.
- The quality of existing measures of capital input typically suffers from an insufficient empirical basis. For example, there are too few and often outdated empirical studies to determine the service lives of assets and their age-efficiency and age-price profile. More generally, capital measures for productivity analysis (capital services) should be set up consistently with capital measures for asset balance sheets (wealth stocks), and consumption of fixed capital in the national accounts.
- *Input-output tables* are sometimes missing or dated, and not always integrated with national accounts. The development of a consistent set of supply, use and industry-by-industry tables and their full integration with national accounts at current and constant prices is an important element in deriving reliable productivity measures."

Many of these issues still resonate today. A full evaluation of progress in these areas is beyond the scope of this paper.

The KLEMS methodology

The theoretical basis for the OECD's approach rests ultimately on the fundamental contribution of Solow (1957) who pioneered growth accounting by estimating labour-augmenting technical progress for the aggregate US economy. Labour-augmenting technical progress is closely related to the growth of total factor productivity (TFP) at it came to be called, also known as multifactor productivity (MFP). This growth accounting methodology was greatly enriched by Griliches and Jorgenson (1967). The crucial distinction between capital services and capital stocks is due to Jorgenson (1963) and its extension to incorporate tax considerations is due to Hall and Jorgenson (1967). The framework for building up aggregate productivity from productivity at the industry level is set out in Jorgenson *et al.*. (1987), following Domar (1961) and Hulten (1978), and extended in Jorgenson *et al.*. (2005), (2016) and (2018). The OECD's approach is also influenced by developments in index number theory due to Diewert (1976) and (1978). This approach is commonly known by the acronym KLEMS (capital, labour, energy, materials, and services) referring to the expanded list of inputs that are taken into account.

Since the KLEMS approach will be familiar to most readers I will summarize it briefly in algebraic terms. The formulation is in continuous time using Divisia indices since this not only simplifies the algebra but leads to important results holding exactly as opposed to only approximately. For each industry gross output is assumed to be determined by a production function with Hicks-neutral technical progress:

$$Y_j(t) = A_j(t) F\left(K_j(t), L_j(t), M_j(t)\right) \qquad j = 1, \ldots, N \tag{1}$$

Here Y is gross output, A is the level of TFP (or MFP), K is capital services, L is labour services and M is intermediate input, all considered to be functions of time (t). By totally differentiating with respect to time and assuming perfect competition, we derive the basic growth accounting equation for the jth industry:

$$\hat{Y}_j(t) = \hat{A}_j(t) + v_j^K \hat{K}_j(t) + v_j^L \hat{L}_j(t) + v_j^M \hat{M}_j(t) \tag{2}$$

Here a hat ($\hat{}$) denotes a logarithmic growth rate and the shares of each input in the value of gross output (v) are denoted by:

$$v_j^K = \frac{P_j^K K_j}{P_j Y_j} \qquad v_j^L = \frac{P_j^L L_j}{P_j Y_j} \qquad v_j^M = \frac{P_j^M M_j}{P_j Y_j} \tag{3}$$

Here P_j^K, P_j^L, P_j^M are the prices of (respectively) capital services, labour services and intermediate input to the jth industry and P_j is the price of gross output. Under the assumption of perfect competition these shares can be interpreted as the elasticity of output with respect to each input. From equation (2) we can calculate the growth of TFP in the jth industry as a residual, all other terms being in principle observable.

The basic accounting identity for each industry is that the value of output equals the value of inputs:

$$P_j Y_j = P_j^K K_j + P_j^L L_j + P_j^M M_j \tag{4}$$

Or, defining value added in nominal terms as output minus intermediate input:

$$P_j Y_j = P_j^V V_j + P_j^M M_j \tag{5}$$

where P_j^V is the price and V_j is the quantity of value added (real value added). From this accounting relationship we can derive a Divisia index of the growth of real value added:

$$\hat{V}_j = \frac{1}{v_j^V}\left[\hat{Y}_j - \left(1 - v_j^V\right)\hat{M}_j\right] \tag{6}$$

where v_j^V is the share of nominal value added in nominal gross output. Equation (6) is the definition of double-deflated real value added in continuous time. The price of value added P_j^V can now be derived as the implicit deflator: nominal value added divided by the quantity of value added.

Let us now simply define TFP growth in the *value added sense*, $\hat{A}_j^V$, as:[4]

$$\hat{A}_j^V = \hat{V}_j - v_j^{VK}\hat{K}_j - v_j^{VL}\hat{L}_j \tag{7}$$

where $v_j^V K$ and $v_j^V L$ are the shares of capital and labour in value added:

$$\begin{aligned} v_j^{VK} &= \frac{P_j^K K_j}{P_j^V V_j} \\ v_j^{VL} &= \frac{P_j^L L_j}{P_j^V V_j} \end{aligned} \tag{8}$$

The relationship between TFP growth in the gross output sense and TFP growth in the value added sense can then be seen to be:

$$\hat{A}_j^V = \frac{\hat{A}_j}{v_j^V} \tag{9}$$

So far we have been setting out the framework as if there were only a single capital input, a single labour input and a single intermediate input. But this is not necessary. Each of these inputs can be considered as an aggregate of as many types as we like (or can obtain data for). These aggregates can also be defined by Divisia indices:

$$\begin{aligned} \hat{K}_j &= \sum_{k=1}^{N_K} w_{jk}^K \hat{K}_{jk} \\ \hat{L}_j &= \sum_{l=1}^{N_L} w_{jl}^L \hat{L}_{jl} \\ \hat{M}_j &= \sum_{m=1}^{N_M} w_{jm}^M \hat{M}_{jm} \end{aligned} \tag{10}$$

Here K_{jk}, L_{jl}, and M_{jm} are the inputs respectively of the kth type of capital ($k = 1, \ldots, N_K$), the lth type of labour ($l = 1, \ldots, N_L$), and the mth type of in-

4 Alternatively, we could assume the existence of a value added function for each industry. But this requires some restrictive assumptions. However, even in the absence of such a function nothing stops us from calculating TFP growth in the value added sense from equation (7). The fundamental assumption of the KLEMS approach is the existence of the gross output production function for each industry, equation (2).

termediate input ($m = 1, \ldots, N_M$) into the jth industry. The shares of these inputs in respectively the total compensation of capital, of labour and of intermediate input in the jth industry are:

$$\begin{aligned} \hat{K}_j &= \sum_{k=1}^{N_K} w_{jk}^K \hat{K}_{jk} \\ \hat{L}_j &= \sum_{l=1}^{N_L} w_{jl}^L \hat{L}_{jl} \\ \hat{M}_j &= \sum_{m=1}^{N_M} w_{jm}^M \hat{M}_{jm} \end{aligned} \tag{11}$$

For the economy as a whole we can define the growth rates of aggregate capital services and aggregate labour services as:

$$\begin{aligned} \hat{K}_j &= \sum_{k=1}^{N_K} w_{jk}^K \hat{K}_{jk} \\ \hat{L}_j &= \sum_{l=1}^{N_L} w_{jl}^L \hat{L}_{jl} \\ \hat{M}_j &= \sum_{m=1}^{N_M} w_{jm}^M \hat{M}_{jm} \end{aligned} \tag{12}$$

Let V be aggregate real value added or real GDP, given by:

$$\hat{V} = \sum_{j=1}^{N} v_j \hat{V}_j \tag{13}$$

with the shares v_j of each industry in nominal GDP defined as:

$$v_j = \frac{P_j^V V_j}{\sum_{j=1}^{N} P_j^V V_j} \tag{14}$$

The aggregate TFP growth rate is defined as:

$$\hat{A} = \hat{V} - v^K \hat{K}_j - v^L \hat{L} \tag{15}$$

Here the aggregate capital and labour shares, the shares of capital and labour in the value of final output (nominal GDP), v^K , v^L are defined as:

$$\begin{aligned} v^K &= \frac{P^K K}{P^V V} \\ v^L &= \frac{P^L L}{P^V V} \end{aligned} \tag{16}$$

The aggregate TFP growth rate can be related to *the social production possibility frontier* of the economy. This shows the maximum feasible level of output of any single industry which can be produced given the outputs of all other industries and given the stocks of primary inputs and the level of technology. The latter concept can be written as:

$$G(V_1, \ldots, V_N, K, L, t) = 0 \tag{17}$$

Where time t indexes technology. It has been shown by Hulten (1978) (see also Gabaix, 2011: Appendix B), that the aggregate TFP growth rate of equation (15) can be interpreted as the rate at which the social production possibility frontier is shifting out over time, provided that perfect competition prevails.

What is the relationship between the industry-level TFP growth rates and the aggregate TFP growth rate? The answer is:

$$\hat{A} = \sum_{j=1}^{N} \left(\frac{P_j Y_j}{P^V V} \right) \hat{A}_j \qquad (18)$$

This result is known as Domar aggregation (Domar, 1961; Hulten, 1978), also as Hulten's Theorem. Note that the weights here typically exceed 1, so this is a weighted sum not a weighted average. In view of (9), equation (18) can written alternatively as:

$$\hat{A} = \sum_{j=1}^{N} \left(\frac{P_j^V V_j}{P^V V} \right) \hat{A}_j^V \qquad (19)$$

So aggregate TFP growth is also a weighted average of industry-level TFP growth rates in the value added sense.

Hulten's Theorem (as it is known in the modern macro literature) requires full efficiency; that is, not just perfect competition in all industries but also an absence of distortions in input markets. A given input must be paid the same price whichever industry it is employed in. For example, in the case of labour a given type must be paid the same wage in every industry: $P_{jl}^L = P_{rl}^L$ all j,r,l. If this is not the case then aggregate productivity can be improved by reallocating inputs towards industries where they earn a higher return. Formulas for these reallocation effects were developed in Jorgenson *et al.* (1987).

Real value added measured by double deflation was defined above, equation (6). Double deflation is significant for two reasons. First, the relationship between TFP growth in the gross output and value added senses, equation (9), only holds when real value added is measured by double deflation. Second, consistency in the national accounts requires double deflation. Consistency requires that the growth of aggregate real value added equals the growth of aggregate real final expenditure:

$$\sum_{j=1}^{N} v_j \hat{V}_j = \sum_{i=1}^{M} e_i \hat{E}_i \qquad (20)$$

Here there are M categories of final expenditure, E_j , with corresponding shares in nominal GDP, e_j.[5] Equation (20) is the counterpart in real terms of the basic national income accounting identity that output must equal expenditure (and income) in nominal terms.

The relationships sketched out here justify the Productivity Manual's stress on the following points (which it does not always justify in detail):

- Productivity accounts should be integrated into and be consistent with the national accounts.
- Supply and use tables should be employed to ensure consistency in the national accounts.
- Real value added should be measured by double deflation.

The OECD Manuals are intended to be practical guides so they do not for the most part employ Divisia indices. But the formulas above can be translated into discrete terms by using some superlative index. Törnqvist indices are one possibility and are used in the Manuals. They have been employed for example by the Bureau

5 For this to hold, both final expenditure and value added must be measured on a common price basis, e.g. at basic prices.

of Economic Analysis (BEA) in the US; See the BEA/BLS joint productivity Program discussed in Section 6. They have also been employed by the Office for National Statistics (ONS) in the United Kingdom in their own productivity publications even though neither the ONS nor the BEA use the Törnqvist in the rest of their national accounts. The Törnqvist is also used by the US Bureau of Labor Statistics (BLS) in its own productivity publications: see below, section 5.

Measurement Issues

Output and Intermediate input

The Productivity Manual devotes a chapter each to the measurement of output, labour input, capital input and intermediate input.

The Manual is committed to a gross output approach[6] to measuring productivity, since "gross output-based productivity measures capture disembodied technical change", though it also argues that "value-added-based-productivity is meaningful in its own right". Many users are interested in labour productivity, for which real value added per hour worked is the preferred measure.

This emphasizes the issue of how real value added should be measured. The Manual recommends that real value added should be estimated by double deflation. But the Manual also adds that there may be a problem if Laspeyres quantity indices are employed for inputs and outputs, since there is then the possibility of negative real value added. This problem also arises for Fisher indices since a Fisher index is the geometric mean of a Paasche and a Laspeyres index. It does not arise for a Törnqvist index.[7] Double deflation requires an input-output approach, or, more precisely a supply-use table. These are commonly used for balancing the national accounts in nominal terms. But for double deflation they need to be balanced in real terms too. The Manual does not go into detail on how to do this. Subsequently, there has been much work on this in the world of official statistics, culminating in a new UN manual on supply, use and input-output tables (United Nations, 2018, see particularly Chapter 9).

There are issues here that are yet to be fully explored. Having started with consistency in the supply use tables in nominal terms, there is then the problem of maintaining consistency when the tables are revalued in real terms. This issue arises because the prices appropriate for deflating industry outputs, e.g. producer price

6 To avoid double counting, gross output at the industry level should exclude sales and purchases within the industry itself. The empirical importance of this point depends on how finely the industry is defined. The data necessary to make this adjustment should be available from the input-output tables. For a recent discussion, see Eldridge and Powers (2023): note that their term for gross output after the exclusion of intra-industry sales is "sectoral output".This adjustment is certainly made in US and Canadian productivity accounts. It is not clear which other NSIs also make it.

7 The Törnqvist index of real value added is defined as the difference between a weighted average of the growth rates of the outputs and a weighted average of the growth rates of the inputs. So it can never generate a negative *level* of real value added, provided that the level of nominal value added in the reference year is positive (a condition always fulfilled in practice with industry data.)

indices (PPIs), may not be consistent with the prices appropriate for deflating expenditures, e.g. consumer price indices. This is quite apart from the fact that CPI prices are inclusive of imports, transport and trade margins, and taxes on products less subsidies, while producer prices are not. A simple way to do double deflation is to start with a supply use table which is balanced in nominal terms and then deflate each industry's gross output by its own PPI (or the equivalent for service industries). For each industry, intermediate purchases from each of the other domestic industries can then be deflated by the latter's own PPI (adjusted to a purchasers' price basis). Imported inputs can be deflated by the appropriate import price. (Note that the supply use table has to be expanded from its standard form so that for each industry domestically-supplied inputs are distinguished from imported ones). This method will produce a supply use table which is balanced in real as well as in nominal terms.

The problem with this method is that the resulting estimates of real GDP may differ from those hitherto accepted, even in the absence of any changes in the underlying data or in other methodology. Most countries which have not adopted double deflation base their annual estimates of real GDP on the expenditure side. [8] This is because expenditure-side price indices such as the components of the CPI are considered more reliable than the corresponding PPIs. After all, NSIs make considerable efforts to ensure that the basket of goods and services in their CPI is up to date and to adjust for quality change (even if there is still scope for improvement).

Much less effort goes into the PPI and service industries prices programs. PPIs are widely believed to understate quality change even though in areas like ICT some countries have made large improvements.[9] The actual procedures used by NSIs to implement double deflation unfortunately remain somewhat opaque. In the United Kingdom case there is the following statement: "This balancing process [i.e. in real terms] draws heavily on the quality of the deflators used. Broadly speaking, this results in more emphasis given to the expenditure approach for balanced years – that is, the years for which the SUTs have been compiled. This is because it allows the volume estimates to draw more heavily upon the higher-quality Consumer Prices Index (CPI) deflators used within the expenditure approach." (Office for National Statistics 2022b, section2).

Labour Input

On labour input, the Manual states: "The quantity of labour input in production is best measured by hours worked

8 Prior to adopting double deflation in its 2021 national accounts, the United Kingdom estimated real GDP from the output side by assuming that the growth of real value added in each industry could be proxied by the growth of real gross output in that industry. This generated a discrepancy with the expenditure-side estimates of annual growth in real GDP which were believed superior. The discrepancy was eliminated (at first totally and then within a small margin) by adjusting the growth rate of private services industries (e.g. banking and business services) but leaving the growth rates in the public and production sectors unchanged (Lee, 2011).

9 These issues are discussed in more depth in Oulton *et al.*(2018). They suggest a method of implementing double deflation which is consistent with previous expenditure-side estimates of real GDP.

and its price by average compensation per hour". It notes that labour input includes the self-employed. Therefore part of the latter's income, called "mixed income" in the national accounts, must be allocated to labour. Finally, the labour chapter recommends disaggregating labour into skill types. In practice carrying out this recommendation entails integrating statistics on wages and labour into the national accounts, a non-trivial undertaking.

It is often useful to distinguish between labour input in the crude sense of hours worked and hours worked after adjustment for the age-sex-skill mix of the labour force. So labour input can be thought of as hours worked multiplied by an index of labour quality or, more neutrally, of labour composition.

Capital Input

The Capital Manual sets out the now familiar distinction between capital *services* and capital *stocks*. Capital stocks are to be estimated using the Perpetual Inventory Method (PIM), i.e. by cumulating flows of gross investment with allowance for *decay*, the decline in the ability of an asset to produce services as it ages, and retirement. The decay rate may vary with an asset's age but does not vary with the date of installation: i.e. the rate at which a 5-year-old asset of a given type decays this year is the same as the rate at which a 5-year-old asset of the same type 10 years ago was decaying then. Hence for each asset type there is an age-efficiency profile. Distinct in principle from the age-efficiency profile is the age-*price* profile which shows how, at a point in time, the price of an asset varies with its age. If the efficiency of an asset declines geometrically then it turns out that the second-hand price declines at the same geometric rate, i.e. the depreciation rate equals the decay rate. In constructing aggregate capital services the flow of services is assumed proportional to the stock of each type and the different types of services are to be aggregated using user costs as weights; for aggregating capital stocks asset prices are to be employed.

User costs are conceptually identical to what were called the prices of capital services in the previous section. Here I give a brief outline of user costs since the Capital Manual, though very comprehensive, makes quite difficulty reading in places.

The user cost of capital in year t, i.e. the cost of holding a new example of an asset of a particular type for (say) one year, can be thought of as the interest cost plus the capital loss (or minus the capital gain) from holding it for one year:

$$P_t^K = r_t P_{t,0}^A + \left(P_{t,0}^A - P_{t+1,1}^A \right) \qquad (21)$$

Here r_t is the interest rate or required rate of return in year t. The capital loss (gain) term captures the change in value from all sources: inflation, wear and tear, and obsolescence. This is now a *discrete* formulation so I have added a time subscript to the user cost P_t^K (asset type and industry subscripts have been omitted for clarity). The asset price in year t of this type of capital when new is $P_{t,0}^A$; here there is a double subscript, the first to indicate the year (t) and the second to indicate the asset's age (0 in this case). (The user cost is also affected by tax *considerations* but is ignored here.) The user cost can be expressed in a more economically meaningful way. Define the rate of depreciation in the "cross-section" sense as δ so that:

$$P_{t,1}^{A} = (1-\delta) P_{t,0}^{A} \quad (22)$$

And let asset price inflation, i.e. the growth in the price of a new asset, be defined as:

$$\pi_t \equiv \frac{P_{t+1,0}^{A} - P_{t,0}^{A}}{P_{t,0}^{A}} \quad (23)$$

Then after a bit of manipulation the user cost of capital becomes:

$$P_t^K = \left[r_t + \delta \left(1+\pi_t\right) - \pi_t \right] P_{t,0}^{A} \quad (24)$$

The second term in square brackets, $\delta \left(1+\pi_t\right)$, captures depreciation in the "cross-section" sense. The third term, π_t , captures inflation (or deflation). In my view, this should be interpreted as the expected rate of inflation since investment decisions are necessarily forward-looking and made without full knowledge of the future.

The Capital Manual recommends that capital stocks and capital services should be estimated in a consistent way. This means for instance that the types of capital recognized in the SNA should also be included in productivity statistics. And the assumptions used about decay in measuring capital services should be consistent with those used to estimate depreciation in capital stocks and capital consumption in the national accounts. It is also clear that asset prices should be adjusted for quality.

The second edition of the Capital Manual goes further than the first edition in recommending the use of geometric patterns for depreciation. Apart from simplicity and convenience, the main justification is that what is needed is the depreciation rate for a *cohort* of assets of a given type, not just for a single example. So even in the case of the legendary "one-hoss-shay"[10], the depreciation rate for a *cohort* of one-hoss-shays may be geometric if they disintegrate after a lifetime of random length. Hence the geometric assumption may be a good approximation empirically.

There is an extensive discussion of how to estimate the required rate of return r. Under the endogenous approach, given the depreciation rates and data on asset prices, one solves for r using the condition that total returns to capital must add up to Gross Operating Surplus (including the capital part of mixed income). Under the exogenous approach financial data are used to select some market interest rate. The endogenous approach has the advantage that, by definition, total returns to all types of capital must add up to Gross Operating Surplus. This then makes Gross Operating Surplus exactly analogous in the national accounts to labour compensation which is the total of payments to all types of labour. On the whole the Manual favours the endogenous approach, though it notes that there must be no missing types of capital. This condition may be hard to satisfy in

10 Namely a capital asset that delivers the same flow of services throughout its lifetime before failing with zero scrap value. The subject of a poem by Oliver Wendell Holmes Sr.

practice since land, inventories, and environmental assets (important in some industries) are often excluded.[11]

The Capital Manual recommends the use of something similar to equation (24) for the user cost of capital, partly because it is consistent with the practice of NSIs in estimating wealth stocks in the national accounts. But it expresses some doubts about the third term in the formula, expected inflation. One reason is that if actual inflation is used to estimate expected inflation then in turbulent periods user costs can become negative which makes no sense economically.

The Capital Manual recognizes that the user cost formula should take account of taxes and subsidies affecting the profitability of investment, along the lines of Hall and Jorgenson (1967), but is reluctant to make this a formal recommendation because of the considerable effort involved in doing so. It relies on empirical studies suggesting that the effect of including taxes and subsidies on the magnitude of user costs is fairly small.

Limitations and omissions in the OECD approach

The OECD manuals do a good job of pointing out their own limitations and omissions (see above). But the following six points should perhaps be noted in addition:

First, the Manuals have very little discussion of comparing productivity levels across countries, whether at the whole economy or the industry level. As they point out, all international comparisons at the industry level require industry-level currency conversion factors. The fundamental (and well-known) difficulty here is that the International Comparison Program (ICP) constructs Purchasing Power Parities (PPPs) from the expenditure side of the national accounts. So the bulk of these are consumer prices; these are inclusive of taxes on products less subsidies (sales taxes and non-refundable VAT), and transport and wholesale and retail margins, and they include the prices of imported goods and services alongside those of domestic industries. Also they only cover intermediate inputs insofar as these also form part of final expenditure.

Efforts have been made by researchers to overcome these difficulties by utilizing the input-output tables to estimate industry-level basic prices from PPPs (e.g. Inklaar and Timmer *et al.*, 2007). The EU KLEMS project drew on this approach (O'Mahony and Timmer, 2009). But I am not aware of any work by NSIs in this area. The main use made by NSIs of PPPs is for international comparisons of living standards at the whole economy level, e.g. GDP per capita or household consumption per capita. But if one is interested in understanding why one country's productivity level is lower than another's, then knowledge of growth rates in both countries is

11 Some would argue that they are important in all industries. This may well be true from a welfare point of view. But the point here is that only natural assets which are owned by some economic agent influence investment decisions. Improvement or deterioration in environmental assets can still influence TFP; e.g. excessive heat may reduce TFP by requiring more expenditure on air conditioning.

not enough: levels are needed too.

Second, the manuals do not discuss productivity at the sub-national or regional level, a subject of increasing interest today. The basic KLEMS approach could in principle be applied just as well to regions or even cities as to whole countries. The main difficulties would be empirical: disaggregating national data on industry-level outputs and inputs to the regional level and constructing regional level input-output tables (though Canada has already done this). Finding appropriate industry-level prices for each region would be challenging too.

Third, labour input, which is supposed to be hours actually worked, may in practice be measured differently in different countries, one of the "challenges for statisticians" noted above in the Productivity Manual. This has been confirmed by later work. OECD research has found that if hours worked were calculated in a different but more comparable way across countries, then Britain's labour productivity gap in the market sector with the United States would be reduced from 24 per cent to 16 percent (OECD, 2018 and ONS, 2019a). This does not necessarily mean that the true gap is 16 per cent, only that there is a large margin of uncertainty.

Fourth, depreciation is considered independent of expenditure on maintenance and repairs; the latter are counted as intermediate consumption in the SNA.[12] But at least for some types of depreciation this is unrealistic. The decline in market value of a car (or of a building) as it ages can surely be reduced to some extent by spending more on maintenance and repairs. In fact, there is an economic calculation to be made here about the optimal level of maintenance expenditure (Feldstein and Rothschild, 1974). (Of course maintenance and repairs can do nothing to offset loss of value due to obsolescence).

Fifth, the manuals are founded on the assumption of perfect competition. Traditionally, this has been defended as quite appropriate for long run analysis. But nowadays productivity statistics are often quarterly and productivity analysis is applied over business cycle frequencies. And most macroeconomists now work within an imperfect competition framework. A great deal of empirical work (summarized in Basu, (2019)) is devoted to estimating the size of margins and whether they have been increasing or not. Hall (1988) was one of the first to consider the implications of imperfect competition for the measurement of productivity. One response is just to say that we should be using cost share weights rather than revenue weights in measuring the contribution of each input, i.e. we should subtract an estimate of monopoly profit from Gross Operating Surplus. This would reduce the relative weight attached to capital inputs while increasing that of labour inputs. But this is not enough in my view. If we take imperfect competition seriously, we should be looking for the cause of non-zero margins, e.g. increasing returns or proprietary knowledge.

12 However. major repairs and renovations that extend the life of an asset are treated as capital formation and their value is added to the value of the asset before the work was undertaken (2008 SNA 20.61).

Sixth, related to the previous point, in the presence of imperfect competition, some firms may be able to charge higher prices than their competitors in the same industry. This could be interpreted as these firms having higher productivity. If so, then a shift in resources to the high price firms is an additional source of aggregate productivity gains. But this source is not accounted for in the KLEMS framework. Also, if prices are not equal to marginal costs, then there is an additional distortion from the point of view of purchasing industries, again not accounted for in the KLEMS framework.

Response of Selected NSIs and Other Organizations

In this section I look at how some selected NSIs and international organizations have responded to the OECD's manuals.

OECD

As well as producing the manuals the OECD also publishes productivity statistics. While their MFP measures are limited to the total economy, they cover a large number of countries (24 member states), they are timely (currently up to 2022), and they go back to 1985. Labour productivity series are also available at the industry level. [13]

Canada

Actually, Canada did not need to "respond" to the OECD manuals since it was already producing MFP statistics when the manuals first appeared. Canada's MFP statistics were in response to the same intellectual influences which also lay behind the manuals (section 3). After focusing initially on labour statistics the Canadian program was refocused on MFP in the mid-1980s. A comprehensive account of Canada's productivity statistics is the User Guide (Baldwin *et al.*, 2007).[14]

Statistics Canada publishes MFP at the industry-level, for the business sector and also for major sectors within the business sector. Törnqvist indices are used to estimate MFP from data on output and inputs. To quote the User Guide: "Statistics Canada's MFP programs provide data on chained-Fisher quantity indices and nominal values of output and intermediate inputs for the individual industries of the business sector. Output is valued at basic prices, while intermediate inputs are valued at purchaser prices. The output of the total business sector is measured as value-added, while the output at the industry level is measured as GDP (or value-added), sectoral output and gross output. The main source data for estimating output and intermediate inputs for the MFP programs are the annual input–output tables of Statistics Canada. The construction of output and intermediate inputs involves the aggregation of a large number of commodity outputs and intermediate inputs. For all of our aggregations, we use annually chained-Fisher indices." (page 18).

Real value added is measured by dou-

13 The relevant website is https://www.oecd.org/sdd/productivity-stats/.

14 See Baldwin and Gu (2013) for some updates on official Canadian methodology.

ble deflation using the input-output tables, but the User Guide does not state whether or how consistency is achieved between the expenditure and output measures of real GDP.

Capital: "The asset detail for capital services estimates in the MFP programs consists of 15 types of equipment, and 13 types of structures, and land and inventories for a total of 30 types of assets." (page 24). Note the inclusion of land and inventories. User costs employ endogenous rates of return, varying across industries. Negative user costs are eliminated by setting them equal to the average user cost across all industries and then adjusting for inter-industry differences in the user cost (page 25). Geometric depreciation is assumed (Table 9, page 42). Apart from land, no environmental assets are included. At that time, R&D, other intangible capital, and infrastructure capital are not included amongst assets. Since then the assets added by the 2008 SNA — R&D, software, and exploration — have been included (Baldwin and Gu, 2013).

Labour: labour composition includes age (7 groups), education (4 levels) and employment type (employee or self employed) but not industry or sex. Industry is excluded since unlike capital it does not change the measure very much. Sex is excluded since it is argued to reflect "workplace discrimination" rather than productivity (page 26).

The latest (18th April 2023) labour productivity and MFP estimates are for 41 industries in the business sector from 1961 to 2019.

United States

At the time that the Productivity Manual was published in 2001, the US productivity statistics were not fully consistent with the national accounts. One agency, the Bureau of Labor Statistics (BLS), produced the productivity statistics while another, the Bureau of Economic Analysis (BEA), produced the national accounts, including estimates of fixed asset stocks. As an example of inconsistency, the BLS assumed that decay was hyperbolic in its estimates of capital input while the BEA assumed depreciation was geometric for its estimates of asset stocks (Fraumeni, 1997).

This situation has now completely changed with the development of the BEA-BLS industry-level production account. The KLEMS methodology used and the data itself draw on many years of work by Jorgenson with his various collaborators, e.g. Jorgenson *et al.* (1987), (2005), (2016) and (2018). The data in this new production account include annual gross output, value added, intermediate input, capital input, labour input (all in both nominal and real terms), and MFP for 63 industries, classified by NAICS, covering the whole economy (including federal, state and local government). The period covered is currently 1987-2020.[15] Nominal value added in these 63 industries adds up to nominal GDP.

Real value added is double deflated,

15 Extending the data back to 1947 is possible. At the moment however that cannot be done on a fully consistent basis. In addition, the quality of the estimates for years prior to 1987 is lower (Eldridge *et al.*, 2020).

though unfortunately not much detail seems to be available on how this is done in practice. The growth of real labour input is the share-weighted growth of hours worked for approximately 170 different groups of workers cross-classified by sex, eight age groups, six education groups, and employment class (payrolled vs. self-employed). Nominal labour input is compensation of employees. The growth of capital input is the share-weighted growth rate of capital services based on about 100 types of capital including inventories and land. Nominal capital input is gross operating surplus plus the portion of mixed income assigned to capital. A full description of the BEA-BLS-industry-level production account is in Garner *et al.* (2020) and (2021). Further detail on methodology is available from Garner *et al.* (2018).[16]

Despite the considerable level of detail at which the estimates are constructed, the published data for the inputs are quite a bit more aggregated. Thus at the industry level, nominal compensation and real quantities for only two types of labour are published: college and non-college. Nominal compensation and real quantities for only 5 types of capital are published: Entertainment, Literary, and Artistic Originals; Research and Development; IT ; Other capital and Software.

Nominal expenditures on and quantities of three types of intermediate input are published: energy, materials and services.

For capital, more detail is available on an "experimental" basis. Capital is now disaggregated into 9 types: Communications equipment; Computer hardware ; Research and Development ; Software; Entertainment, Literary, and Artistic Originals; Instruments and other office equipment; Structures, land, and inventories; Transportation equipment; Other equipment.

The "IT" category has been disaggregated into two sub-categories (communications equipment and computer hardware), and the "other capital" category into four (instruments and other office equipment, structures, land and inventories, transportation equipment, and other equipment).

United Kingdom[17]

Labour Productivity

The Office for National Statistics (ONS) publishes data on labour productivity (output per hour worked) on an annual and quarterly basis for both the whole economy and for individual industries, using the 2007 Standard Industrial Classification (SIC);[18] the methodology is set out in ONS (2023). It also publishes data for the market sector. The market sector is defined by the institutional type of the establishments within it, not by the industry. So the mar-

16 The data for 1987-2020 can be downloaded from the BEA website (www.bea.gov) in the form of a spreadsheet named "BEA-BLS-industry-level-production-account-1987-2020.xlsx", available at https://www.bea.gov/data/special-topics/integrated-industry-level-production-account-klems. This spreadsheet was released on May 11 2022 and comprises the latest data available at the time this paper was begun.

17 An account of the current state of play in UK productivity measurement is Oulton (2020).

18 SIC 2007 corresponds exactly down to the 4 digit level to the EU classification system, NACE. The US and Canadian NAICS is somewhat different.

ket sector excludes establishments classified to the public sector or as Non-Profit Institutions Serving Households (NPISH). A drawback is that private researchers do not generally have access to establishment-level data so that it is impossible for them to replicate the ONS's series. Presumably this is one reason why the EU KLEMS project defined its "business sector" on an industry basis, by excluding industries which are predominantly (though not wholly) made up of public sector or NPISH establishments.

The whole economy annual labour productivity (output per hour worked) series goes back to 1971, on a chained volume basis, i.e. using a chained Laspeyres index. The ONS also publishes output per job (by industry) and output per worker (for whole economy and market sector only).

The disaggregated quarterly labour productivity data generally go back no further than 1997Q1. For all except the most recent quarters real value added since 1997 is double deflated, after an annual supply use table has been balanced in both nominal and real terms, i.e. at both current and previous year's prices.

The labour productivity series are available for 17 industries including public services (sections O-Q of the 2007 SIC combined) and real estate; the latter excludes the imputed rental of owner-occupied housing. The following aggregates are distinguished: whole economy (sections A-U of SIC 2007), production (B-E)[19], manufacturing (C) and services (G-U); Also, 10 Divisions within manufacturing and 11 within services. In addition, output per hour is available separately for 25 "bespoke" groups of Divisions; these Divisions, 98 in number, comprise the whole economy.

MFP

The ONS began publishing multifactor productivity (MFP) estimates in 2007,[20] characterized from then till now as "experimental", i.e. they do not meet the quality standards required for them to be classified as "national statistics", unlike the labour productivity estimates discussed above. There is no indication of what is required for them to be upgraded to "national statistics". But as the real value added and hours worked are the same for both MFP and labour productivity, presumably any problems are thought to lie in the capital and labour quality measures.

The ONS methodology broadly follows that of the OECD manuals, with an important exception noted below, and is set out in ONS (2007), summarized in ONS (2016). For MFP, ONS (2020a) provides an overview while for more detail on capital input see ONS (2019b) and (2020c), and for more detail on labour input (labour qual-

19 i.e. mining, construction and manufacturing

20 Prior to then the Bank of England Industry Dataset appeared in 2005. This produced KLEMS estimates for 34 industries covering the whole economy, of which 31 were in the market sector, over the period 1970-2000. Special attention was paid here to the role of ICT capital; US price indices instead of UK ones were used as deflators. See Oulton and Srinivasan (2005) for a full description. This dataset was superseded by the UK part of the EU KLEMS project (see below).

21 What was previously known as Quality-Adjusted Labour Input (QALI) has now (since November 2023) been rebranded as Compositionally Adjusted Labour Input (CALI). However, the methodology is the same.

Table 1: Asset Types Included in the UK Volume Index of Capital Services

1	Buildings other than dwellings
2	Other structures (e.g. chemical works, motorways)
3	Land improvements
4	Transport equipment
5	ICT equipment (excluding telecoms)
6	Telecoms equipment
7	Other machinery and equipment
8	Cultivated biological resources (e.g. cows)
9	Research and development
10	Mineral exploration and evaluation
11	Computer software and databases (Own-Account)
12	Computer software and databases (Purchased)
13	Entertainment, literary or artistic originals

Source: Source: ONS (2019c).

ity)[21] see ONS (2021).

The latest data release at the time of writing is in ONS (2022d). It gives value added, capital services, labour hours, labour composition (quality), labour share, and MFP of 16 industries plus the market sector as a whole; the annual data cover 1970-2020 and the quarterly data cover 1994Q1 to 2021Q2. The 16 industries are sections of the 2007 SIC and cover the whole economy but with non-market sector components (including the whole of sections O, P and Q) removed, so the total aggregates to the market sector. Gross output and intermediate input are not published though real value added is double deflated. Note that the MFP series employ the value added concept (equation (7). It is not possible to derive the gross output concept of MFP since neither nominal value added nor nominal gross output are published.[22] Market sector MFP growth is calculated as a Törnqvist index of the industry MFP rates.

Table 1 provides a list of the asset types that are currently distinguished in what the ONS calls the Volume Index of Capital Services (VICS).

Note that dwellings are excluded. The output of dwellings in national accounts terms is measured from the income side as the imputed rental on owner-occupied housing plus ordinary commercial rents. The latter accrues to the real estate sector while the former is part of the income of households. The difficulty lies with the imputed rental element since there is no industry corresponding to this. The activities of households in maintaining and managing their own properties are outside the production boundary of the national accounts. In other words the value of their labour in these activities is excluded from GDP and their expenditure on home improvement products and the like is counted as final not intermediate consumption. So though there is a case for including dwellings when measuring whole economy productivity, there is no industry in the industrial classification which corresponds to this stream of output and no corresponding measured labour input. So exclusion of

22 Though it may be possible to derive MFP on a gross output basis using equation (9) and employing data on nominal gross output and nominal value added from the supply use tables.

dwellings is quite appropriate for measuring MFP in the market sector.

However, what is less defensible is the exclusion of land and inventories from the UK VICS, contrary to the recommendations of the manuals. Also, the level of detail (the number of asset types and labour types) is considerably lower than in the United States or Canada. Note too that the assumptions underlying the VICS are not currently consistent with those underlying the assets included in the balance sheet estimates which form part of the national accounts.

Public Sector

As we have just seen, the ONS publishes a labour productivity series for the public sector. It also producers a separate publication on "Public Sector Productivity" (ONS, 2022a). The methodological basis is different from that of labour productivity. Public sector output is measured by gross output, not value added. Productivity is measured by the output index divided by the input index. Inputs here include labour, capital and intermediate index. So "productivity" here means MFP (or TFP). Real output is measured mostly by a cost-share-weighted index of activities, with allowance for quality change where possible.

In 2019, 41 per cent of output was measured using the "output = inputs" convention while 59 per cent is measured directly, i.e. by activities. The whole of police and defence output and large parts of local and central government are measured by inputs. In addition to this, quality adjustment is applied to some output estimates. In health this includes a host of indicators such as survival rates after some operations and waiting lists. In education, output is measured by the numbers of pupils passing through the various stages (primary, secondary, etc); quality adjustment is measured by attainment at the various stages (exam grades). The ONS adopted this approach to measuring public sector output following the influential Atkinson Review (Atkinson, 2005); there was earlier work in Sweden along similar lines. This approach only applies in full to the separately published public sector productivity estimates. In the national accounts, including the labour productivity statistics, there is a much more limited use of output measurement due to the need (until the United Kingdom exited from the EU) to conform to Eurostat rules imposing harmonization in GDP statistics across EU member states.[23]

Capital inputs are weighted together just by capital consumption with no allowance for the cost of capital (i.e. the rate of return on capital plus capital gains or losses). So only part of the private sector user cost of capital is included here. This reflects the treatment of public sector capital in the national accounts where only capital consumption is included. That is to say, value added in the public sector is defined under the 2008 SNA as payments to labour plus net taxes on production plus capital consumption, not profit.

23 Contribution by each member state to the EU budget is determined by its Gross Domestic Income. This still has some relevance to the UK even after Brexit because of continuing financial obligations under the withdrawal agreement.

The EU KLEMS Project

Much the most ambitious project to date designed to implement the KLEMS methodology, in the spirit of the OECD manuals, was the EU KLEMS project. This was led by two independent research organizations, the National Institute for Economic and Social Research in the United Kingdom and Groningen University in the Netherlands, working originally with a consortium of 24 research institutes and NSIs. It was funded by the European Commission's 6th Framework Program and ran from 2003 to 2008; the last of several later, smaller-scale updates to the original project appeared in October 2012.[24] It is discussed here because of its unique, semi-official character.

The consortium members provided detailed data, some of it unpublished, particularly on labour and gross fixed capital formation. The project published two datasets: first, a conventional one which reproduced each country's official series (as they stood at that time) and second a larger, analytical dataset which was as far as possible "harmonized" across countries. In the latter a common set of assumptions about depreciation and asset lives was employed. Depreciation rates were assumed to be geometric and constant over time, varying across asset types but not across countries. The rate of return was estimated endogenously, so varying across, countries, industries and time. The prices of ICT assets were made consistent across countries following the method suggested by Schreyer (2002), so they fell much more rapidly than in the typical country's own official series.[25]

Subsequent follow-up projects have carried the terminal date up to 2020[26]. The latest version also incorporates a much wider list of intangible assets following the lead of Corrado, Hulten and Sichel (2005) and (2009); for details consult Bontadini *et al.* (2023). These additional intangibles are not counted as investment in the 2008 SNA though that may change in future versions of the SNA. 27 EU countries plus the UK (now no longer an EU member state of course), the US and Japan are now covered. On the downside, the degree of disaggregation is now down to 55 industries. This latest version contains a statistical module which is compatible with Eurostat's official statistics. These accounts are published separately from the extended analytical module which includes non-national accounts intangibles. Note too that this latest version of the data now starts in 1995 and there has been no attempt to reconcile the earlier data for 1979-2007 with the more recent data for the period in which

24 The author was involved in this project but was not one of its leaders.

25 A full description of the resulting dataset is in O'Mahony and Timmer (2009); see also the project website https://www.rug.nl/ggdc/productivity/eu-klems/ where the data and more detailed explanations will be found. The analytical dataset covers 25 EU member states, plus Japan, the US and Australia. Data coverage began in 1970 (later for the former communist countries who had by then joined the EU) and in the original project concluded in what turned out to be a turning point for Western economies, 2007. The March 2011 update, also spanning 1970 to 2007, achieved a high level of disaggregation: 72 industries under ISIC Rev. 3. The last update, March 2012, switched to ISIC Rev. 4 and the data period was 1970-2011, but now for only 12 countries and 34 industries.

26 See the EUKLEMS website, https://www.rug.nl/ggdc/productivity/eu-klems

the two versions overlap.

In my view the original EU KLEMS project did everything which it set out to do and has been widely used by the research community. But it proved difficult to fund initially. The original application in 1998 under the EU's 5th Framework programe was rejected before a second application under the 6th succeeded in 2003. As just stated, the last update issued by the EU KLEMS consortium was in October 2012. Thereafter ownership passed to a series of research institutes (The Conference Board, the Vienna Iinstitate for International Economic Studies (WIIW) and currently the Luiss Lab of European Economics at Luiss University).

It might have been hoped that after the first project had achieved proof of concept it would be taken over by some official agency which could have kept the database up to date on a routinized basis. The natural body to do this would have been Eurostat. But this did not happen, whether from lack of interest or inadequate funding of Eurostat. This is particularly surprising given that the years since 2007 have been the period of the productivity puzzle, when virtually all European countries have seen a drastic fall in the growth rates of both labour productivity and of TFP. Furthermore since at least 2007 in most European countries productivity has been growing more slowly than in the United States, whose growth has itself fallen quite substantially. So certainly since 2007 Europe as a whole has ceased to converge with the United States.

Though the original EU consortium is no more, the KLEMS approach has been pursued more widely under the banner "World KLEMS", an initiative launched by the late Dale Jorgenson of Harvard (Jorgenson 2012). There is now an Asia KLEMS, an India KLEMS, and Latin America KLEMS amongst other similar developments in Japan, Korea and China.[27]

Though as their names imply these various projects draw inspiration from the KLEMS framework, they are not harmonized with each other. So in this sense they are less ambitious than the original EU KLEMS project. Nor do they enjoy the same degree of support from NSIs. For example, I am informed that China has no official productivity statistics . Within the realm of official statistics, the World KLEMS website reports that in addition to the countries already mentioned the following seven NSIs are producing multifactor productivity data using the KLEMS framework: Australia, Denmark, Finland, Italy, Mexico, Netherlands, and Sweden. All of these are in the OECD and only one is within the Global South.

Conclusions

The KLEMS approach now has a worldwide spread but outside of the OECD progress has been mostly unofficial. This matters because NSIs have access to much more detailed data (via their own surveys and administrative records) than do private researchers. Within the OECD, the level of support and take-up has been variable. In

27 See the website www.worldklems.net for more details.

North America support for the approach preceded the manuals and has continued after their appearance. In Canada and the United States the estimates of labour and capital inputs are built up from much more detailed data than seems to be available in Europe. In the EU and the United Kingdom, there has been progress but there is still some way to go. The promise of the EU KLEMS project has not been fully maintained. Productivity statistics are still not fully integrated into national accounts.

In the United Kingdom and Europe, there is only limited acceptance of the US approach to measuring ICT prices. For example, in the UK only the CPI uses a US-type price index for computers, while the PPI and the corresponding import price index do not. Software prices are poorly measured everywhere. This is worrying if we really are living in the age of AI which we are told is going to transform productivity.

The original purpose of the KLEMS approach was to study growth and productivity, rather than the business cycle. But it has also proved very useful in studying economic fluctuations. The idea here is that a relatively small shock in one industry can propagate through the economy via that industry's interconnections with others, so that the size of the original shock is greatly amplified (Gabaix, 2011). Baqaee and Farhi (2019) develop that idea, arguing that an industry's Domar weight may give a misleading impression of its role in propagating shocks since the Domar weight is only the first order effect and second order effects may be important. They estimate these effects using one of the Jorgenson datasets which underlie the official BEA/BLS dataset, finding that second order effects are indeed important.[28]

A final point relates to the KLEMS framework itself. As noted above, the framework assumes perfect competition while most macroeconomists believe in imperfect competition. How (if at all) should the framework be adapted to incorporate imperfect competition? Economists will have to reach a consensus on this before recommending any changes to NSIs.

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28 I believe that a growth accounting approach using chained indices allows one to estimate second order as well as first order effects. But over a given period one is estimating the impact of all shocks together and the effect of a shock to a single industry cannot be isolated. This point is addressed rather obliquely in footnote 45 of Baqaee and Farhi (2019).

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