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

Jonathan Barr, Peter Foltin and Jianmin Tang
Innovation, Science, and Economic Development Canada[1]

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

1 Jonathan Barr is a Senior Director of Economic Research and Analysis in the Strategy, Research and Results Branch at Innovation, Science, and Economic Development Canada (ISED). Peter Foltin and Jianmin Tang are economists in the same organization. The authors would like to thank Ana Davreux for providing statistical support in the preparation of this report as well as Don Drummond, Andrew Sharpe, Tim Sargent, Steven Schwendt and Ryan Kelly for useful comments and feedback. The views and opinions expressed are those of the authors alone and do not represent, in any way, the views and opinions of ISED. Email: Jonathan.Barr@ised-isde.gc.ca.

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.

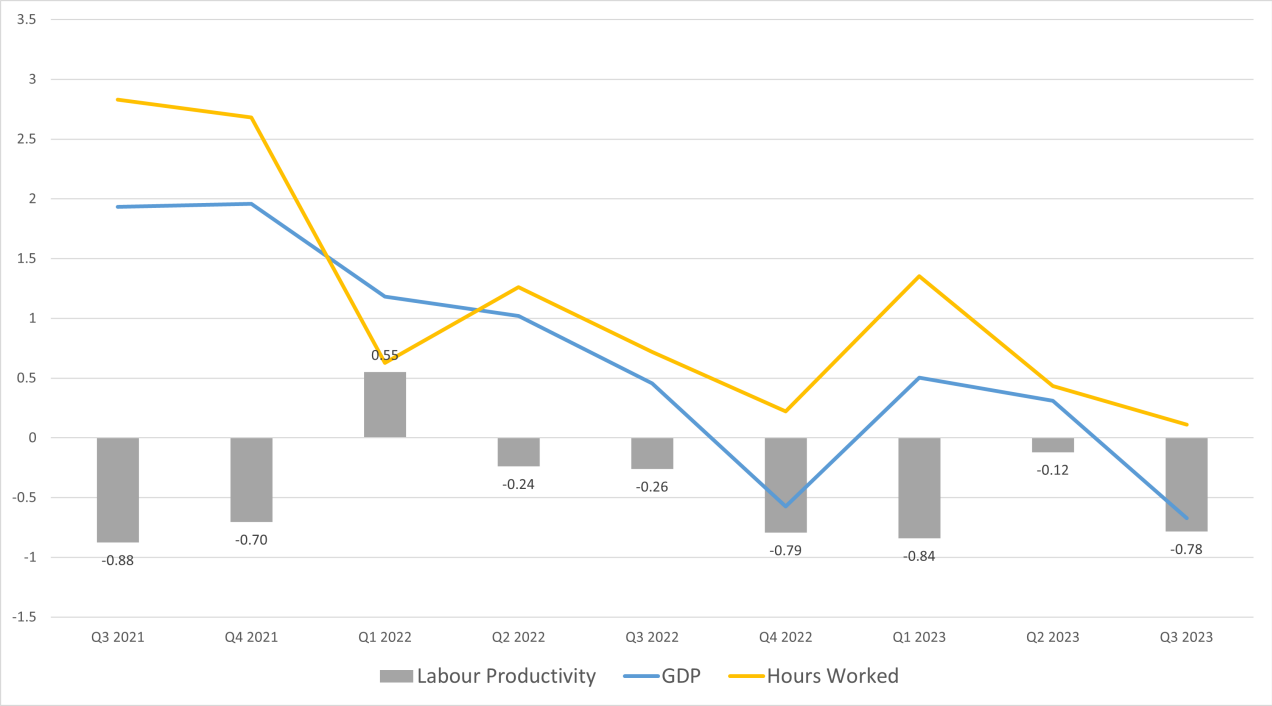
This article will examine factors that could impact Canada's future productivity performance in light of the twin transitions of green and digitalization. Section 1 starts by exploring recent productivity trends in Canada. Section 2 discusses challenges and opportunities for productivity associated with 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).

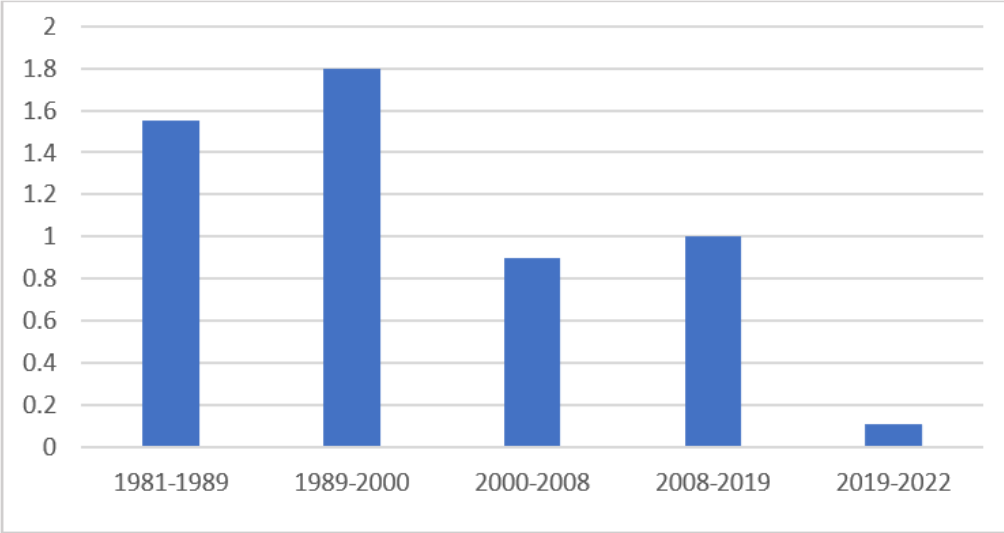
The overall productivity growth slowdown has mainly occurred in goods-producing industries such as the mining and oil and gas and manufacturing sectors. Some services industries (administrative and waste management; arts, entertainment, and recreation; and accommodation and food services) have experienced 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)



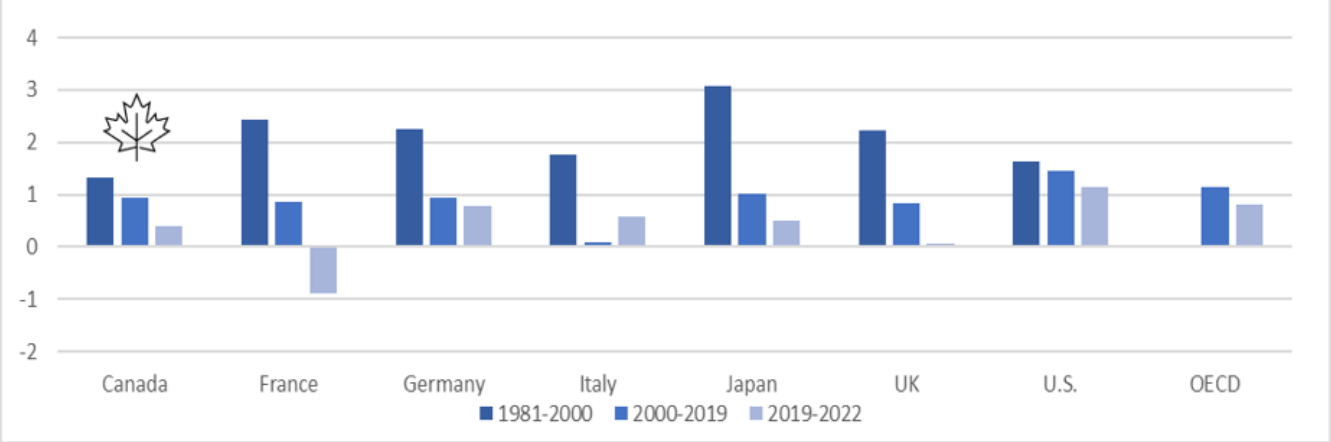
Source: Statistics Canada. Table 36-10-0208-01 and Table: 36-10-0207-01, ISED's Calculations.

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)



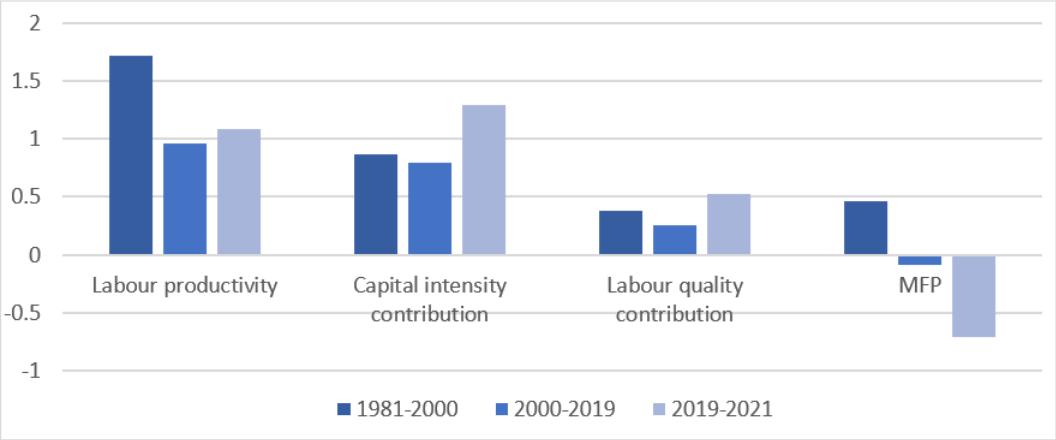
OECD STAN Database. OECD average is weighted, calculated as the sum of output over countries divided by the sum of hours worked over countries, not available for 1981-2000.

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.

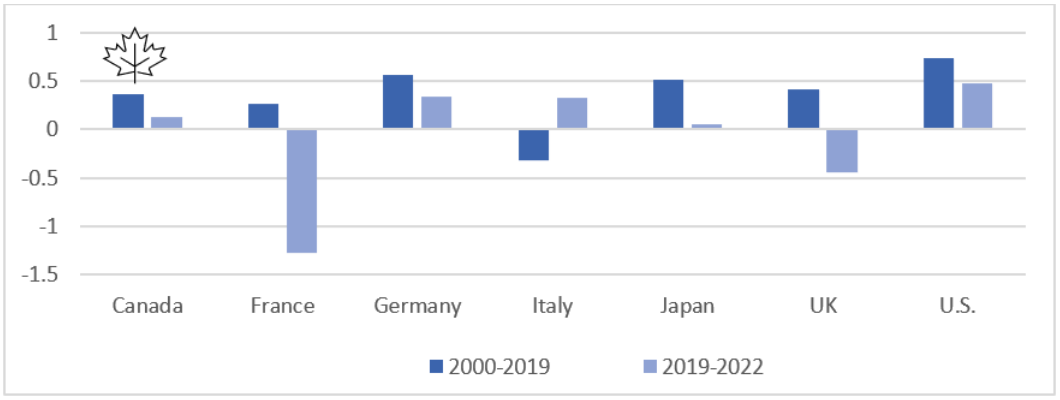
Green Transitions and Productivity

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.

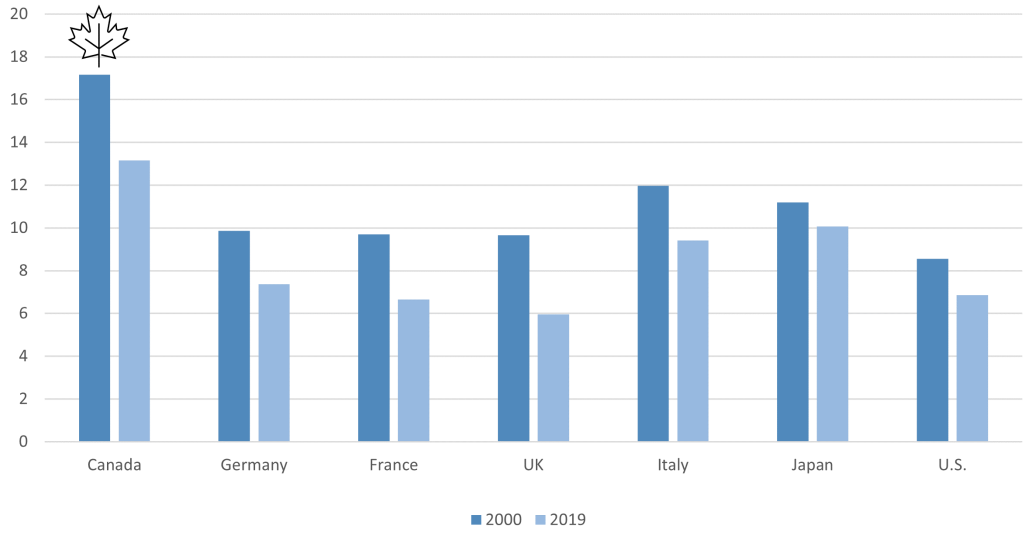
5 See Leung *et al.*, 2008; Nicholson, 2009; Tang, 2014 and 2016; Sharpe and Tsang, 2018; Gu, 2019; and Deslauriers and Gagné, 2023.

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 non-metallic mineral products; and basic metals and fabricated metal products (excluding machinery and equipment) (Chart 7).

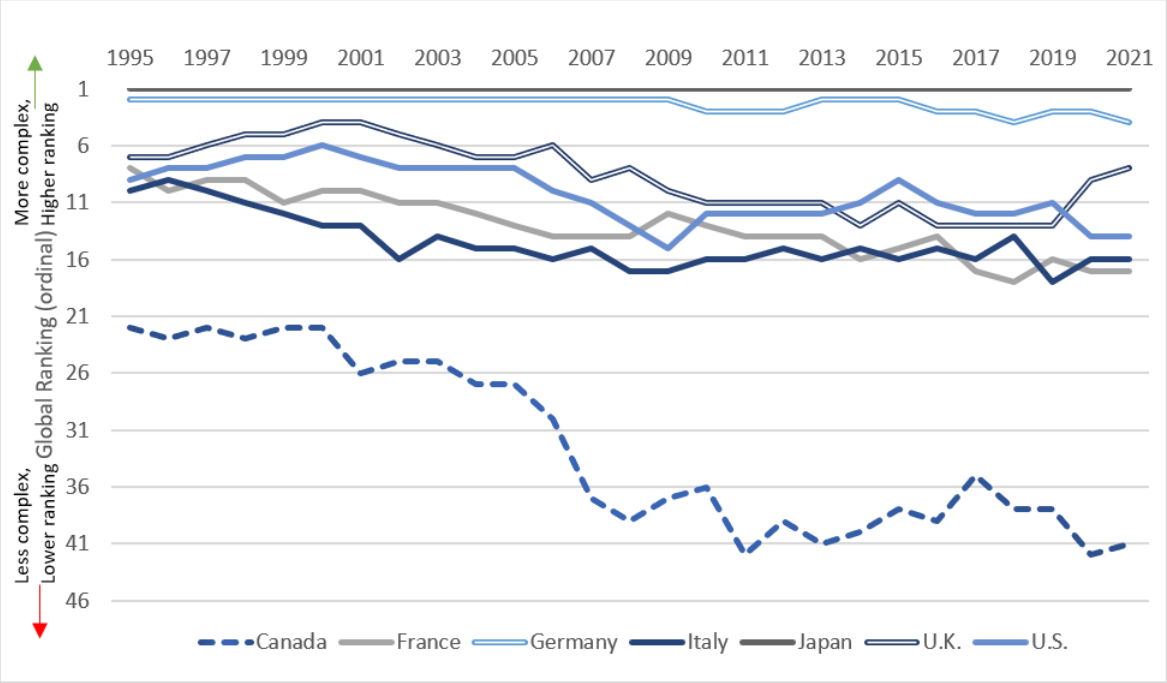
Over the past two decades, the Canadian economy shifted from resource-dependent industries to service industries, and the value-added share of resource-dependent industries declined from 17.2 per cent of nominal GDP in 2000 to 13.2 per cent in 2019, the largest decline among G7 countries. That said, 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."

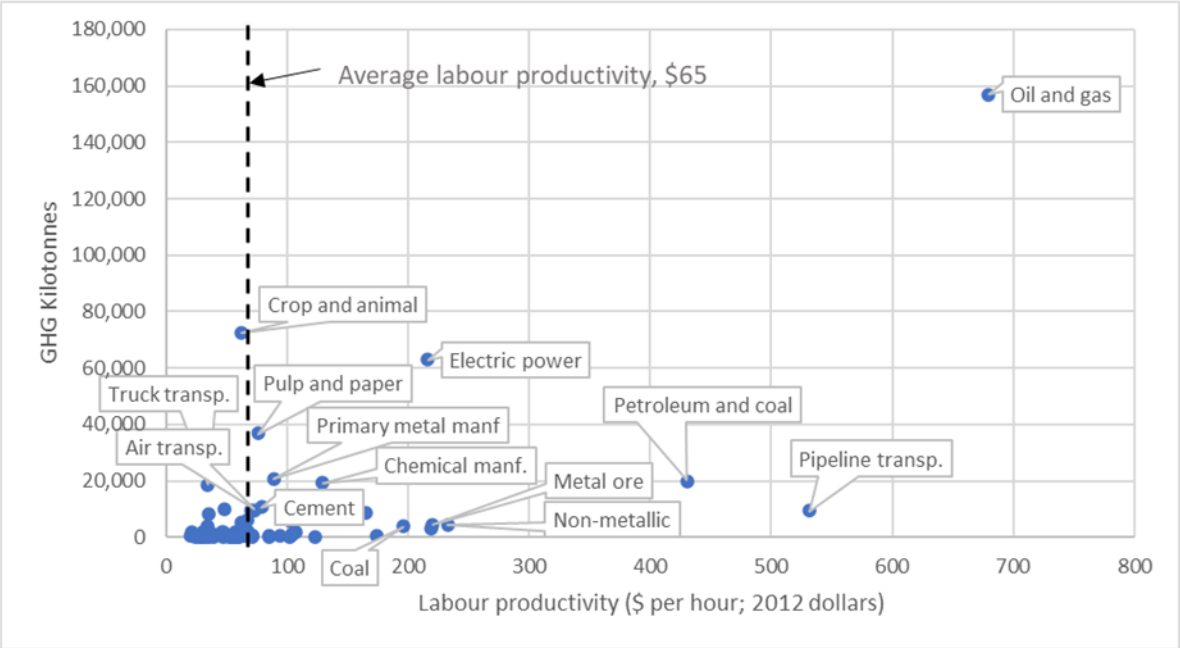
are goods, led by crude petroleum, followed by cars, petroleum gas,[7] gold, and sawn wood products. The dependence of trade of carbon-intensive products may not be sustainable, as the global economy and consumer consumption patterns move away from these products, driven by the global green imperative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

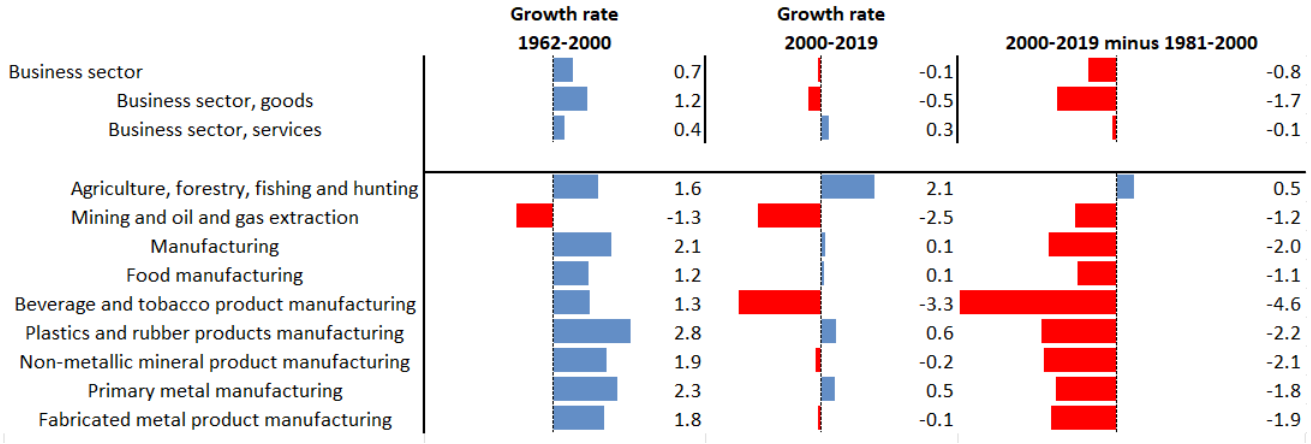
which factors in the cost of capital, the growth rate of the mining and oil and gas sector is even worse. Multifactor productivity (value-added based) declined from an average growth rate of negative 1.3 percent annually in 1962-2000 to an average growth rate of negative 2.5 percent annually in 2000-2019 (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.

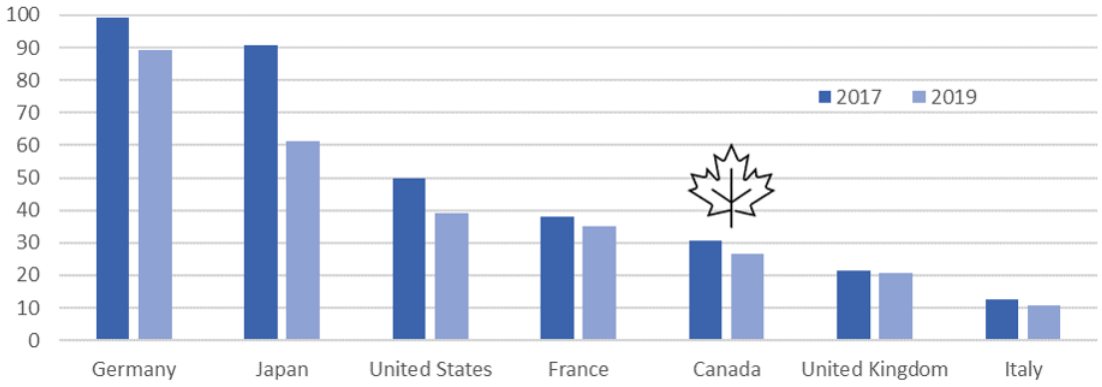
cent of Canada's GDP in 2021. This study also finds that the ECT sector grew by 21 per cent in real terms over the last decade, outpacing the economy's overall 15 per cent growth. Export growth was particularly strong, up 90 per cent from 2012 to 2021. Export growth came mainly from increased amounts 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 in-

dustry), 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).

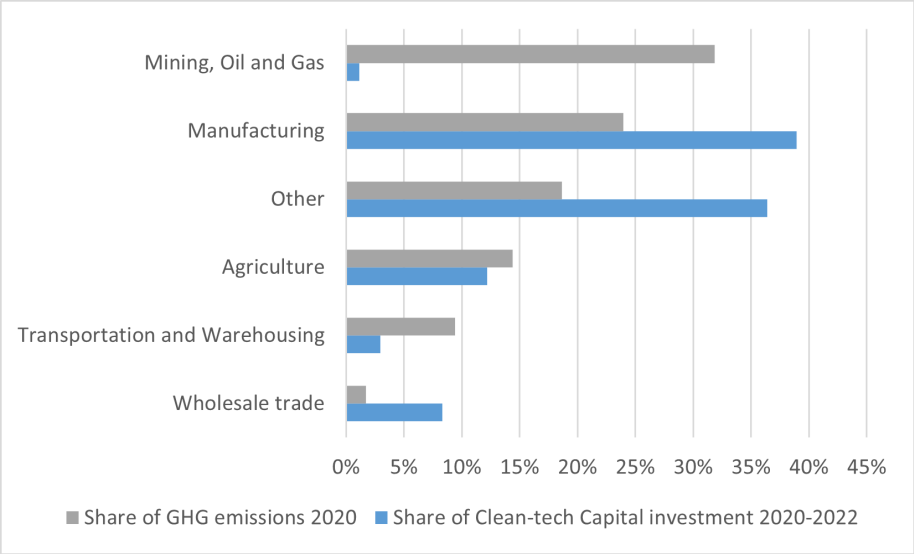
By sector, investments in clean technologies tended to correlate with overall share of GHG emissions (Chart 12) with the notable exception of the mining, oil, and gas extraction sector. This sector produced about a third of all GHG emissions in Canada in 2020 but made only 1.1 per cent of all clean technology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

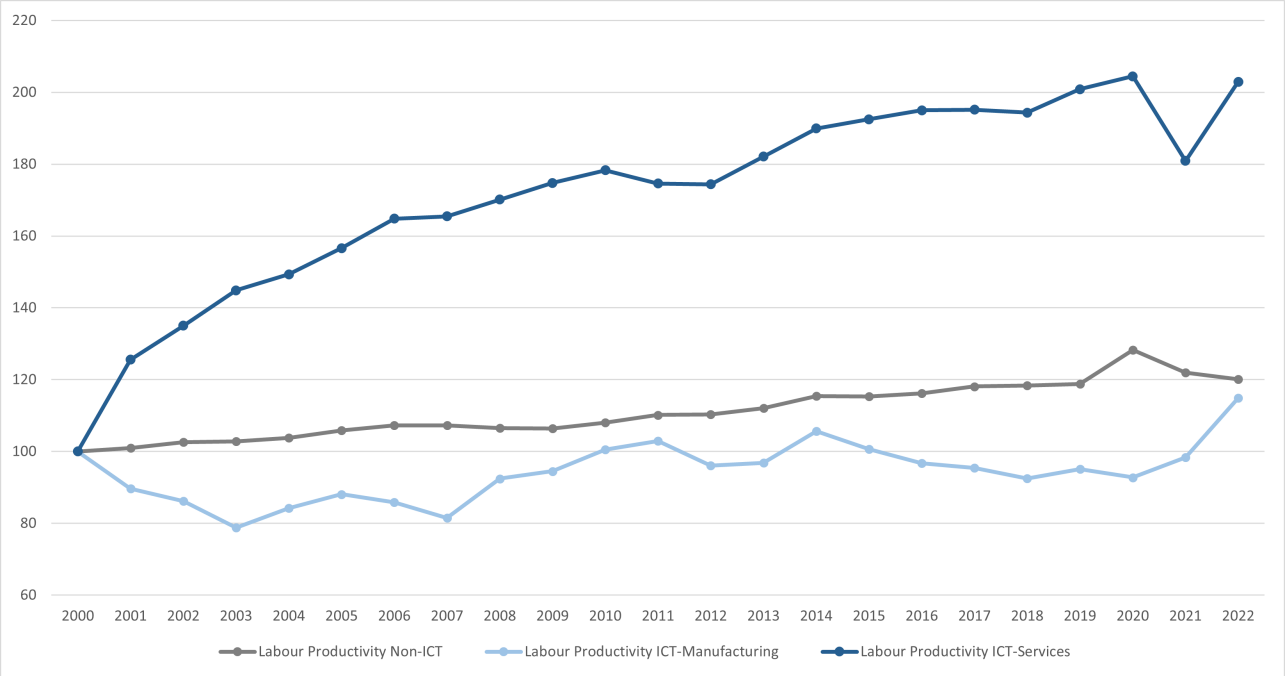
help firms overcome them is needed. Typical barriers include access to financing, uncertain returns on investment, and a lack of skills or technical knowledge required to implement new technologies. Finally, it is vital that steps are taken to help smooth the green transition, not just for firms but 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 man-

ufactures 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]

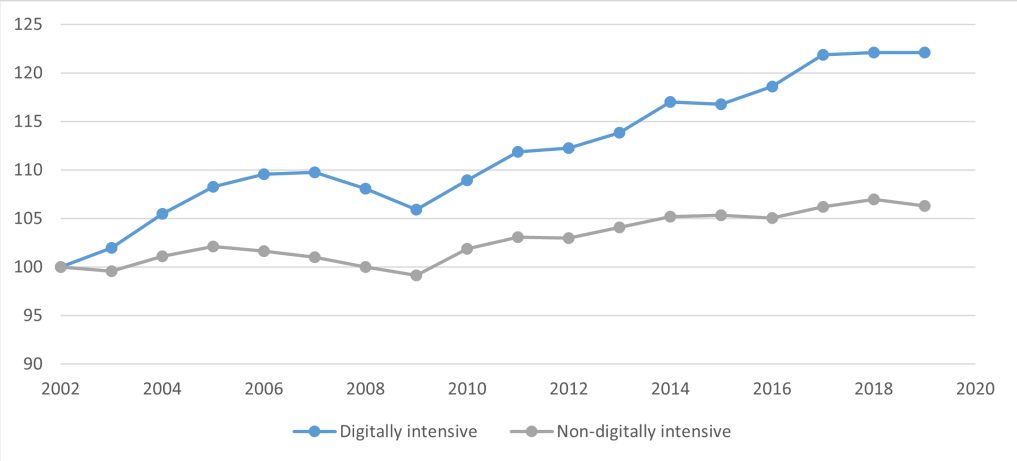
Beyond the highly productive ICT sector itself, there is evidence that digitally intensive sectors in Canada have experienced strong economic growth. Employing a measure of digital-intensity developed in Liu and McDonald-Guimond (2021), Liu (2021) sheds light on the economic performance associated with 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

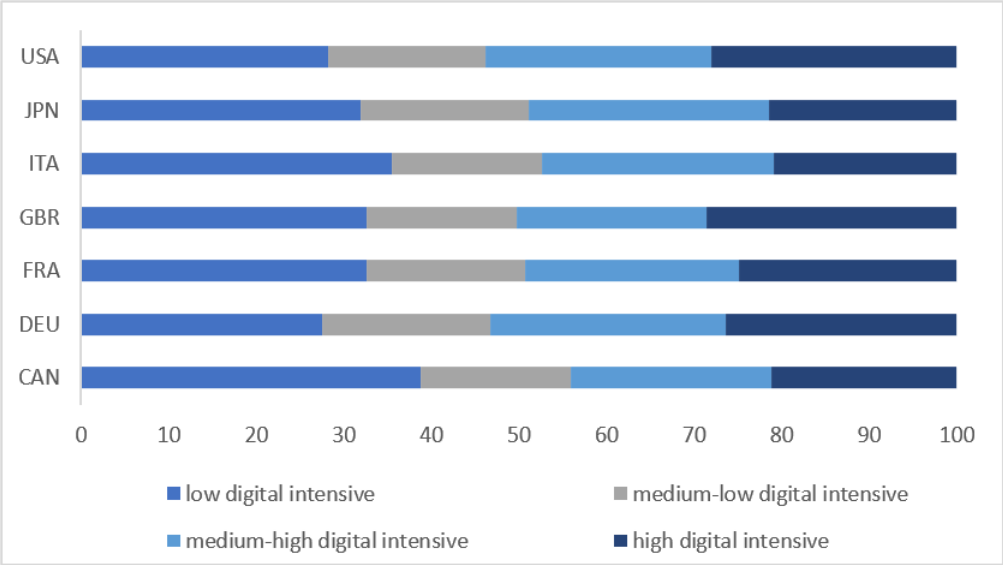
11 This article follows the definition for the ICT sector used in Statistics Canada Table 36-10-0480-01. It defines the ICT - Services sector as the business establishments of the North American Industry Classification System (NAICS) codes 4173 (Computer and communications equipment and supplies merchant 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



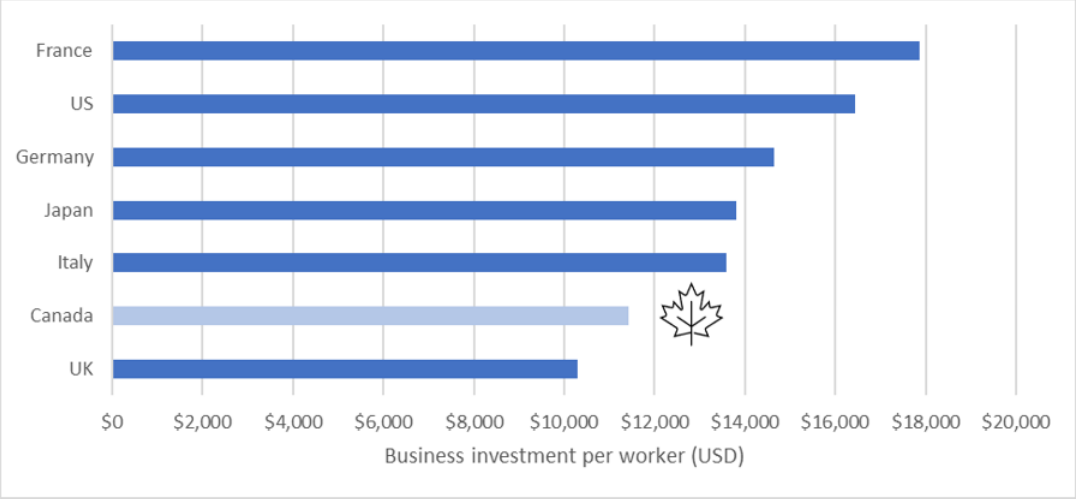
Source: OECD STAN Database.

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).

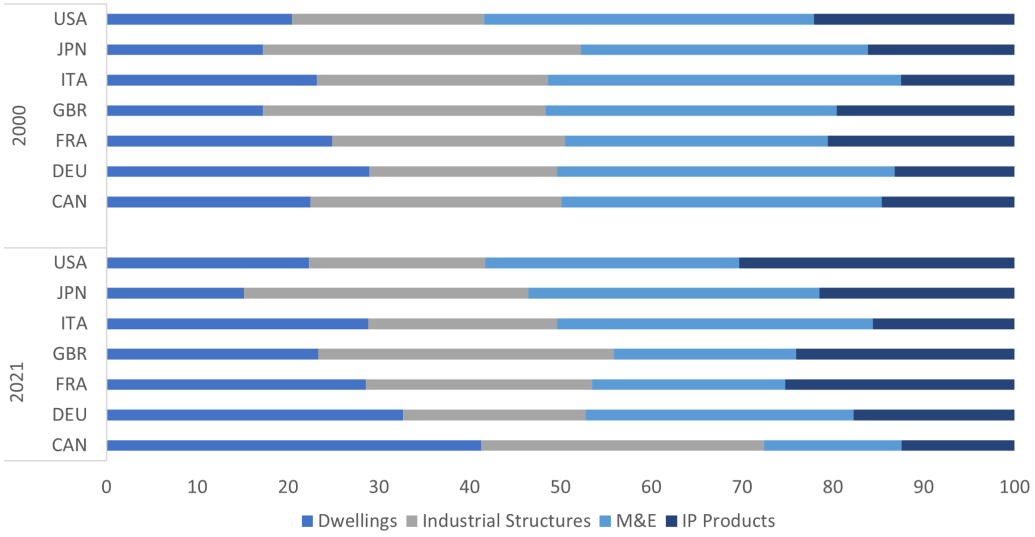
in dwellings was 22.4 per cent of total gross fixed capital formation, the 3rd highest among G7 countries, but by 2021, the share had almost doubled to 41.3 per cent, the highest among G7 countries (Chart 17). This means that Canada is investing less and less in productivity-enhancing forms of capital 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-

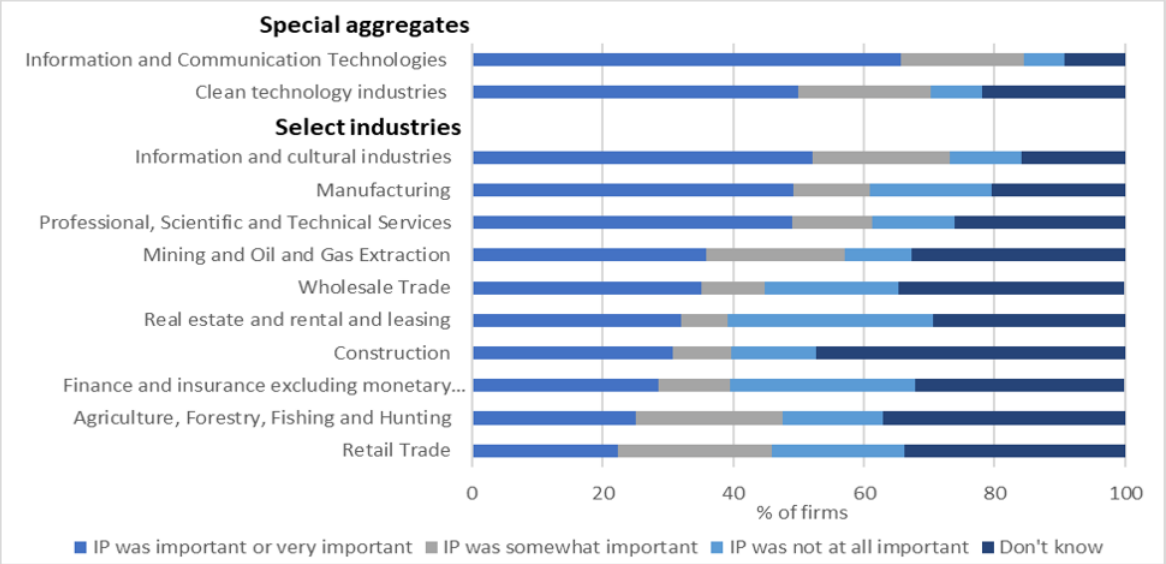
13 Globerman and Press (2018) indicate that "the environment for business investment in assets that are critical to productivity growth has apparently become less favourable in recent years than the environments for other categories of assets".

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



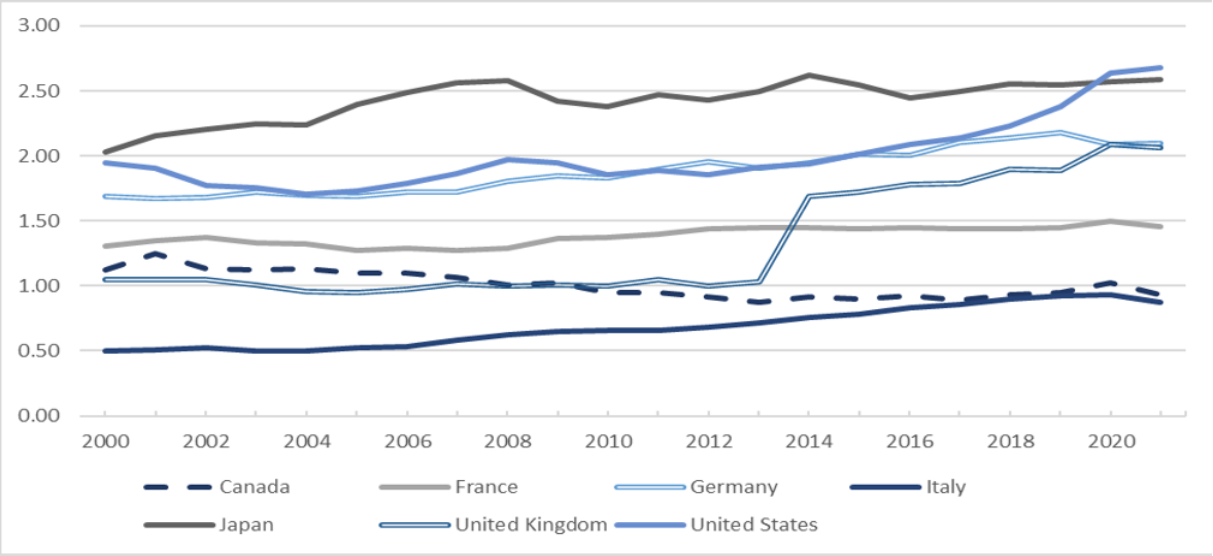
Source: OECD.
Note: Gross fixed capital formation is in current United States dollars (PPP adjusted).

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



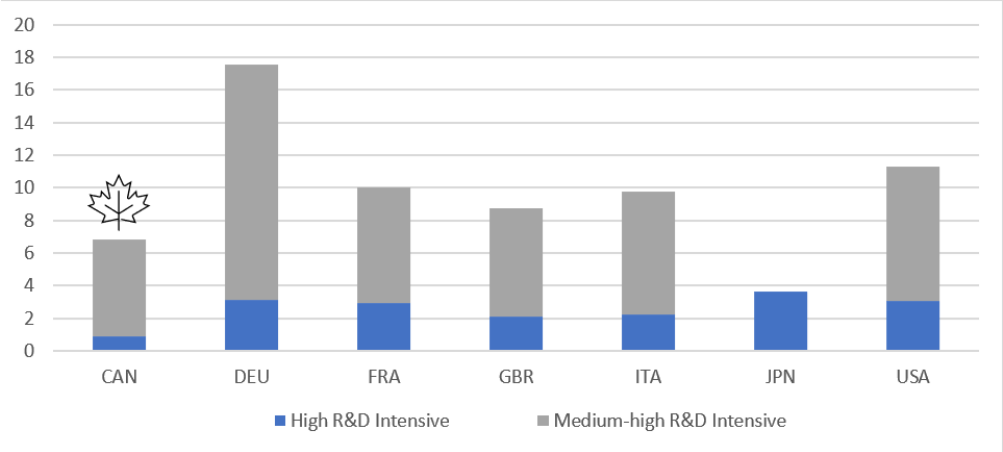
Source: Statistics Canada "Survey of Intellectual Property Awareness and Use."

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.

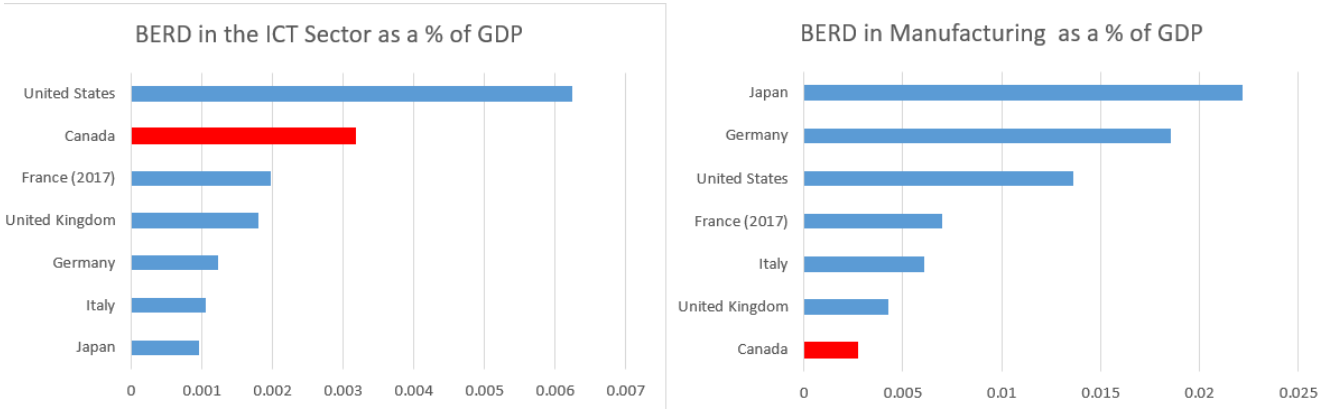
Industry structure is related to Canada's performance in BERD. To see this, consider a measure of industry R&D intensity developed by the OECD, which categorized industries based on the ratio of R&D to value added (Galindo-Rueda and Verger, 2016).[14] Industries classified as having high R&D intensity 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).

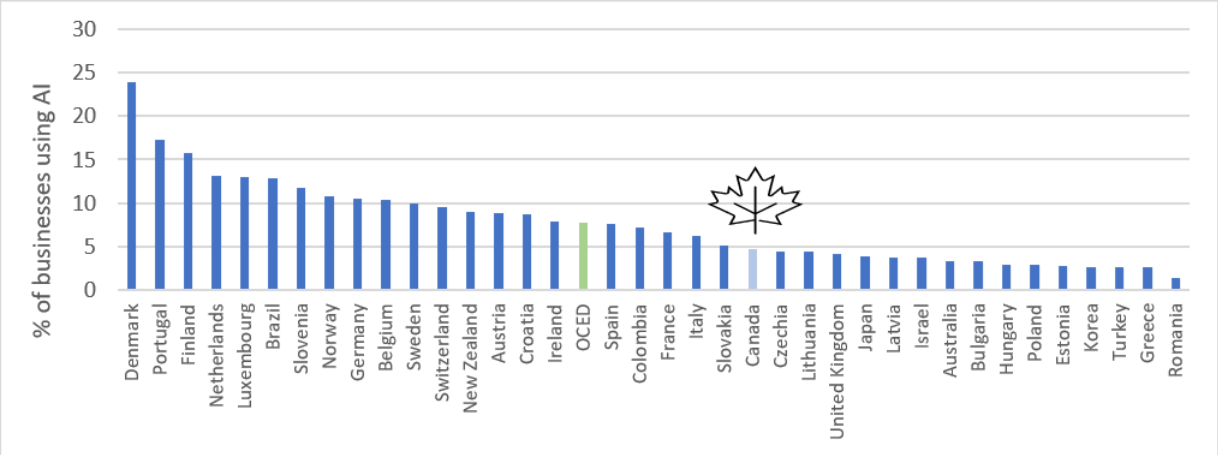
AI can improve productivity by automating tasks, identifying key patterns and trends, and help knowledge workers achieve more in less time, leading to cost savings and efficiency gains. The Brookings Institution (Baily, Brynjolfsson, and Korinek, 2023) has summarized the nascent literature on AI productivity 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 grow-

ing 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 Cana-

dian 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.

References

Aghion, P., B. Jones, and C. Jones (2017) "Artificial Intelligence and Economic Growth," Working Paper No. 23928, NBER. http://www.nber.org/papers/w23928.

Albrizio, S., E. Botta, T. Koźluk, and V. Zipperer (2014) "Do Environmental Policies Matter for Productivity Growth: Insights from New Cross-Country Measures of Environmental Policies," Economics Department Working Papers No. 1176, OECD.

Almon, M.J. and J. Tang (2011) "Industrial Structural Change and the Post-2000 Output and Productivity Growth Slowdown: A Canada-U.S. Comparison," *International Productivity Monitor*, No. 22, pp. 44-81. http://www.csls.ca/ipm/22/IPM-22-Almon-Tang.pdf.

Andrews, D., C. Criscuolo and P.N. Gal (2016) "The Best versus the Rest: The Global Productivity Slowdown, Divergence across Firms and the Role of Public Policy," Productivity Working Papers, No. 5, OECD. https://doi.org/10.1787/63629cc9-en.

Arrow, K. J., L. Cohen, P.A. David, R. W. Hahn, C. D. Kolstad, L. Lane, W. D. Montgomery, R. R. Nelson, R.G. Noll, and A. E. Smith (2009) "A Statement on the Appropriate Role for Research and Development in Climate Policy," *The Economists' Voice*, Vol. 6, No. 1.

Baily, N.M., E. Brynjolfsson, and A. Korinek (2023, May 10) "Machines of Mind: The Case for an AI-powered Productivity Boom." Brookings https://www.brookings.edu/articles/machines-of-mind-the-case-for-an-ai-powered-productivity-boom/.

Berman, E., and L. T. Bui (2001) "Environmental Regulation and Productivity: Evidence from Oil Refineries," *Review of Economics and Statistics*, Vol. 83, No. 3, pp. 498-510.

Brynjolfsson, E., D. Rock, and C. Syverson (2018) "Artificial Intelligence and the Modern Productivity Paradox: A Clash of Expectations and Statistics," in *The Economics of Artificial Intelligence: An Agenda*, pp. 23-57 (University of Chicago Press).

Brynjolfsson, Erik, D. Rock, and C. Syverson. (2021) "The Productivity J-Curve: How Intangibles Complement General Purpose Technologies," *American Economic Journal: Macroeconomics*, Vol. 13, No. 1, pp. 333-72.

Carta, M. and F. Demers (2023) "Analysis on Federal Business Innovation and Growth Support to Clean Technology, 2016 to 2020," Analysis in Brief. Statistics Canada, ISSN 1707-0503, ISBN 978-0-660-49328-2.

Calvino, F., C. Criscuolo, L. Marcolin, and M. Squicciarini (2018) "A Taxonomy of Digital Intensive Sectors," Science, Technology, and Industry Working Papers No. 2018/14, OECD. https://doi.org/10.1787/f404736a-en.

Cette, G., S. Nevoux and L. Py (2022) "The Impact of ICTs and Digitalization on Productivity and Labor Share: Evidence from French Firms," *Economics of Innovation and New Technology*, Vol. 31, No. 8, pp. 669-692. 10.1080/10438599.2020.1849967.

Chui, M., E. Hazan, R. Roberts, A. Singla, K. Smaje, A. Sukharevsky, L. Yee, and R. Zemmel (2023) "The Economic Potential of Generative AI," McKinsey and Company. https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-economic-potential-of-generative-AI-the-next-productivity-frontier.

Commins, N., S. Lyons, M. Schiffbauer, and R. S. Tol (2011) "Climate Policy and Corporate Behavior," *Energy Journal*, Vol. 32, No. 4.

Deslauriers, J., and R. Gagné (2023) "The Low Productivity of Canadian Companies Threatens our Living Standards," *Policy Options*, - Institute for Research on Public Policy.

The Economist (2021) "An Eco-wakening: Measuring Global Awareness, Engagement and Action for Nature," The Economist Intelligence Unit Limited.

Fernald, J., R. Inklaar, and D. Ruzic (2023) "The Productivity Slowdown in Advanced Economies: Common Shocks or Common Trends?," Working Paper 2023-07. Federal Reserve Bank of San Francisco. https://doi.org/10.24148/wp2023-07. https://doi.org/10.1787/18151965.

Frey, S., J. Bar Am, V. Doshi, A. Malik, and S. Noble (2023) "Consumers Care About Sustainability—and Back it up With their Wallets," McKinsey and Company and NielsenIQ.

Gal, P., G. Nicoletti, T. Renault, S. Sorbe, and C. Timiliotis (2019) "Digitalisation and Productivity: In Search of the Holy Grail–Firm-level Empirical Evidence from EU Countries," Economics Department Working Papers No. 1533, OECD.

Galindo-Rueda, F., and F. Verger (2016) "OECD Taxonomy of Economic Activities Based on RandD Intensity," Science, Technology, and Industry Working Papers 2016/04, OECD.

Global Affairs Canada (2023) "Canada's State of Trade 2023," https://www.international.gc.ca/transparency-transparence/state-trade-commerce-international/2023.aspx?lang=eng.

Globerman, S. and T. Press (2018) "Capital Investment in Canada: Recent Behaviour and Implications," Fraser Research Bulletin.

Goldman Sachs (2023) "Generative AI Could Raise Global GDP by 7%," Goldman Sachs Intelligence, April 23.

Goldsmith, T. (2021) "Picking Up Speed: Digital Maturity in Canadian SMEs and Why Increasing it Matters," Brookfield Institute for Innovation and Entrepreneurship, June.

Gordon, R. J. (2018) "Why Has Economic Growth Slowed When Innovation Appears to Be Accelerating?," Working Paper No. w24554, NBER. https://ssrn.com/abstract=3170773.

Gu, W. (2019) "Frontier Firms, Productivity Dispersion and Aggregate Productivity Growth in Canada," *International Productivity Monitor* No. 37, pp. 96-119. http://www.csls.ca/ipm/37/Gu.pdf.

Hausmann, R., J. Hwang, and D. Rodrik (2007) "What You Export Matters," *Journal of Economic Growth*, No. 12, pp. 1-25.

Hottenrott, H., Rexhäuser, S., and Veugelers, R. (2016) "Organisational Change and the Productivity Effects of Green Technology Adoption." *Resource and Energy Economics*, Vol 43, pp. 172-194.

Innovation, Science and Economic Development (2023) "Government of Canada Announces Renewed Funding for the Global Innovation Clusters,". https://www.canada.ca/en/innovation-science-economic-development/news/2023/02/government-of-canada-announces-renewed-funding-for-the-global-innovation-clusters.html.

Jiang, K. (2023) "Canada's Environmental and Clean Technology Sector (2021)," Office of the Chief Economist, Global Affairs Canada. https://www.international.gc.ca/trade-commerce/economist-economiste/analysis-analyse/ect-etp.aspx?lang=eng.

Leung, D., C. Meh, and Y. Terajima (2008) "Productivity in Canada: Does Firm Size Matter?," *Bank of Canada Review*.

Li, J., L. Shute, and J. Tang (2013) "Multifactor Productivity Growth Estimation in Canada and the United States: Do Different Methodologies Matter?," *International Productivity Monitor*, No. 26, pp. 36-62. http://www.csls.ca/ipm/26/IPM-26-Li-Shute-Tang.pdf.

Liu, H. (2021) "Economic Performance Associated with Digitalization in Canada Over the Past Two Decades," *Statistics Canada Economic and Social Reports*, Catalogue No. 36-28-0001.

Liu, H., and J. McDonald-Guimond (2021) "Measuring Digital Intensity in the Canadian Economy," Statistics Canada Economic and Social Reports, Catalogue No. 36-28-0001.

Mollins, J. and T. Taskin. (2023) "Digitalization: Productivity," Staff Discussion Paper No. 2023-17, Bank of Canada.

Nicholson, P. (2009) "Innovation and Business Strategy: Why Canada Falls Short," *International Productivity Monitor,* No. 18, pp. 51-71. http://www.csls.ca/ipm/18/IPM-18-Nicholson.pdf.

OECD (2019) *OECD Economic Outlook*, Vol. 2019, No. 1, OECD Publishing, Paris. https://doi.org/10.1787/b2e897b0-en.

OECD (2021) *The Digital Transformation of SMEs*, OECD Studies on SMEs and Entrepreneurship, OECD Publishing, Paris. https://doi.org/10.1787/bdb9256a-en.

OECD (2022) "Identifying the Main Drivers of Productivity Growth: A Literature Review," OECD. https://doi.org/10.1787/00435b80-en.

OECD. (2023) National Accounts; Annual National Accounts; 8A. Capital formation by activity ISIC rev 4 [Data table].

Oxford Economics (2023) "The Global Green Economy: Understanding and Capturing the Opportunity," https://www.oxfordeconomics.com/resource/the-global-green-economy-understanding-and-capturing-the-opportunity.

Popp, D. (2012) "The Role of Technological Change in Green Growth," Working Paper No. 18506, NBER.

Porter, M. (1991) "America's Green Strategy," *Scientific American*, Vol. 264, No. 168.

Pujolas, P., and O. Loertscher (2023) "Canadian Productivity Growth: Stuck in the Oil Sands," Department of Economics Working Paper, Mc Master University.

Sharpe, A., and J. Tsang (2018) "The Stylized Facts about Slower Productivity Growth in Canada," *International Productivity Monitor* No. 35, pp. 52-72. http://www.csls.ca/ipm/35/IPM-35-Sharpe-Tsang.pdf.

Solow, R. (1987) "We'd Better Watch Out," *New York Times Book Review*, July 12.

Spiezia, V. (2012) "ICT Investments and Productivity: Measuring the Contribution of ICTS to Growth," *OECD Journal: Economic Studies*.

Statistics Canada (2021) Custom Tables – Survey of Intellectual Property Awareness and Use [Data table]. https://www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=5291.

Statistics Canada (2023a) "Survey of Advanced Technology, 2022," *The Daily*.

Statistics Canada (2023b) Table: 27-10-0392-01 Obstacles to the Adoption of Advanced Technologies, by Industry and Enterprise Size [Data table]. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2710039201.

Statistics Canada (2023c) Table: 36-10-0480-01 Labour Productivity and Related Measures by Business Sector Industry and by Non-commercial Activity Consistent with the Industry Accounts [Data table]. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610048001.

St-Amant, P., and D. Tessier (2018) "Firm Dynamics and Multifactor Productivity: An Empirical Exploration," Staff Working Paper No. 2018-15, Bank of Canada.

Syverson, C. (2011) "What Determines Productivity?"*Journal of Economic Literature*, Vol. 49, No. 2, pp. 326-365.

Tang, J. (2014) "Are Small or Large Producers Driving the Canada-U.S. Labour Productivity Gap? Recent Evidence from Manufacturing," *Canadian Journal of Economics*, Vol. 45, No. 2.

Tang, J. (2016) "Industrial Structure Change and the Widening Canada–US Labor Productivity Gap in the Post-2000 Period," *Industrial and Corporate Change* Vol. 26, No. 2, pp. 259–278.

Tang, J., and W. Wang (2020) "Industry Productivity Performance in G7 Countries after the Global Financial Crisis: A Canadian Perspective," *International Productivity Monitor*, No. 39 pp. 33-52. http://www.csls.ca/ipm/39/Tang-Wang.pdf.

Westerlund, M (2020) "Digitalization, Internationalization and Scaling of Online SMEs," *Technology Innovation Management Review* Vol. 10, No. 4.

World Bank Group (2022) "Eswatini Digital Economy Assessment" Washington, DC: World Bank. License: Creative Commons Attribution CC BY 3.0 IGO.

World Bank (2023) "Exports of Goods and Services," https://data.worldbank.org/indicator/NE.EXP.GNFS.ZS.