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Digitalization: Definition and Measurement

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Overview

How has digitalization shaped the landscape of Canada's economy? In this paper, we seek to grasp the breadth of digitalization. We define digitalization and distinguish it from other related concepts, such as information and communication technologies (ICT) and the digital economy. We then assess the scope of digitalization in Canada by looking at measures based on outputs and inputs as well as the challenges that come with trying to estimate it. Finally, we raise important questions for future research about the impacts of digitalization.

Key messages:

- **Digitalization is transforming processes and interactions between economic agents.** The output of digital products was 5.5% of gross domestic product (GDP) in 2019, and the number of digital-related jobs was 7.1% of GDP in 2015. These metrics reveal similar proportions of the digital economy in Canada's overall production process.
- **Challenges remain when it comes to accurately measuring all aspects of the effects of digitalization:**
    - Free or reduced-price digital products are increasingly driving a wedge between GDP and consumer welfare that was estimated to represent 2.3% of GDP for Canada in 2019.
    - Intangible capital represents a growing share of the capital holdings of Canadian firms. The national accounts still do not capitalize many forms of intangibles, such as:
        - product development, brand equity, human capital and organizational capital (augmented by digitalization)
        - data, which were estimated to represent about 5% to 8% of gross fixed capital formation in 2018
    - The adoption of cloud computing technology means that many Canadian firms are substituting away from in-house investment and toward purchasing cloud services. This substitution may help explain some of the under-investment seen in Canada relative to that in the United States.
    - The gig economy may be leading to the underestimation of the labour force participation rate or work hours. Most recent estimates suggest gig workers represented about 8.2% of Canadian workers in 2016.

1. How we define digitalization

The digital revolution—which involves shifting production processes from using predominantly mechanical technologies to using analogue and digital technologies—began in the latter half of the 20th century. This transformation led to the fourth industrial revolution, which included automation, computerization and the shift of investment from tangibles to intangibles. This revolution continues to impact and reshape the Canadian economy. In this paper, we explore the technologies that drive digitalization, how we measure them, the ambiguities they entail and how Canada's adoption of them compares with other countries.

Digitalization's boundaries are often unclear relative to ICT, digital adoption and the digital economy. **We define economic digitalization as the process through which the use of data, digital platforms and advanced analytics (such as machine learning and artificial intelligence) transforms the production process and interactions with other economic agents.**[1] This definition captures both the drivers and the economic impacts in accordance with the existing literature. Since most of the related technological advancements are in their early stages, we anticipate that this definition will evolve over the coming decades.

We differentiate digitalization from ICT and the digital economy. According to the fourth revision of the International Standard Industrial Classification of All Economic Activities, **ICT is more formally known as the sector in which "the production of goods and services of a candidate industry must primarily be intended to fulfill or enable the function of information processing and communication by electronic means, including transmission and display"** (UNSD 2008, 278). Hence, digitalization encompasses some parts of ICT, such as ICT services, but not others, such as ICT hardware.[2]

Digitalization also goes beyond the pure digital economy as defined by the common framework of the Organisation for Economic Co-operation and Development (OECD). Here, the **digital economy "incorporates all economic activity reliant on, or significantly enhanced by the use of digital inputs, including digital technologies, digital infrastructure, digital services and data. It refers to all producers and consumers, including government, that are utilising these digital inputs in their economic activities"** (OECD 2020, 5). Once again,

[1] In a similar spirit, the European Central Bank (2021, 9) defines digitalization as "including, inter alia, a wide range of information and communication technologies enabling automation and robotisation, and technologies related to the processing and analysis of digital data, including big data, such as artificial intelligence and machine learning, and edge and quantum computing."

[2] While ICT hardware is technology that enables digitalization, it is not part of it—just as the electricity network and power plants enabled electrification technologies but were not part of that technological revolution.

digitalization captures some components of the digital economy that include digitally delivered products, but not the infrastructure or telecom services associated with it.

Digitalization comprises all the processes enhanced by the use of digital inputs, which could be digital labour or digital capital. However, some aspects of digitalization are difficult to quantify, and the impact of these extends far beyond traditional economic measures. For example, the field of health services sees benefits of digitalization that do not fit conventional measures. These benefits include the use of personalized genomics to customize cancer treatment for patients or handheld scanners that use machine learning to easily detect a cancerous melanoma. So while ICT and the digital economy capture the number of computers in the economy, digitalization also considers all the technologies they enable. Important to consider are the diffusion effects of these technologies to other sectors that may not be directly measured as part of the digital economy or ICT measures. Some of these benefits can be difficult to measure in national accounts.

In the remainder of this section, we touch on the scope for digitalization to change the economic future of Canadians. In section 2, we go over some of the broader characteristics of digitalization and how we measure its impact. Section 3 discusses particular challenges associated with measuring digitalization. We conclude in section 4 by outlining important future trends and open questions.

1.1 Digitalization's role as a general purpose technology

Some technologies are more important than others, and the potential of a technology in its early stages is hard to assess. Considering historical precedence, economists have identified three characteristics that are critical for a technology to have a major impact (Jovanovic and Rousseau 2005; Bresnahan 2010):

- **pervasiveness**, meaning that the technology diffuses to other sectors
- the ability to generate **ongoing technical enhancement** or, more generally, to improve over time
- the tendency to **enable innovation complementarities**, meaning the technology can precipitate the creation of other new products and processes

A general purpose technology (GPT) is one in which all three features come together. GPTs can drive entire eras of technical progress and economic growth (Bresnahan and Trajtenberg 1995). Well-known and generally accepted examples of GPTs over history include the steam engine, electricity and, more recently, computers. These technologies reshaped the world once they were widely adopted.

Evidence in the literature suggests that **digitalization is a GPT because it is pervasive, it improves over time and it spawns innovation**. An open question is what aspects of digitalization can be considered GPTs. Because of how rapidly digitalization continues to evolve, assessing which of its underlying technologies will be key remains difficult.

Many aspects of digitalization could be considered GPTs, including artificial intelligence, machine learning, big data and cloud computing. Recent research by Goldfarb, Taska and Teodoridis (2023) presents a systematic approach to determining which of these should be considered GPTs. They analyze and rank 21 different emerging technologies using a quantitative approach.[3] Other studies look at particular technologies to assess whether they are GPTs, such as robots (Dixon, Hong and Wu 2021) and artificial intelligence (Brynjolfsson, Rock and Syverson 2021). The latter study also shows evidence that the introduction of a GPT will likely cause an initial underestimation of productivity growth, since early adoption of technology is typically slow, with productivity quickly accelerating after the technology is adopted.

Recently, Petralia (2020) proposed using patent data to identify GPTs. Using patent counts as a GPT indicator follows the existing literature on that topic, such as Hall and Tratjenberg (2004) in the context of ICTs and Moser and Nicholas (2004) in the context of electricity. However, Petralia (2020) offers a more systematic framework. He implements a three-dimensional index that uses patenting growth rates to measure improvement, applies a text-mining algorithm to identify the range of uses and, finally, uses co-occurrence of technological claims in patents to assess complementarity with other technologies. This approach allows him to evaluate the pervasiveness of each GPT technology and to produce a ranking.

Given digitalization's GPT features, we argue that it should be considered general purpose. Historical examples show similar technologies transforming processes and reshaping the structure of the economy. While assessing the current stage of digitalization is difficult, its importance is clearly increasing and an adoption wave of digital technologies is underway. In another paper in this Digital Overview series, Mollins and Taskin (2023) discuss the likely productivity potential of digitalization as a GPT. In the next section, we highlight the importance of measuring digitalization's impact and its evolution.

[3] See Goldfarb, Taska and Teodoridis (2023) for the complete list of technologies they consider in their analysis as well as their ranking. To quantitatively rank the emerging technologies, they use information related to job postings and map emerging technologies to skills needed along the three common characteristics of a GPT. They find that machine learning, alongside a set of complementary technologies (business intelligence, big data, data mining, data science and natural language processing) consistently ranks at or near the top, suggesting it is likely a GPT. However, during the period they consider, most of the other emerging technologies in their dataset are unlikely to be on the path to becoming GPTs.

2. How we measure digitalization

Assessing digitalization's size and impact is challenging because of its ubiquitous nature. Nonetheless, measuring it remains important since its adoption affects many aspects of the economy, such as productivity, labour markets and inflation.

Digitalization can be measured in different ways. In this section, **we focus on three approaches to estimate the scope of digitalization in Canada**:

- using **output-based measures**, which estimate the value of products or outputs from the digital economy
- measuring the **capital type used in production, both tangible and intangible**
- using **employment-based measures,** focusing on the jobs associated with digital activity

What we know about digitalization in Canada depends largely on the work done by Statistics Canada. Statistics Canada's satellite accounting for the digital economy uses the output-based approach to measure digitalization.[4] Its approach to estimating software, research and development (R&D) and intellectual property products measures the capital associated with digitalization. And its estimates for data, database and science exploit the labour cost approach. These approaches focus on the more easily quantifiable aspects of digitalization at the expense of leaving out aspects that are potentially sizable but less cleanly attributable. We augment Statistics Canada's measures with related measures from the literature.

2.1 Measuring output of the digital economy

The digital economy satellite accounts were released in 2019 to present estimates of the output value, GDP and jobs associated with the digital economy (Statistics Canada 2019a). These satellite accounts were replaced by the digital supply and use tables in 2021.[5] They do not represent a change in the core national accounting framework but simply present a reorganized breakdown of the supply and use tables (SUTs) into new categories considered to be part of the digital economy.[6] Other countries currently estimate the digital economy but without a common definition, making cross-country comparisons challenging (Moulton, Tebrake and Tovar 2022). Statistics Canada adopted a modified version of the framework

[4] Satellite accounting involves rearranging the classification of data to better understand an activity or sector, such as digital transactions (Statistics Canada 2019a).

[5] Statistics Canada, "Digital supply and use tables, 2017 to 2019," *The Daily* (April 2021).

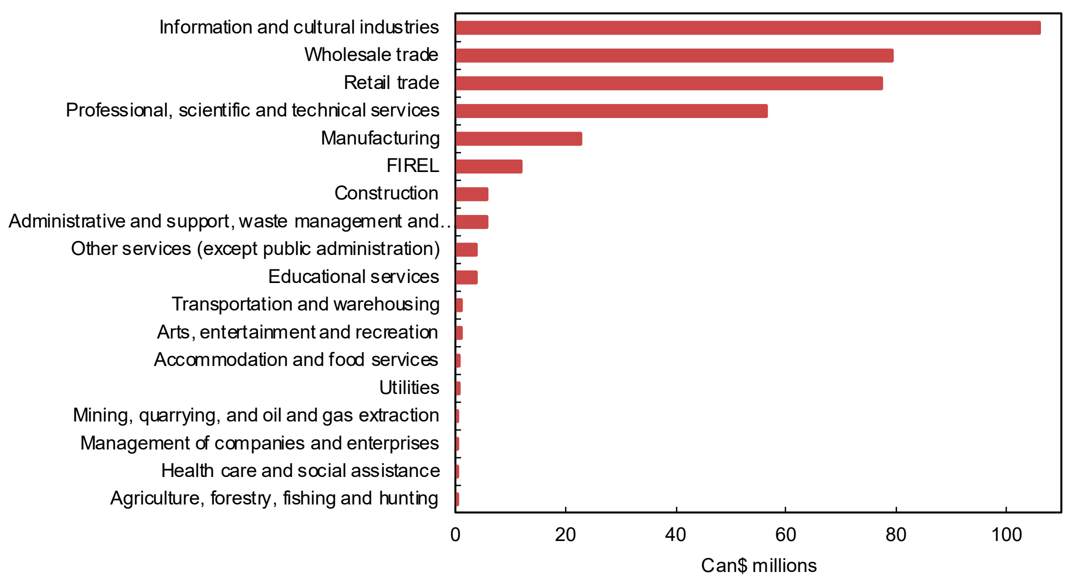
[6] The purpose of the SUTs is to trace the production by domestic industries (including imports) through their use as intermediate inputs, final consumption products, investments or exports. In this case, satellite accounting is used to disaggregate and recompile the information from the SUTs into new categories (Statistics Canada 2019a).

outlined by the OECD (2020). It identifies "full" and "partial" digital products in the SUTs to measure the value of digital activity (output, GDP and jobs) in Canada by province and industry. These are broken down into three categories:

- **Digitally enabled technology.** This includes computer hardware, software, telecom equipment and services, support services, structures used to produce digital economy goods and services and the internet of things (devices and objects that can be controlled through the internet).
- **Digitally ordered transactions (e-commerce).** This is when the sale of goods or services is done through the internet.
- **Digitally delivered products.** This is when content is transmitted and consumed in a digital format.

Nominal GDP associated with digital economic activities in Canada totalled 5.5% of the total economy in 2019, or $118 billion (Statistics Canada 2021). From 2010 to 2019, **the digital economy grew roughly 40% faster than overall GDP**. **Chart 1** shows the size of the digital economy by industry in 2018 according to use of these digital products. Unsurprisingly, services industries—information and cultural industries, wholesale trade, retail trade and professional services—dominate production in the digital economy.

Chart 1: Size of the digital economy output by business sector industries in 2018

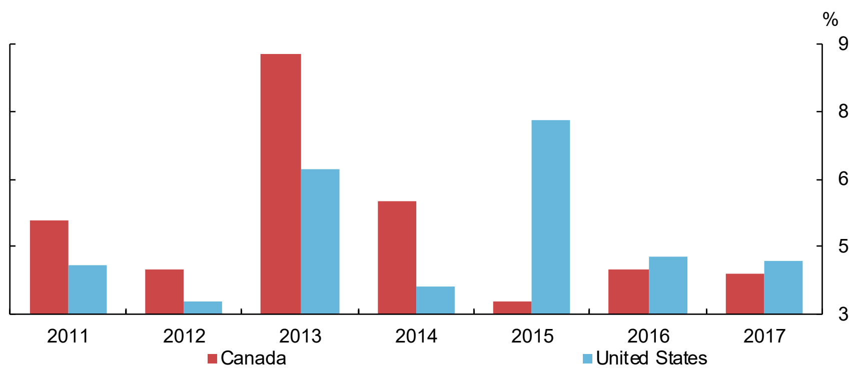


Note: The chart shows output of digital products as defined in Annex A in Statistics Canada, "Measuring digital economic activities in Canada: Initial estimates," Catalogue No. 13-605-X (May 2019). For our calculations, we have used supply-use table 2018 (15-602-X)—supply of digital products by sector. FIREL stands for finance,insurance, real estate and leasing.

Sources: Statistics Canada and Bank of Canada calculations

One of the drawbacks of using these digital economy satellite accounts is that they were only recently developed and therefore do not cover a long enough time horizon to analyze the evolution of the digital economy from its origin.[7] For example, the digital economy satellite account data start only in 2010 for Canada and in 2005 for the United States (see **Chart 2** for a growth comparison), but the digitalization process started earlier. Also, the SUTs that these accounts use are often released with a lag of a few years and only annually. The data they provide are also available only in nominal terms, and therefore researchers need to make additional assumptions when using them to track real activity. We discuss further challenges related to output-based measures in section 3.

Chart 2: Growth in the digital economy's gross domestic product, Canada and the United States



While both Canada and the United States follow the framework provided by the Organisation for Economic Co-operation and Development, their measures have some methodological differences.

Sources: Statistics Canada and Bureau of Economic Analysis

Last observation: 2017

2.2 Measuring the capital type used in production

Since the early days of the internet, statistical agencies have been adjusting how they create the national accounts to incorporate the digital economy into their measurements. In this section, we first outline Statistics Canada's incorporation of capital goods in investment measures, what Statistics Canada has incorporated (software and R&D) and what it is currently working on incorporating (data). Then we look at additional measures of capitalization, such as the digital capital stock, robots and technology adoption.

[7] The way Statistics Canada compiled estimates also changed between when the initial estimates were published (Statistics Canada 2019a) and when they were released in SUTs (Statistics Canada 2021).

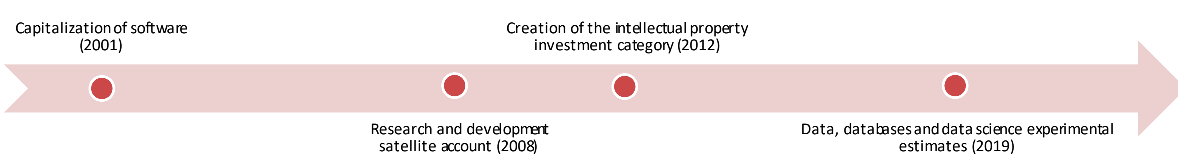
Early days: Capitalizing software and research and development

The 1997 revision of the Canadian System of National Accounts, implemented in 2001, was the first step to incorporating the intensifying digital landscape. The machinery and equipment investment category of capital expenditures was expanded to include three types of software: pre-packaged (licensed), custom-designed and own-account. Software was previously treated as a current expense, meaning that it would be consumed within the same period as an intermediate input, which is not included in value added. As a result, GDP was raised by the amount of software investment done by businesses, net investment in hardware that was already counted. **Estimates showed that the new accounting treatment for software raised GDP by $10.2 billion in 2000** (Jackson 2003). This new accounting also revealed a higher share of GDP over time, from 0.3% of the revised GDP in 1981 to 1.0% in 2000.

The R&D satellite account was launched in 2008 following the recommendations of the United Nations' System of National Accounts (SNA) (United Nations 2008). It was initially launched to explore conceptual issues around R&D's capitalization and inclusion in core accounts. Before this, expenditures in these R&D categories were not capitalized in Canada or internationally, other than for software R&D. Barber-Dueck (2008) developed estimates from 1997 to 2004 and found that additional **R&D capitalization raised GDP by $20.4 billion in 2004 and that total R&D capitalization represented 2.9% of GDP in 2004**.

The 2012 and 2015 SNA revisions brought additional changes. Software and R&D were reclassified under a new investment category: intellectual property products. Also, following the publication of the R&D satellite accounts in 2008, expenditures on R&D were reclassified from intermediate consumption to gross capital formation (investment—as recommended by SNA 2008). This meant that R&D changed from being used in production in the same year it was purchased or built to being capitalized over many years. This led to upward revisions of both the expenditure-based GDP, due to business investment increasing, and income-based GDP, due to gross operating surplus increasing. **Figure 1** presents an evolution of Statistics Canada's efforts to include capital-based measures of digitalization.

Figure 1: **Timeline of Statistics Canada's inclusion of digital capital**



Modern quandary: Incorporating data

More recently, Statistics Canada released a conceptual framework to estimate the value of data, databases and data science (data-related products) in the Canadian economy (Statistics Canada 2019c). Data-related products can be either produced by the firm (own-account) or sold on the market. Since Statistics Canada does not have comprehensive information on market sales of data-related products, it imputes the value of own-account data-related products using the cost of production (labour costs with a return to capital markup). It provides lower- and upper-bound estimates to account for the fact that even though workers' jobs may be related to the production of data-related products, workers likely do not spend all their time on this. **Total gross fixed capital formation for data-related products in 2018 was between $29 billion and $40 billion at current prices (5% to 8% of total gross fixed capital formation for Canada in 2018 prices)**.[8] Using the perpetual inventory method, **Statistics Canada also estimated the net capital stock of data-related products to be between $157 billion and $217 billion as of the end of 2018**. However, it noted challenges with estimating the data-related capital stock, which we discuss in section 3.

Services sectors: The most intensive in digital capital

The stock of digital capital is currently ill-defined, and estimating its value is difficult. Examples of challenges include the definition and value of intangible capital and data-related products, which are both discussed in the section on challenges in measurement. In this section, we follow the definition and measure developed by Liu and McDonald-Guimond (2021). Specifically, they use both the National Accounts Longitudinal Microdata File (NALMF) and Statistics Canada's capital, labour, energy, material and service (KLEMS) datasets to build an ICT capital metric. This measure—the ICT capital intensity metric—represents the ratio of the volume of digital capital over the volume of productivity-enhancing capital across industries. Using this metric, Liu and McDonald-Guimond (2021) determine which industries use digital capital more intensively and assess the evolution of its use over time. By using productivity-enhancing capital as the denominator instead of non-residential capital stock, they can control for the fact that some sectors have a higher share of capital in non-residential buildings than others.

Liu and McDonald-Guimond (2021) find that, from 2013 to 2015, ICT capital intensity was higher in the services-producing sectors than in the goods-producing sectors, with the ratio of ICT capital over total capital averaging 0.19 and 0.08, respectively. In terms of evolution, compared with 2000–02, the ICT intensity metric increased in all industries but at a faster pace in the services-producing sectors. Nonetheless, the results are driven mostly by a

[8] We used Statistics Canada Table: 36-10-0108-01.

few industries with a high intensity, as shown by the median at only 0.03 and 0.09, respectively, much lower than the average, across all industries for the two time periods considered.[9, 10]

Automation: Increasing robot adoption

Robots are not new. Their adoption started to reshape the economy and labour supply before the beginning of the fourth industrial revolution around the start of the 21st century. A distinctive feature of this fourth revolution highlights the difference between automation and robots. **Automation is a series of technological processes that allow machinery to do tasks that would otherwise be performed by humans, while robots are physical machines that execute predetermined programs**. The complexity of automation increased significantly over time and now includes technology's the ability to learn and make decisions in more sophisticated ways. In another paper in the Digital Overview series, Chernoff and Galassi (2023) discuss labour market implications and the impact of robots and automation on labour reallocation across occupations and sectors. In this section, we focus on the measurement of the robot stock.

The number of robots in the economy could be a proxy to assess the evolution of automation in an economy. As mentioned, robots and automation are not interchangeable, and some challenges exist in directly measuring automation adoption. Dixon, Hong and Wu (2021) estimate the Canadian aggregate robot stock from 1996 to 2017 using data from the Canadian Border Services Agency that identify robots imported by Canadian firms.[11] **Their paper finds that the value of aggregate robot stock in Canada was $1.6 billion in 2017**. One of the drawbacks of using import data is that these data do not provide a full picture of where the robots are actually used within the country. For example, robot imports may be handled by robot wholesalers or a parent firm that in turn ships the robots to plants elsewhere.

Liu and McDonald-Guimond (2021) also examine the evolution of robot intensity in Canada. They extend Dixon's (2020) work with the Canadian Border Services Agency data by creating a

[9] From 2013 to 2019, the industry with the highest ICT capital ratio in goods-producing sectors was computer and electronic product manufacturing (ratio of 0.222), and in services-producing sectors, it was advertising, public relations and related services (ratio of 0.478).

[10] Liu and McDonald-Guimond (2021) also use other metrics, such as digital labour and robots, to build a composite index. They find that the high intensity goods-producing sectors are computer and electronic products manufacturing; machinery manufacturing; transportation equipment manufacturing; and utilities. The highest intensity services-producing sectors are design, computer systems, management services; architectural, legal, accounting, engineering, and other professional services; information services; broadcasting and telecommunications; and advertising.

[11] Dixon et al. (2021) argue that Canada is not a meaningful producer of robotics hardware domestically and therefore the quantity imported, measured by Canadian Border Services Agency data, is a relevant proxy. To estimate the capital stock, the authors use a depreciation rate that assumes a useful life of 12 years, as stated in International Federation of Robotics guidance.

metric for the intensity of adoption across industries. Specifically, this metric represents the real value of robot stock in a given industry divided by employment from the Labour Force Survey in the same industry. **Comparing two samples (2000–02 with 2013–15), they find that robot adoption increased in all industries analyzed except for wholesale trade, where it remained mostly unchanged**. [12, 13]

The International Federation of Robotics also provides data on the stock of robots by country and by industry. Using the IRF data, the European Central Bank (2021) shows that global robot diffusion, measured as the number of robots per million hours worked, is only at about 0.75. Canada is well behind other regions such as Japan, the United States and the euro area. In fact, Canada outperforms only the United Kingdom among the 10 regions considered. The robot density, measured by the number of robots installed in the manufacturing industry per 10,000 employees, increased during the COVID-19 pandemic. The advantage of the International Federation of Robotics data is that the federation, unlike most other sources of data, directly measures the adoption of digital technologies instead of relying on some indicators that measure adoption of technologies only indirectly. However, as mentioned in Aghion et al. (2022), the International Federation of Robotics data have some limitations—for example, they are available only at the country level (which does not allow for provincial comparisons in Canada) and from only 13 manufacturing industries.

Latest advances: Prevalent technology adoptions

In its Survey of Digital Technology and Internet Use, Statistics Canada provides estimates to assess the impact of digital technologies on businesses. This survey includes measures of the value of e-commerce, the adoption of technologies and the use of the internet. The 2021 release highlighted the implications of the COVID-19 pandemic by comparing the evolution of these indicators relative to 2019.

This survey also assesses trends in the adoption of various emerging technologies. Each firm provides a list of the ICTs they use, including cloud computing, robotics, 3D printing, big data and blockchains. **Between 2019 and 2021, the largest increases were in cloud computing (from 39% to 45%) and industry-specific software (from 40% to 46%). Overall, the number of businesses that mentioned they do not use any ICT decreased from 20% to 15% (Statistics Canada 2022).** In terms of emerging technologies, the adoption of artificial

[12] Liu and McDonald-Guimond (2021) measure robot intensity in millions of chained 2007 dollars per 100 employees.

[13] Wholesale trade had the second highest level of robot intensity between 2000 and 2002, after machinery manufacturing. Most of the robot adoption in the wholesale trade sector could have taken place before 2000.

intelligence and 3D printing increased by 1.4 and 0.3 percentage points (pps) respectively, while blockchain, big data and advanced robotics were relatively unchanged.

2.3 Measuring digital work in the labour force

A growing digital workforce

A third way to measure digitalization is by looking at the number of employees working in digital occupations based on Canadian SUTs. Statistics Canada determines a digital output ratio for each product in the digital economy (described in section 2.1). It then multiplies this ratio by total jobs to estimate a proxy of the number of digital economy jobs. According to this metric, close to 900,000 jobs were associated with digital economy activities in 2017.[14] **This represents about 4.7% of all the jobs in Canada responsible for producing 5.5% of nominal GDP in that year. Between 2010 and 2017, jobs in the digital economy grew at a pace of 37%, much faster than the 8.6% growth rate of the total economy for the same period.** Using data up to the end of October 2021, Bellatin and Galassi (2022) show that this trend has continued during the pandemic period. They find that job postings in digital infrastructure outpaced the postings in the rest of the economy after the first wave of the pandemic. In fact, the gap between the two growth rates exceeded 40 pps by May 2021.

Lamb and Seddon's (2016) results, based on a slightly different definition, point in the same direction, whereby **the tech sector represented 5.6% of employment and 7.1% of GDP in 2015**. They define the tech sector more broadly than just the companies operating in ICT and include industries such as aerospace manufacturing and pharmaceutical and chemical manufacturing. They also find that 55% of employees in this sector are working in ICT. Architecture, engineering and design accounted for most of the remaining non-ICT workers, with a share of 25%. Tech employees tend to be among the most highly educated members of the labour force, with over 50% of them having a university degree. They also earn the third highest annual wage compared with employees in other industries, just below mining, oil and gas, and utilities (Lamb and Seddon 2016).

Digital workforce intensity

Liu and McDonald-Guimond (2021) build a measure of the intensity of the digital workforce that allows us to compare various industries in Canada. They define this measure as the ratio of workers employed in the digital occupations over the sum of all workers. They find that **the industries with the highest digital intensity are computer and electronics manufacturing,**

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[14] This metric includes both paid and self-employed jobs associated with the production of digital output. However, it doesn't consider employees working in a digital job but in an industry without any digital output. For example, it would not include a web designer who is hired by a bakery and then develops a website for online orders.

professional services, and information, culture and telecommunications (Liu and McDonald-Guimond 2021).

The challenge in creating such a metric is to determine the list of occupations that could be considered digital. This difficulty could lead studies to exclude people who perform some digital tasks due to the fact that they are employed in an occupation that is not classified as digital. The literature shows clear consensus on classifying some jobs as "digital," while others remain ambiguous (**Table 1**). To obtain their workforce-intensity metric, Liu and McDonald-Guimond (2021) use a definition of occupation that is slightly narrower than Lamb and Seddon's (2016) mentioned above, but they add occupations not included in previous studies.

Table 1: Selected digital occupations

Digital occupation included in each study	NOC code	OECD (Calvino et al. 2018)	McKinsey (Manyika et al. 2015)	Brookfield (Lamb and Seddon 2016)	Liu and McDonald-Guimond (2021)
Telecommunications carrier managers	131	Yes	Yes	Yes	Yes
Engineering managers	211	No	No	Yes	Yes
Computer and information systems managers	213	Yes	Yes	Yes	Yes
Statistical officers and related research support	1254	No	No	No	Yes
Mechanical engineers	2132	No	No	Yes	Yes
Electrical and electronic engineers	2133	Yes	Yes	No	Yes
Industrial and manufacturing engineers	2141	No	No	No	Yes
Metallurgical and materials engineers	2142	No	No	Yes	Yes
Aerospace engineers	2146	No	No	Yes	Yes
Computer engineers	2147	Yes	Yes	Yes	Yes
Mathematicians, statisticians, actuaries	2161	No	No	Yes	Yes
Information systems analysts and consultants	2171	Yes	Yes	Yes	Yes
Database analysts and data administrators	2172	Yes	Yes	Yes	Yes
Software engineers and designers	2173	Yes	Yes	Yes	Yes
Computer programmers and interactive media developers	2174	Yes	Yes	Yes	Yes
Web designers and developers	2175	Yes	Yes	Yes	Yes
Industrial and manufacturing technologists	2233	No	No	No	Yes
Electrical and electronic technologists	2241	No	No	No	Yes
Technical occupations in geomatics and meteorology	2255	No	No	No	Yes
Computer network technicians	2281	Yes	Yes	No	Yes
User support technicians	2282	Yes	Yes	No	Yes
Information systems testing technicians	2283	Yes	Yes	No	Yes

Graphic art technicians	5223	No	No	Yes	Yes
Graphic designers and illustrators	5241	No	No	Yes	Yes
Supervisors, electronics manufacturing	9222	No	No	No	Yes

Note: NOC is the National Occupational Classification; OECD is the Organisation for Economic Co-operation and Development. New unit groups have since been created for emerging occupations, such as data scientists and cybersecurity specialists. See Employment and Social Development Canada, "Changes to the National Occupational Classification," (June 2023) for details. Data for this table are from H. Liu and J. McDonald-Guimond, "Measuring digital intensity in the Canadian economy," Statistics Canada Economic and Social Reports, Catalogue No. 36-28-0001 (February 2021).

2.4 Comparing other advanced economies

Assessing the size of the digital economy could also be done by directly analyzing the diffusion of digital technologies. Researchers across different institutions have created many international indexes and indicators to measure specific aspects of digitalization, allowing for cross-country comparisons. For example, the European Commission tracks data on broadband access and coverage, the size of e-commerce and employment in the ICT sector.[15] Some of these metrics are used to construct the International Digital Economy and Society Index (I-DESI), an international index that ranks countries along many dimensions related to digitalization. **While many indicators exist in the literature, we focus on three: the I-DESI, the ICT Development Index (IDI) and the Network Readiness Index (NRI)**.

Some common conclusions emerge from these indicators. One is that digital public services—which include e-government, legislation and open public data—are a strength in Canada. Some differences also emerge—for example, the divergence between the NRI and I-DESI on the human skills dimension—but these are due mainly to the methodology and choice of variables. **Table 2** provides a brief overview of each indicator, with additional details in the Appendix.

[15] For a complete list of the indicators, see the "ICT sector" in the Key Indicators of the I-DESI (European Commission and Tech4i2 2020).

Table 2: Summary of international indexes

Index	Description	Geography	Canada's ranking	Canada's strengths	Canada's weaknesses
I-DESI	Measures digital economy performance based on 24 indicators across 5 different dimensions: ▪ connectivity ▪ human capital ▪ citizen use of internet ▪ integration of digital technology ▪ digital public services	Total of 45 countries: ▪ 27 EU member states ▪ 18 non-EU	2018 normalized score for Canada: 55 Canada's rank: 11 2017 normalized score for Canada: 57 Canada's rank: 18	Canada has a high *citizen use of internet* score for its number of internet users and activities performed online, such as: ▪ video calls ▪ social networking ▪ banking ▪ shopping Canada performs well in the *digital public services* dimension for its digitalization of public services, such as: ▪ eGovernment ▪ online service completion ▪ open data	Canada performs poorly in the *human capital* dimension for its relatively low: ▪ share of employees working in telecommunications ▪ proportion of graduates in information and communications technology (ICT)
IDI	Measures the evolution of ICT development using 11 indicators (2017) across 3 sub-indexes: ▪ ICT access ▪ ICT use ▪ ICT skills	176 countries	IDI (2017) Canada's score: 7.8 Canada's rank: 29 IDI (2016) Canada's score: 7.6 Canada's rank: 26	Canada performs well in the *ICT skills* dimension, in particular for its: ▪ tertiary enrolment ratio ▪ mean number of years of schooling	Canada scores poorly in some of its *ICT access* dimension, particularly for: ▪ fixed-telephone subscriptions per 100 people ▪ mobile-cellular subscriptions per 100 people

NRI	Measures the impact and application of ICT with the use of 60 selected indicators across different dimensions: ▪ governance ▪ technology ▪ people ▪ impact	130 countries	NRI (2021) Canada's rank: 11 NRI (2020) Canada's rank: 13	For each of the 4 dimensions and 12 sub-dimensions, Canada scores higher than the high-income group average. Among the 4 dimensions, Canada performs best in: ▪ *governance* (6th place) ▪ *technology* (9th place)	Canada performs poorly in its *impact* dimension (20th place), specifically in the: ▪ *economy* sub-dimension: ○ growth rate of GDP per person engaged ○ ICT services exports ▪ *sustainable development goals contribution* sub-dimension: ○ affordable and clean energy

Note: I-DESI is the International Digital Economy and Society Index; IDI is the ICT Development Index; and NRI is the Network Readiness Index.

3. Challenges in measuring digitalization

In the previous section, we discussed several ways to measure digitalization and its components. However, challenges remain in accurately measuring all its elements. This section explores first how digitalization introduces difficulties in measuring output due to free digital products. Then we discuss digitalization's impact on measuring capital in light of the rise in intangible digital forms of capital, followed by how it changes the measurement of labour because of the gig economy. Finally, we investigate how digitalization affects the determination of prices.

3.1 Missing "free" digital products widen the gap between GDP and surplus

The rise in digitalization has enabled many digital products to be easily accessible to and customized for every consumer. An output-based measurement of digitalization is difficult mainly because of free or reduced-priced digital products. It is also exceedingly difficult to distinguish between what should be measured as increasing value added and what should be measured as enhancing welfare. Many online platforms offer free products to users in exchange for database information or advertising revenues. These products are often offered at no charge or a reduced price, with companies funding their production through different methods. Some digital products are freely accessible through crowd-production schemes where users consume and build the product, such as Wikipedia and Stack Overflow. Others are funded through building customer databases or advertising revenue, and often both, such as most social media websites (e.g., Facebook, Instagram and TikTok) and many Google products and other streaming services (e.g., Maps, Calendar, YouTube and Spotify).[16]

Offering free versions of a product is also a common strategy for sellers of high-quality, low-marginal-cost products, such as computer software and certain digital applications and services. Free versions serve as a partial information signal of the quality of the product because price is not always a sufficient indicator (see Bourreau and Lethiais 2007). This is consistent with online financial information markets: coupling high-quality services with a proportion for free allows consumers to assess the quality of the service.

Since consumers spend little or nothing to use these platforms, these services are inherently challenging to value, and the national accounts may be underestimating them. **This can become especially problematic in measuring output or value added if consumers are increasingly substituting away from paid, tangible products to free or quasi-free digital products.** Such a development leads to lower consumer expenditures even though there is no change in the demand for the goods or services—only in how they are delivered to consumers.

Free digital products bring two challenges to measuring production. First, these products may be missing from our measurement of GDP since there is no or a reduced-price market transaction between the final user and the producer. Second, their contribution to household and even worker production is likely understated—for example, delivery drivers using Google Maps to find the shortest path between deliveries or programmers resolving small bugs using Stack Overflow.[17] These would lead to a higher consumer or producer surplus without necessarily affecting GDP measurements.[18] The full implications of this for productivity measurements are discussed in other papers in the Digital Overview series (see, for example, Mollins and Taskin 2023).

Researchers can take two approaches to impute a value for these digital products: using a money-based measure such as advertisement revenues or using a time- or use-based measure such as time spent on certain apps. The latter approach more closely reflects the value these products add to consumer surplus.[19]

Nakamura, Samuels and Soloveichik (2017) use a money-based approach and find that including free media has little impact on GDP. They explore adding advertising-supported

[16] Some of these platforms, such as Spotify and YouTube, also offer ad-free versions for a price.

[17] However, some argue that many of the free digital products, such as social media, may also have a negative impact on production (Schimmele, Fonberg and Schellenberg 2021; Braghieri, Levy and Makarin 2022).

[18] This would be because a worker’s use of free digital products would be counted as an intermediate input.

[19] Bourgeois (2020) mentions that one could assign free digital products a monetary value through the value of the data generated with the use of the platform. However, the scarcity of good statistics on the value of data, mentioned in greater detail in the next section, makes this approach less feasible.

media to GDP from 1998 to 2012 by including it as both a final expenditure and a business input. However, advertising can also be seen as a form of investment in a brand rather than an intermediate input (Bourgeois 2020; Nakamura 2015).

On the welfare side, by using a time- or attention-based measure of the value of free digital goods, Brynjolfsson and Oh (2012) claim that measuring advertising expenditure understates the welfare gains these products give to households. The use of these goods has been rising as consumers have substituted away from other, costly non-digital products and toward free digital goods. **This highlights the wedge digital products are driving between traditional measures of GDP—which are expenditure-based—and consumer welfare measures** (Heys, Martin and Mkandwire 2019). We explore the welfare effects of digitalization in **Box 1,** focusing on consumer surplus.

Box 1

A shift toward consumer surplus

Since expenditures may not capture the full benefits of "free" digital products, some studies instead impute the value of the extra surplus these products can yield to consumers.

- For the United States, Byrne and Corrado (2019) estimate that accounting for digital innovation adds $2,000 in consumer surplus per connected user per year—the equivalent of an extra 0.6 percentage points per year—to growth in US real gross domestic product (GDP) from 2007 to 2017. Goolsbee and Klenow (2006) and Syverson (2017) measure consumer surplus by considering the time spent using these digital goods and services.
- For Canada, Bellatin and Houle (2021) construct a similar measurement and find the increase in technology use by households yielded Can$26.17 billion more in consumer surplus from 2005 to 2019. They measured total consumer surplus from digital goods to be approximately $48.15 billion in 2019, representing about 2.3% of Canada's GDP in 2019.

Overall, these free digital goods and services appear to yield an extra benefit, but this benefit is not large relative to the size of the economy.

Another approach to assess the value of free goods is based on large-scale online choice experiments or surveys to understand how much money people would require in exchange for giving up access to free digital goods—the so-called willingness to accept (WTA) loss. WTA is a proxy for the consumer surplus, which tends to be higher than the market price. For example, Brynjolfsson et al. (2019) find that in 2016, the sample's median WTA loss of one month of Facebook was $48.49, and this valuation dropped to $37.76 in 2017. Coyle and Nguyen (2020) find significant increases in valuations of digital goods and services (such as online groceries, online learning, WhatsApp, Netflix, Facebook) between February and May of 2020.

We can either capture consumer surplus as a way of imputing the value of these free digital products or estimate their full contribution to economic surplus using a modified calculation of GDP. To get at the latter aspect, studies have suggested tracking alternative measures of GDP that would better encompass these free digital products. Brynjolfsson et al. (2019) and Hulten and Nakamura (2017; 2019) propose GDP-B and expanded GDP, respectively. These measures aim to better capture improvements in living standards from free digital platforms.

3.2 Accounting for digital capital

Digitalization has allowed for the rise in value and use of intangible forms of capital. From using data in machine learning to targeted online advertising algorithms, digitalization enables the expansion of intangible capital. Though not all forms of intangible capital are digital, those that are have a greater likelihood to be located across multiple platforms and are difficult to value because they are usually produced in house. This section explores the challenges in properly valuing the various forms of intangible capital, including data and databases.

Uncapitalized intangibles understate GDP

Intangible capital represents a growing share of firms' balance sheets in Canada (Gu and Macdonald 2020). Most forms of intangible capital are different from tangible capital because they are non-rival but can also be firm-specific. For example, the knowledge of a new drug innovation can be used across different firms (once the patent expires). In contrast, intangibles like supply chain knowledge and brand awareness (e.g., Walmart's strategy to gain market share in the early 2000s [Holmes 2011]) cannot be easily replicated across firms. Improvements in intangible capital are made not only through R&D but also through making supply chain innovations, hiring workers with new knowledge, and implementing marketing campaigns, all of which are facilitated by digitalization.

Not all intangible assets are related to digitalization. Those directly related to it include own-account software, databases and systems infrastructure, while those indirectly related could include patents or organizational capital.[20] Exactly how much intangible capital is directly related to digitalization remains unclear, but Tambe et al. (2019) combine firm-level data with LinkedIn profiles and estimate that about 25% of US firms' holdings of intangible capital is IT intangible capital. **Table 3** lists the different types of intangible capital and whether they are currently included in Canada's national accounts.

[20] Organizational capital may or may not embed digitally driven processes.

Table 3: Types of intangible capital in Canada

Categories of intangible capital	Business intangible item	Included in national accounts?
Computerized information	Computer software	Yes
	Computerized databases	Partially
Innovative property	Science and engineering R&D	Yes
	Mineral exploration	Yes
	Copyright and licence costs	Yes
	Other product development, design and research expenses	No
Economic competencies	Brand equity	No
	Firm-specific human capital	No
	Organizational capital	No

Note: Details in this table are based on work from C. Corrado, J. Haskel, C. Jona-Lasinio and M. Iommi, "Intangible Investment in the EU and US before and since the Great Recession and Its Contribution to Productivity Growth," *Journal of Infrastructure, Policy and Development* 2, no. 1 (2018): 11–36 and W. Gu and R. Macdonald, "Business Sector Intangible Capital and Sources of Labour Productivity Growth in Canada," Statistics Canada Catalogue no. 11F0019M—No. 442 (2020).

Measuring intangibles is especially difficult for a few reasons. First, this type of capital is typically created within the firm and tends to be under-reported as an asset on firms' balance sheets.[21] Second, depreciation rates are hard to establish for assets whose reduction in value is not physical (through wear and tear) and whose economic lifespans vary hugely.[22] Finally, it is difficult to differentiate firm from industry value-added improvements. Often, intangible investments such as marketing or brand equity lead to gains in market share at the firm level rather than higher value added at the industry level.

In the United States, the term "broader investment puzzle" was coined by Crouzet and Eberly (2019) to designate the separation of firms' investment from their market valuation. In essence, the firms with the top valuations no longer necessarily have the highest level of investment. Some papers (Ewens, Peters and Wang 2020; Crouzet and Eberly 2019) explain this puzzle by pointing to firms' under-reporting of intangible capital. Corrado, Hulten and Sichel (2009) find

[21] Ledoux and Cormier (2013) find that the reporting of intangibles in Canadian firms' financial statements was lower than firms' voluntary disclosure about innovation from their corporate websites.

[22] For example, the value of data used for advertisement targeting may be short-lived, while genomics data stay relevant for at least the individual's lifetime.

that more than $3 trillion of business intangible capital stock is missing from investment data as of 2003. Kogan et al. (2017) use patent grants and resulting stock market valuation changes to improve the estimation of innovation at the firm level. They find substantial improvements when they use their measure to explain the relationship between firm growth and market value.

The consequences of mismeasuring intangible capital are twofold. First, if intangible investments are missing, then **firms may appear to have much higher profits relative to the amount of capital they use as an input**. This is exacerbated by the finding that production functions tend to have constant returns to tangible capital but increasing returns to intangible capital (Corrado et al. 2022). Second, **if expenditures on intangibles are no longer counted as being consumed in the same period, as intermediate inputs, and instead are capitalized, measured GDP would be understated**. These impacts on productivity are discussed in another paper in the Digital Overview series (Mollins and Taskin 2023).

In Canada, Gu and Macdonald (2020) reclassify many new forms of intangibles from intermediate inputs and capitalize them as an investment. Many of these new categories are directly or indirectly related to the digital economy (advertising and brand equity, financial innovation, architectural design, purchased non-R&D science, own-account non-R&D science, firm-specific human capital and own-account and purchased organizational capital). Gu and Macdonald 's estimates suggest that **intangible capital represents about 36% of gross fixed capital formation as of 2016** and that the intangible assets category with the largest expenditure is own-account organizational capital. However, these estimates are derived from firms' balance sheet reporting and are likely to be underestimates of the true value.

Internationally, a key implication of the non-rivalry of digital capital is the ease of relocation across countries. If a capital input is intangible, firms are more likely to choose its country of residence based on tax advantages. Lipsey (2008) compares multinational firms' reporting of the relative size of total assets with their reporting of the size of their tangible assets. He tallies the amount of labour and tangible capital (plants and equipment) relative to the total amount of reported assets (tangible plus intangible) and identifies locations with the greatest imbalance. He finds the ratio of assets per employee of US multinationals in tax haven Caribbean islands to be $16 million per employee in 2005, relative to $4 million per employee in Europe. In particular, US multinational affiliates held $150 million per employee in Bermuda. However, the intangibles typically targeted in these overseas strategies are usually more finance-related and not necessarily directly tied to digitalization, though digitalization does enable their displacement.

In Canada, Caribbean tax havens (Bermuda, Barbados, Cayman Islands and Bahamas) receive 11.4% of Canada's foreign direct investment.[23] Collectively, they were the second largest

[23] Our calculations are based on Statistics Canada's Table no. 36-10-0008-01.

recipient of Canadian foreign direct investment after the United States in 2021. Since this investment is largely not going into tangible assets (such as factories or machinery and equipment), much of it is done under the umbrella of intangible capital. This makes it complicated to identify the origin and the location of use of intangible capital for Canada.

Reallocation from investment to cloud computing services

Powered by digitalization's ease of movement across locations or platforms, cloud computing has transformed companies' ability to outsource computational tasks. Servers can reside in areas where cooling services, electricity and land are more affordable, provided the location is well integrated in the global network. Cloud computing is relatively simple to integrate within a firm and typically much less expensive than buying the computing capital and hiring the skilled labour to operate it. Otherwise, a firm would have to invest in the maximum amount of information technology capacity it needs even if it did not always use it. By purchasing cloud services, a firm can rapidly scale production up or down and reduce the amount it needs to invest in ICT infrastructure.[24] The adoption of cloud computing has blurred the boundaries for both investment and production accounting.

On the investment side, the increasing returns to scale in this industry make this market highly concentrated. In 2021, the biggest providers of cloud computing worldwide—Amazon Web Services, Microsoft Azure, Alibaba, Google Cloud Platform and Huawei—represented 80.2% of the global market share.[25] These companies are headquartered in a small number of countries. Firms are increasingly moving toward these cloud services and away from hosting the infrastructure necessary to run software, computations and data in house. This means that much of the investment in software and ICT hardware to run cloud computing services is often not made in the country where the firm purchasing these cloud services is located. Instead, **these services are recorded as a service import and do not contribute to the country's capital stock. This may help explain some of the under-investment seen in Canada relative to the United States.**

On the production side, the national accounting problems created by cloud computing can be explained through a simple example, outlined in Baer, Lee and Tebrake (2020). Consider a situation where the cloud services are located outside of Canada. In this case, an **import of cloud computing services may be made in Canada, while the servers (where the production activity is done) are in another, or multiple other, countries**. This makes it

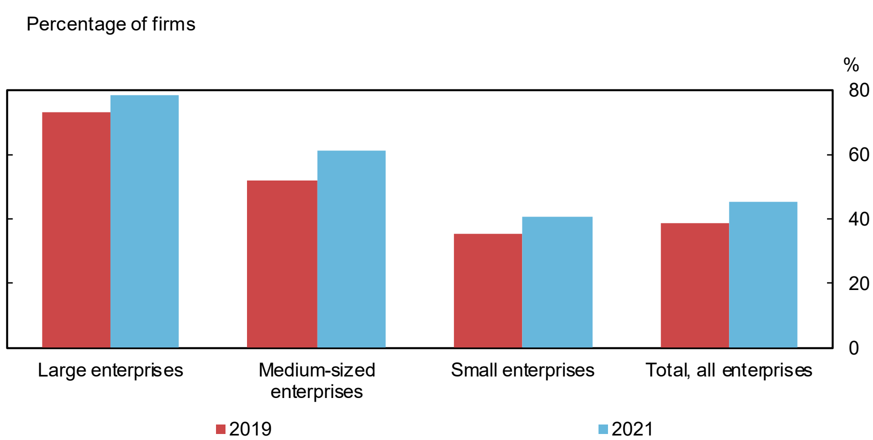
[24] However, this gain in efficiency for the firm is done at the expense of stability of production. If the connection to the cloud platform goes down, it will significantly impact the firm's cloud-based production.

[25] "Gartner Says Worldwide IaaS Public Cloud Services Market Grew 41.4% in 2021," Press release, Gartner, June 2, 2022.

difficult to establish where the production of cloud services is taking place and the proper production structure between the involved countries.

Baer, Lee and Tebrake (2020) also show how cloud computing is often misclassified in various categories of the Canadian Annual Survey of Manufacturing and Logging Industries (ASML). Cloud computing involves trade in digital services captured through enterprise surveys rather than through customs transaction data. This makes tracking its development and impact on the Canadian economy difficult. As **Chart 3** shows, based on results from Statistics Canada's Survey of Digital Technology and Internet Use, a large portion of Canadian firms reported purchasing cloud computing services, especially large firms. **Almost 80% of Canada's large firms and almost half of all firms purchased cloud-based services**. Large firms spend a significantly larger amount on cloud computing services—$558,000 per year on average—whereas small business spend on average $8,800 per year (Statistics Canada 2022). Additionally, the **share of firms using cloud computing services increased by 6.4 pps across all firm sizes between 2019 and 2021**.[26]

Chart 3: Comparison of Canadian firms' purchase of cloud computing by size



Note: Data are from Statistics Canada's 2019 and 2021 Survey of Digital Technology and Internet Use and from Statistics Canada Table 22-10-0117-01.

Source: Statistics Canada

Missing capitalization of data

Data are a critical component of digitalization. Data and datasets act as input, intermediate goods and output in production. Many challenges are associated with estimating and capitalizing the value of digitalization. **Some datasets have significant value as investment**

[26] It is worth nothing that the Survey of Digital Technology and Internet Use covers fewer firms than the ASML.

goods, while the value of others is short-lived. As a result, measuring the value of data in the Canadian economy and being able to capitalize it accurately are challenging.

Data are non-rival goods, meaning that **the same data point can be copied and used simultaneously across different platforms without diminishing the quantity available to a single user**. Data also do not physically depreciate the same way buildings, machinery and equipment do, but they may depreciate in their economic usefulness. For example, the value of customer data to advertisers can be very short-lived, whereas the value of journal archives can be long-lasting.

Another challenge for valuing data-related products in Canada arises when using firms' own estimations from their tax statements. The firms' own valuations of their data and databases might provide good information to establish the value of their stock. However, few firms in Canada report this number on their balance sheets, or they tend to group it with other categories of intangible capital, such as goodwill.

Statistics Canada (2019b) outlines the main method for estimating the stock of data-related products and its associated challenges. As recommended by the SNA 2008, most countries have adopted a perpetual inventory method to measure the stock of data-related products in the economy.[27] Using this method requires making assumptions about data's depreciation profile. Estimates for the stock of data-related products presented in the previous section assume a useful life of 25 years, 5 years and 6 years for data, databases and data science, respectively. Currently, **data and some parts of databases are not included in the Canadian System of National Accounts**.

3.3 Assessing the impact of the gig economy

Digitalization has allowed the expansion of platforms for gig work in Canada. A gig worker is someone who works one or more temporary jobs as an independent contractor or freelancer. The digitalization of these platforms can now match these gig workers with firms or consumers instantaneously and globally. The rise in e-commerce allows gig workers to sell their products directly to consumers almost anywhere in the world. As well, peer-to-peer rideshare and accommodation apps have streamlined the procurement and payment of these services on one platform.

Gig workers benefit from nonpecuniary perks such as flexible schedules. However, they tend to have less predictable earnings and lack the legal rights, health benefits and retirement plans afforded under conventional employment contracts. For firms, gig workers can lower their

[27] Other possible methods include treating data-related products as assets or discounting the future stream of revenue (treating it as a natural resource). These methods are found to be less feasible for data-related products than the perpetual inventory method (Statistics Canada 2019c).

labour costs and allow them to respond to rapidly changing market conditions. By using platforms such as Amazon Mechanical Turk, firms can compartmentalize small components of their projects and outsource them to workers. If the project ends up getting cancelled, they can halt the outsourcing of these tasks without having to make direct modifications to their own labour force.

Measuring the size of the gig economy in Canada is challenging, with different surveys and tax data yielding different estimates. The key issue is that these gig workers are difficult to distinguish from self-employed workers, given that gig work is not likely to be their main work activity. Kostyshyna and Luu (2019) use a special edition of the Bank of Canada's Canadian Survey of Consumer Expectations that asks households about their participation in gig work to estimate the size of the gig economy in Canada. They find that approximately 30% of Canadians participated in gig work in 2018. Overall, they find that properly accounting for gig workers would represent the equivalent of approximately 700,000 full-time jobs or about 3.5% of the labour force in the third and fourth quarters of 2018. In its Labour Force Survey, Statistics Canada (2017) found only 0.3% of Canadians participated in rideshare services and 0.2% in shared accommodations.[28, 29] However, using Canadian administrative tax data, Jeon, Liu and Ostrovsky (2022) find that gig workers represented 8.2% of workers in 2016.[30, 31] **If these workers are not all accounted for in the labour force, then their labour participation rates or contribution to work hours may be underestimated**.

3.4 Tracking prices in a digital world

This section explores how digitalization affects the measurement of prices. Challenges around this impact occur in four main ways:

- the increased difficulty in tracking quality improvements of digital goods
- the delayed introduction of new products to price indexes
- the increase in “free” digital products
- the rise in e-commerce and online data collection

[28] Statistics Canada (2017) used a smaller definition of gig work, surveying respondents’ participation in only the platforms Uber, Lyft, Airbnb and FlipKey.

[29] A newer release of the Labour Force Survey in December 2022 found 1.5% of those employed that month provided either rideshare or food or goods delivery through a digital platform.

[30] Jeon, Liu and Ostrovsky (2022) define gig workers as unincorporated, self-employed workers (sole proprietors) who report business, professional or commission self-employment income on their T1 tax returns and attach at least one T2125 form without a business number.

[31] Jeon, Liu and Ostrovsky (2022) consider this number to be a lower bound because they may be missing gig workers with a gross income above $30,000. They find an upper bound of 10.3% of workers.

We also discuss some benefits, such as improvements in how prices are observed in real time.

The first three challenges to tracking prices, as covered in Reinsdorf and Schreyer (2019), are particularly problematic for digital products. In new iterations of digital products, the product's technological characteristics change when the new version replaces the old. But the quality improvements are more likely to be understated for digital products. Also, novel products may be replacing existing varieties but these new products are too different from their predecessors to be assigned a proper quality adjustment. These quality adjustments require significant revisions before they are added to the price index. Finally, the free digital products discussed in section 2.1 also contribute to this mismeasurement of prices, which is especially problematic when they replace more expensive products (e.g., Wikipedia replacing encyclopedias). However, it is difficult to disentangle what portion of these free products should be added to consumer welfare and what portion contributes to revisions to aggregate deflators.

The fourth way in which digitalization makes it more difficult to measure prices is through the rise in e-commerce. People increasingly turn to e-commerce platforms, where prices tend to be lower, especially for products listed solely online. If the prices on these platforms are not adequately captured in consumer price index (CPI) calculations, the cost of living may be overstated. An important consideration is that e-commerce statistics from Statistics Canada's business survey do not include products sold by Amazon (Chernoff 2019).[32] Leaving Amazon Canada's sales out of the estimates clearly represents a challenge in the measurement of e-commerce, since the estimates would not provide a global view of the e-commerce market.

In some circumstances, e-commerce also allows sellers to charge different consumers different prices for the same product. Recent developments in marketing technologies allow firms to collect and link information about consumers. As a result, they may charge different prices to different consumers based on their perceived willingness to pay.[33] Using Canadian price data, Mitchell (2019) finds that products sold solely online have a higher price variance than products sold only in stores and products sold both online and in stores.

On the positive side, digitalization has the capacity to improve how we collect price data. Traditionally, statistical agencies relied on people visiting physical stores to collect price data

[32] However, Amazon activity is included in other statistical measures through imports by households. As well, any online seller with a physical headquarters located in Canada that sells through Amazon Marketplace would be included in Statistics Canada's Non-store Retail Survey and therefore would be represented in Statistics Canada's estimates of e-commerce sales.

[33] This type of price differentiation is not possible for all online platforms. It requires access to customer data and the capacity to link their information to an account or IP address. Google, Facebook and Amazon's privacy statements say they can collect information on users' views, searches and interactions on their page and third-party pages. Some studies find evidence of this price differentiation by various firms at one point or another (Hannak et al. 2014; Mikians et al. 2013; Valentino-Devries, Singer-Vine and Soltani 2012; Viswanathan et al. 2007) while others do not observe this price discrimination, for example, in the airline industry (Vissers et al. 2014).

on the items in the basket of goods and services contained in the CPI. Obtaining, or scraping, online prices and product information can improve the timeliness and reduce the labour costs associated with data collection. The Billion Prices Project by Cavallo and Rigobon (2016) collects a vast amount of online prices to evaluate pricing dynamics in different countries. This has yielded the PriceStats database, which is used by statistical agencies around the world and is comparable to many price indexes produced in advanced economies. Details of this database are further explored in the Digitalization Overview series paper by Chu, Dahlhaus and Hajzler (forthcoming) on the topic of prices and inflation.

Online price collection leads to new ways of incorporating alternative data in Canadian CPI. Statistics Canada (2021) describes the changes to its CPI data collection, which include the use of web-scraped and application programming interface data. **The main challenge with collecting online prices is that consumers may be buying products from all over the world, and it is difficult to discern exactly which and how many of these products Canadians are buying**.

4. Trends and questions for the future

Given digitalization's broad impact on businesses, households and markets, measuring it is difficult. Our discussion highlighted that digitalization is truly pervasive, relating to automation, ICT, technology adoption, and technological developments in machinery and equipment. The various measures reviewed here strike a balance between leveraging available data and focusing on areas where digitalization is thought to be most transformative. However, some important developments in digitalization and their impacts may not be included.

Section 3 discussed many challenges, but an important open question relates to the future impacts of the COVID-19 pandemic on digitalization. Most studies agree that the pandemic accelerated the pace of digitalization. Examples of this include the increased capacity for employees to work from home, the surge of e-commerce when businesses had to temporarily close their physical stores and the increase in digital skills. It remains to be seen if these were only a front-loading of future improvements or if this pace will be maintained.

Increasing resilience to future pandemics or supply disruptions could lead firms to even higher levels of adopting and investing in ICT. Firms and consumers have so far retained their attitudes toward online shopping and working from home, despite the reopening of the economy. Assessing and measuring the long-term structural implications of these trends is important because of their impacts on inflation, productivity and the labour market.

Another outcome of the pandemic is the enhanced use of timelier high-frequency indicators. Examples include the use of credit card data, mobility data, online bookings and Indeed job postings, all coming from our digitalized economy. These were particularly useful given the publication lags in official statistics and suspensions in data collection. In addition, concerns about the inaccuracy of the CPI basket weights due to rapid changes in consumers' behaviour led price collection to move almost entirely online. While these metrics are valuable in filling information gaps, their timeline does not extend far into the past and the series are volatile, making it difficult to disentangle true signals in the data from noise. Nonetheless, we should continue efforts to develop such indicators and to leverage their use in policy decisions.

A trend with potentially large economic consequences is the rise in intangible capital. In this paper, we discussed how challenging it could be to measure the value of firms' intangible capital. However, an important characteristic of such assets is their sensitivity to monetary policy. The literature shows that, compared with tangible investment, intangible assets tend to be less sensitive to interest rates since they have higher depreciation rates and are less usable as collateral (see Crouzet and Eberly 2019; Döttling and Ratnovski 2021). Given the implications of this for monetary policy, we should aim to better understand the size and evolution of intangible capital in Canada and the effect of interest rate shocks on firms with a greater proportion of intangible assets.

Lastly, another important issue is the potential impact of digitalization on welfare. Most agree that GDP is an imperfect measure of welfare. It remains to be seen how much digitalization will improve the well-being of consumers compared with how much it will improve productivity and output. We discussed the impact of digitalization on consumer surplus in Box 1, but more work should be done. In this paper, we focused on direct metrics such as output, capital and labour. However, analyzing impacts on welfare by using measures similar to the expanded measures of GDP presented in Box 1 could lead to a better understanding of the ubiquitous nature of digitalization.

Key open questions

- How will the COVID-19 pandemic and the related new behaviours of consumers and businesses affect the adoption of new technologies? Will more timely indicators help measure the economy better?
- How will the challenges in measuring intangible capital evolve and how sensitive is this type of capital to monetary policy?
- Will digitalization have a bigger impact on productivity or on the well-being of consumers? What metrics could be developed to assess the impact of digitalization on welfare instead of on GDP?

Appendix: How digitalization in Canada compares internationally

The pace of digital adoption varies across countries. We present several international indicators and indexes and compare how Canada ranks relative to other advanced economies. In this appendix, we refer to the International Digital Economy and Society Index (I-DESI), the ICT Development Index (IDI) and the Network Readiness Index (NRI). However, a full range of other indexes exists (see Csonto, Huang and Tovar 2019 for other examples).

International Digital Economy and Society Index

The European Commission publishes the Digital Economy and Society Index (DESI) along with its international version, the I-DESI. The indexes focus on 24 indicators across five dimensions to assess the degree of digital adoption in each economy. Compared with the 44 other countries assessed, Canada's score (54) is above both the EU average (48) and the non-EU average (49), but the scores vary across dimensions of the index, particularly among European countries (European Commission 2020). Canada's score remains below some other G7 countries, such as the United States (62) and the United Kingdom (58). Canada scores highly overall in terms of digital adoption. This reflects a strong relative performance in three of the dimensions (connectivity, citizen use of internet and digital public services), while the human capital dimension shows significant growth potential. In the following, we consider each of the five dimensions of this index and explain how Canada performs in them.

- **Connectivity** measures the deployment and quality of broadband. It includes fixed and mobile broadband coverage, as well as speed and affordability. Canada's score for connectivity is 60, slightly above the non-EU average of 59 but under the EU average of 62 and well below the US score of 70. The affordability indicator in this category is one where progress could be made. Nonetheless, in terms of the evolution of connectivity, Canada improved between 2015 to 2017 but plateaued in 2018.
- **Human capital** examines the skills needed to take advantage of the possibilities offered by a digital society. This dimension includes two sub-dimensions: internet user skills and advanced skills and development. The first measures the number of users having various levels of digital skills in word processing, using spreadsheets or coding. The second refers to the share of employees working in telecommunications and the proportion of people graduating in ICT. For this dimension, Canada performs relatively poorly with a score of 36.5 compared with the EU average of 41.8 and the non-EU average of 43.0.

- **Citizen use of internet** considers the variety of activities performed by citizens already online. Such activities include the use of internet for video calls, social networks, banking and shopping and, more generally, the number of internet users as a share of the total population. Canada significantly outperforms the average of EU (47.0) and non-EU (51.8), with a normalized score of 61.6.
- **Integration of digital technology** assesses the digitalization of businesses and development of online sales. This dimension is grouped into two sub-dimensions. The first measures the availability of the latest technology and technology absorption. The second captures the proportion of small and medium-sized enterprises selling goods or services online and the number of secure internet servers per one million people. For this dimension, Canada ranks above the EU average of 41.1 and the non-EU average of 46.2 with a score of 55.7.
- **Digital public services** measures the digitalization of public services, focusing on eGovernment. It comprises three specific indicators: the proportion of the population accessing government services online (eGovernment), online service completion (availability of online information and online public consultation) and the OECD indicator for open data. Canada performs well in this dimension with a score of 70.2, well above the EU average of 56.0 and the non-EU average of 60.4.

To obtain the total I-DESI index, scores for these five dimensions are aggregated using a weight of 25% for the first two, 15% for the third and fifth and 20% for the fourth. While Canada is above average across most of the dimensions, it is never among the top five countries and remains behind its closest neighbour, the United States. The area with the most potential for improvement is in the human capital dimension, particularly the sub-dimension associated with the share of employees working in telecommunications and the proportion of people graduating in ICT, where Canada ranks close to the bottom of the list. While improvement is observed overall between 2015 and 2017, a plateau was reached in most dimensions by 2018. More work could be done to assess the underlying causes of this slowdown.

ICT Development Index

The IDI is a composite index published by the UN's International Telecommunication Union. Its main focus is to monitor and compare development in ICT. The 2017 version comprises 11 indicators combined in three sub-indexes: ICT access, ICT use and ICT skills. Each of these sub-indexes includes various indicators to measure the evolution of ICT development. Examples include the percentage of households with computer or internet access, the secondary and tertiary enrolment ratio, and fixed or mobile broadband subscriptions.

Overall, Canada ranks 29th out of 176 countries with a score of 7.8 in the 2017 edition of the IDI, three positions lower than in the 2016 report. By comparison, the top five countries averaged a score of 8.8 while the United States ranked 16th with a score of 8.2. In terms of sub-indexes, Canada performs well in the ICT skills dimension, particularly in the tertiary enrolment ratio, as well as in the mean of years of schooling. It might seem surprising that Canada outperforms in this category since human capital was the weakest sub-dimension in the I-DESI, but this is due to the broader indicators in the IDI used to proxy ICT-related skills. The lowest indicators are the fixed and mobile telephone subscription per 100 people, both averaging a normalized score of only 6.4 out of 10.

Network Readiness Index

The Network Readiness Index (NRI), launched in 2002 by the World Economic Forum, is another composite index to compare the impact and application of ICT. Similar to the I-DESI and the IDI, this index comprises different dimensions: technology, people, governance and impact. Each dimension is then decomposed in three sub-dimensions, and, overall, 60 indicators are selected to compare 130 different economies. An interesting feature of this index is the fact that the latest 2021 edition can be used to examine the impact of the COVID-19 pandemic, which is currently not possible with the IDI and the I-DESI.

Overall, Canada ranks 11th in the 2021 report for the aggregate index. In term of sub-dimensions, Canada performs well in governance (6th place) and technology (9th place). In particular, Canada ranks as a leader in a few indicators, such as e-commerce legislation (1st), good health and well-being (1st) and publication and open data (2nd). However, there is scope for improvement in the other two dimensions, particularly in the impact dimension (20th). The weakest indicators include energy intensity (111th), ICT services exports (66th) and ICT regulatory environment (60th). Nonetheless, Canada's score is higher than the group average of high-income countries in each of the four dimensions and 12 sub-dimensions. Canada's NRI score relative to its GDP per capita is above the trend line determined by other high-income-group countries. Canada is second in the Americas regional group with a score of 76.5, behind the United States with a score of 81.1.

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