Telecom Advisory Services LLC

ECONOMIC IMPACT OF CLOUD COMPUTING AND **ARTIFICIAL INTELLIGENCE IN CANADA**

November 2024

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This report was commissioned by Amazon Web Services. All of the study's content, including its conclusions, are the independent outcome of the analysis conducted solely by the authors and Telecom Advisory Services.

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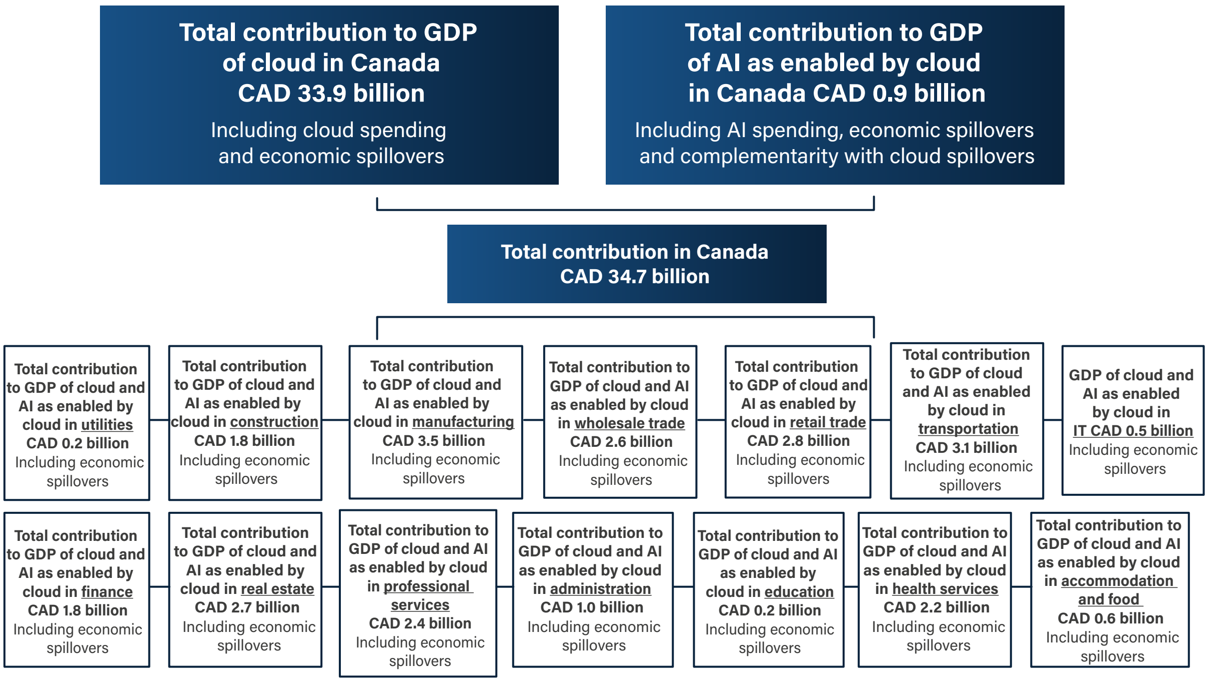
EXECUTIVE SUMMARY

Prior research on the macro-economic contribution of cloud computing has already concluded that, driven by its impact on capital efficiency and stimulus of product development, cloud represents an engine of economic growth. That being said, beyond the economic impact of cloud itself, it is relevant to investigate whether there is additional value generated by Artificial Intelligence (AI) as enabled by cloud computing. The purpose of this study is to assess the economic contribution of cloud computing and evaluate the additional interaction benefits that arise from complementing it with the delivery of AI in Canada. The study conclusion is that cloud computing, as a stand-alone technology and as an enabler of AI, contributed CAD 34.7 billion to the 2021 Canada's Gross Domestic Product (GDP).



Source: Telecom Advisory Services analysis

These results were calculated for 2021 as, at october 2024, this was the last year where official data was available on cloud adoption. Our projections for the following years allow us to estimate a total economic impact of cloud computing and AI enabled by cloud accounting for CAD 34 billion in 2023, increasing to CAD 35 billion in 2024.

The Canadian cloud computing market is evolving fast, having reached CAD 21.86 billion (US$ 16.19 billion) in spending in 2023,[1] which represents 0.8% of the country's GDP. As in the case of cloud computing, AI spending in Canada is also growing, amounting to CAD 2.5 billion (US$ 1.8 billion).[2] In particular, while spending by Canadian businesses in purchasing AI technology from cloud service providers for 2023 amounts to CAD 351.30 million (US$ 260.24 million) (or 14.19% of the total AI market), it has been growing at 39.88% per year.

[1] *Source: IDC Semiannual Public Cloud Services Tracker (2024H1 Release).*
[2] *Source: IDC Semiannual Artificial Intelligence Infrastructure Tracker 2023H2*

Recognizing that the economic contribution of cloud and AI includes not only user spending, but also spillovers in terms of production efficiencies to the whole economy, total impact was estimated as follows:

- **The total GDP contribution of cloud computing in Canada in 2021,[3] comprising cloud spending and its spillovers on the economy, is sizable: CAD 34.7 billion.**

- **The contribution to GDP derived from AI enabled by cloud computing in the same year amounted to CAD 0.9 billion (this does not include other economic gains from AI not enabled by cloud, which comprises purchasing from non-cloud suppliers).**

- **Over the following eight-year timeframe (2022-30), the economic impact of cloud in Canada will be significant, reaching CAD 370 billion (or 1.77% of the forecasted cumulative GDP for the same period), while the impact of AI enabled by cloud computing will reach CAD 25 billion (or 0.12% of the forecasted cumulative GDP for the same time period).**

On the basis of the estimates presented above, the differential economic impact by industry was calculated, leading to the following conclusions:

- **Industries that accelerate their adoption of cloud will generate important economic gains.** The econometric model developed for this study suggests that a 1% increase in cloud adoption in Canada will yield an increase of 0.128% of their economic output. **This impact is equivalent to CAD 265 million in manufacturing, CAD 152 million in wholesale trade, CAD 97 million in transportation and warehousing, CAD 91 million in information and cultural industries and CAD 197 million in finance and insurance activities.**

- **The amount of cloud spillovers depends on the intensity of AI use. Industries which are high AI users will experience a larger increase in economic impact resulting from a 1% increase in cloud adoption.** This additional effect generated by the increase in cloud adoption varies by industry depending on the current AI adoption, which accounts for CAD 9.5 million in manufacturing, CAD 4.3 million in wholesale trade, CAD 3.1 million in transportation and warehousing, CAD 9.0 million in information and cultural industries and CAD 19.1 million in finance and insurance activities.

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[3] While, as reported above, we can report data on cloud spending up to 2023, the estimation of spillovers depends on the adoption of the technology among enterprises, where the latest statistics provided by the Government of Canada are for 2021. See goverment at Canada 2021 Survey of Digital Technology and Internet Use.

- **Accordingly, these results suggest that a more pro-active approach to cloud development will lead Canada to overperform in terms of AI economic impact.**

The estimates of economic impact of cloud-enabled AI adoption presented above are mainly based on AI applications that precede the diffusion of generative AI. Since their launch at the end of 2022, generative AI models have moved from being "modular specialists" (generating images from captions, transcribing text to speech) to getting integrated into applications such as writing assistance, coding, translation used in multiple industries and functions. Most research conducted up to date on the economic impact of generative AI refers to its potential for enhancing labor productivity. By adjusting the productivity estimates calculated for 2023, generative AI has the potential to generate a boost in economic benefits. **Productivity gains from AI, estimated at CAD 1,667 per worker in 2023, can increase in a magnitude that ranges from CAD 327 (pessimistic scenario) to CAD 1,633 (optimistic scenario) due to Generative AI.**

These results demonstrate the importance of cloud computing and cloud enabled AI for the economic development of Canada, and the relevance of creating a policy and regulatory environment aimed at maximizing their impact. A relevant aspect to address is the still low adoption of AI, which should be accelerated to maximize the positive effects on citizens and businesses.

1. INTRODUCTION: CLOUD COMPUTING AND CLOUD-ENABLED ARTIFICIAL INTELLIGENCE

Deep economic transformations have been triggered by the development and diffusion of digital technologies over the past few decades, especially for businesses, where new procedures, reduced expenses, and improved operations have resulted in significant changes in production processes and operating models. These developments have been made possible for public and private organizations using information technology to improve their performance, leading, in turn, to overall economic growth. While the contribution of the internet and broadband connectivity has been extensively researched in the empirical literature over the past twenty years, the analysis of the economic impact of more advanced and sophisticated digital tools is still evolving. Among the most recent technological innovations, cloud computing and artificial intelligence are powerful technologies for organizations looking to execute significant production model changes, accomplish their strategic goals, and remain competitive. In this context, the purpose of this study is to complement the research on economic effects of digital technologies, by focusing particularly on cloud computing and artificial intelligence independently, and also evaluating the interaction effects that arise from complementing both technologies in Canada.

Research on the macro-economic contribution of cloud computing has concluded that, driven by its impact on capital efficiency and stimulus of product development, cloud represents an engine of economic growth. The aggregated economic contribution of cloud computing to GDP is composed of: (i) the domestic revenues generated by cloud service providers and (ii) the spillover effects of cloud services on the total economy. The revenues represent the spending of public and private organizations purchasing cloud services,[4] while the spillover effects are the benefits generated by cloud computing in terms of IT cost efficiencies, new product development, support for incubation of startups and the like.[5] In this context, it would be pertinent to investigate **the potential benefit to be derived in Canada if the country were to reach a higher level of cloud adoption: in other words, yield a higher return to scale.[6]**

Beyond the economic impact of cloud itself, it is also relevant to investigate whether there is additional value generated by the technology as a result of its capacity to enable AI. Technological complementarity[7] is defined as the interaction of technologies that work together to enhance or improve their respective overall performance or functionality.

[4] The revenues are a measure of market demand that can be met through cloud providers based within the country or beyond the country's borders.
[5] For example, when cloud services enable the adoption of IT services in the SME sector, which benefits from the scalability of IT state-of-the-art, that is considered to be a spillover effect.
[6] Return to scale describes what happens to long-run returns as the scale of production increases, when all input levels including physical capital usage are variable. In the cloud case, as cloud adoption increases, the elasticity on GDP impact grows accordingly. See example for broadband in Katz, R., Jung, J. (2021). The economic impact of broadband and digitization through the COVID-19 pandemic: Econometric modelling. Geneva: International Telecommunication Union.
[7] As defined by Pattee (1978), complementarity is defined as two components requiring "a separate mode of description that is formally incompatible with and irreducible to the other (but) where one mode of description alone does not provide comprehensive explanatory power".

The following study assesses a key dimension of complementarity, examining the interrelationship between cloud computing and AI. AI is defined as the use of machine learning and related technologies that use data to train statistical models for the purpose of enabling computer systems to perform tasks normally associated with human intelligence or perception, such as computer visión, speech or natural language processing and content generation. This definition highlights that AI relies on data and other inputs to capture large volumes of information, perform analyses, and formulate customized outputs. With its more recent advances, AI has emerged as a transformative technology with the potential to reshape the economy, revolutionizing the way we work. AI is becoming a driving force behind automation and innovation in various industries, offering immense opportunities while also raising unique challenges from the economics, legal and ethical perspectives.

On the other hand, AI requires an inordinate amount of computing resources to operate. In response to this requirement, cloud computing represents a powerful enabler. Furthermore, Big Data is expected to contribute to accelerate the use of Machine Learning, by providing useful information for AI-related decision-making processes. Under the premise of technological complementarity, it is reasonable to consider that AI adoption would be higher for enterprises that have adopted cloud yielding in turn higher business performance. Accordingly, we argue that **countries with high adoption of cloud computing and AI will create high economic value, as measured by GDP contribution.**

This hypothesis can also be extrapolated to the new AI solutions of generative intelligence. One of the technology primary challenges of generative AI remains computing resources (in this case, Graphics Processing Units (GPUs), and large amounts of memory). Generative AI models (Large Language Models, Transformer-based models, and adversarial networks) rely on neural networks to identify content patterns from large sets of data to generate new and original content or data. The recent class of generative AI models requires a ten to a hundred-fold increase in computing power to train models over the previous generation, depending on which model is involved. Thus, the overall computing resource demand is roughly doubling about every six months.[8] This represents a barrier to adoption by organizations seeking to implement in-house solutions. Beyond its development requirement, computing power is also required for training generative AI models, fine tuning them, and using them to provide responses to user prompts (while this last use requires less power per session, it involves many more sessions). This renders cloud computing as an ideal solution to address the adoption challenge.

In sum, cloud computing and AI (moving from machine learning to generative AI) represent a classic case of technological complementarity. In this regard, the goal of this study is to examine the economic effects of cloud computing while also evaluating the interaction effects that arise from complementing it with AI and, in particular, generative AI in Canada.

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[8] According to Chat GPT-4 size and architecture, the system is based on eight models with 220 billion parameters each, for a total of approximately 1.76 trillion parameters (Source: The decoder).

The study is structured as follows. In Chapter 2, we present a brief description of the current state of adoption of cloud computing and AI in Canada. Following this, Chapter 3 briefly introduces the theoretical model to estimate the economic impact of cloud and AI as complementary technologies. In Chapter 4, we specify the econometric models to estimate the economic contribution of both technologies. In Chapter 5, we present the estimates of economic contribution in the aggregate for the whole country and disaggregated for a subset of industries for cloud computing and, then AI as a technology complementary with cloud. In Chapter 6, we extrapolate the results of the analysis to address the economic impact of generative AI. Chapter 7 presents final conclusions and implications. The appendices review the state of the research literature regarding the impact of cloud computing and AI on economic growth and their potential complementarity examined to frame the study hypotheses and provide methodological background and details on all study econometric models.

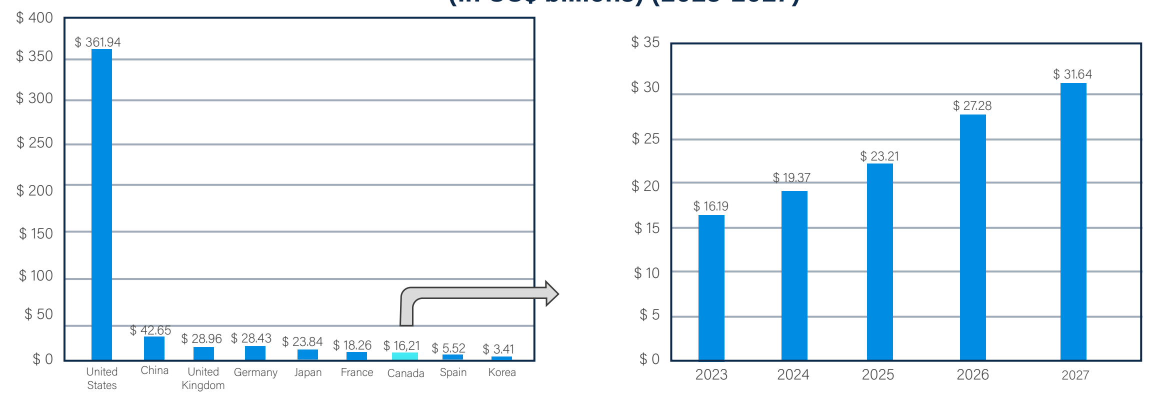
2. THE STATE OF DEVELOPMENT OF CLOUD COMPUTING AND AI IN CANADA

Cloud computing and AI adoption in Canada is developing at a fast pace. This section presents a general overview of adoption and spending of both technologies in the country. Its purpose is to set the stage for the analysis of their economic contribution if adoption were to be accelerated.

2.1 CLOUD COMPUTING

The Canadian cloud computing market, while growing rapidly, is still in development (representing 4.45 % of comparable spending of the United States). Cloud spending in the country accounts for CAD 21.86 billion (US$ 16.19 billion) in 2023 and is expected to reach CAD 41.68 billion (US$ 31.64 billion) by 2027 (see Graphic 2-1).

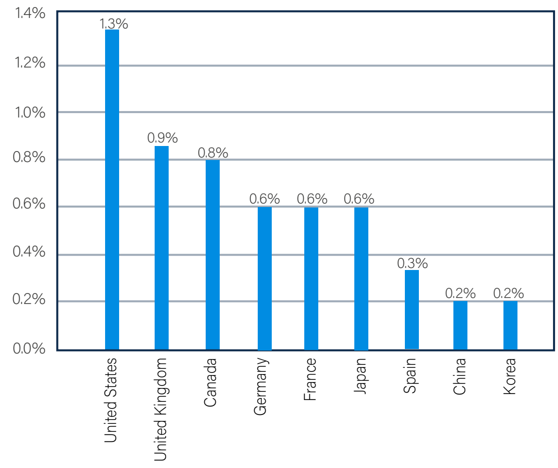
Graphic 2-1. Cloud computing vendor revenues (in US$ billions) (2023-2027)



Source: IDC Semiannual Public Cloud Services Tracker (2024H1 Release).

On an aggregate basis, cloud computing spending in Canada represents 0.8% of the 2023 GDP. This is lower than the corresponding figures for the United States (1.3%) and United Kingdom (0.9%), although larger than Spain (0.3%), China (0.2%) or Korea (0.2%) (see Graphic 2-2).

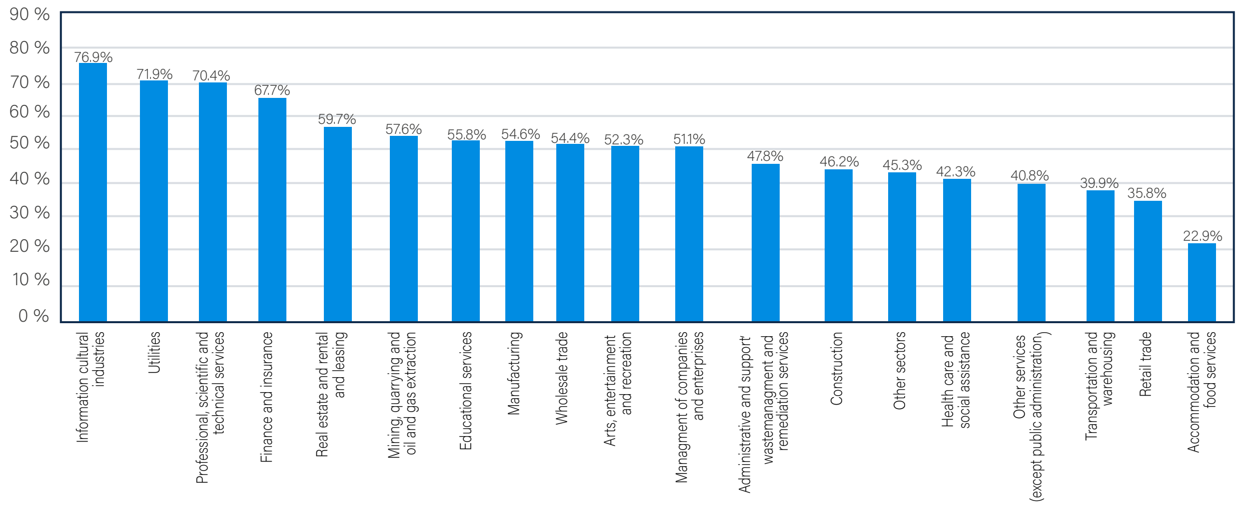
Graphic 2-2. Cloud spending by country as % of GDP (2023)



Sources: IDC Semiannual Public Cloud Services Tracker (2024H1 Release); Statista; World Bank; Telecom Advisory Services analysis

Data on cloud adoption from national statistics is available for 2021, averaging a share of 45.30% of enterprise adopting this technology, although revealing important disparities by economic sector (see Graphic 2-3).

Graphic 2-3. Canada: cloud enterprise adoption (percent of enterprises) (2021)



Sources: 2021 Survey of Digital Technology and Internet Use; Telecom Advisory Services analysis

As suggested in Graphic 2-3, the highest adoption is found in the information and cultural industries (76.9% of companies purchasing cloud services), followed by utilities (71.9%), professional, scientific and technical activities (70.4%), and finance and insurance (67.7%). At the other end, the lowest values are reported for retail trade (35.8%) and accommodation and food services (22.9%). These statistics are fairly consistent with what is observed in other countries, where information businesses comprise a high proportion of "digital natives", companies that are more prone to adopt cloud services in support of their IT function.

From a cloud supply standpoint, hyperscalers have a significant presence in the country, with data centers deployed primarily in Montreal, and Toronto (see table 2-1).

Table 2-1. Hyperscaler availability zone deployment

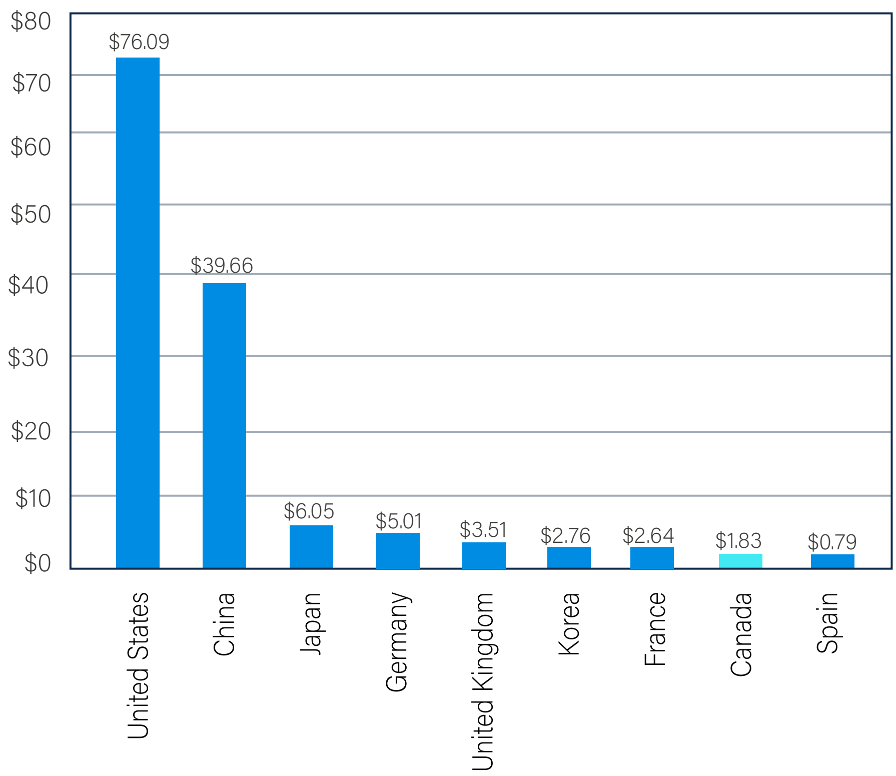
Supplier	Cloud region name	City location	Availability Zones	Launch date
Amazon Web Services	Canada (West)	Calgary	3	2024
Amazon Web Services	Canada (Central)	Montreal	3	2016
Google Cloud Platform	N. America - North East 1	Montreal	3	2018
Google Cloud Platform	N. America - North East 2	Toronto	3	2021
IBM Cloud	CA - For	Toronto	3	2021
Microsoft Azure	Canada East (Quebec City)	Quebec City	1	2016
Microsoft Azure	Canada Central (Toronto)	Toronto	3	2016
Oracle Cloud	Canada Southeast (Montreal)	Montreal	1	2016
Oracle Cloud	Canada Southeast (Toronto)	Toronto	1	2019
OVH	East Coast	Montreal	6	
Tencent Cloud	North America (Toronto)	Toronto	1	2015

Source: Telegeography

2.2 ARTIFICIAL INTELLIGENCE (AI)

As in the case of cloud computing, AI adoption in Canada is also evolving at a fast pace, although still presenting lower spending figures in comparison with other advanced economies. AI spending in Canada, which comprises hardware and software acquisition, fees paid to cloud service providers, and systems integration consulting, amounts to CAD 2.47 billion (US$ 1.83 billion)[9] (or 1.1% of the global market) in 2023 (see Graphic 2-4).

Graphic 2-4. Artificial Intelligence spending (in US$ billions) (2023)

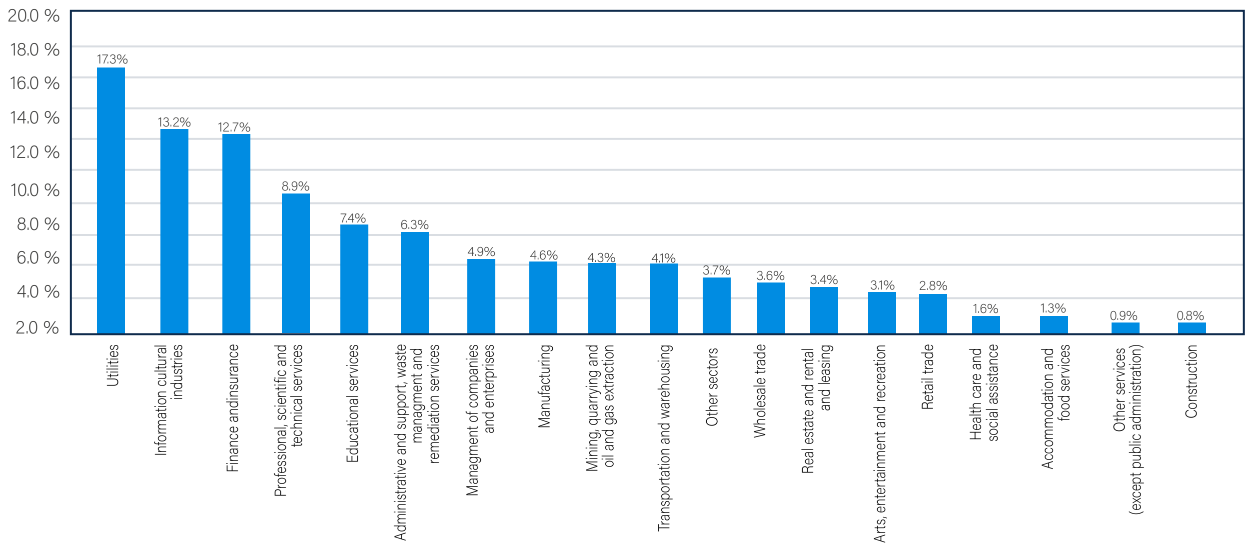


Sources: IDC Semiannual Artificial Intelligence Infrastructure Tracker 2023H2; Telecom Advisory Services analysis

In general terms, the adoption of AI is measured as the percentage of businesses that have adopted the technology in their production processes. On average, 3.70% of Canadian firms adopted AI in 2021, although, as in the case of cloud, important differences by sector arise (see Graphic 2-5).

[9] *Source: IDC Semiannual Artificial Intelligence Infrastructure Tracker 2023H2*

Graphic 2-5. Canada: AI adoption by sector (percentage of enterprises, 2021)



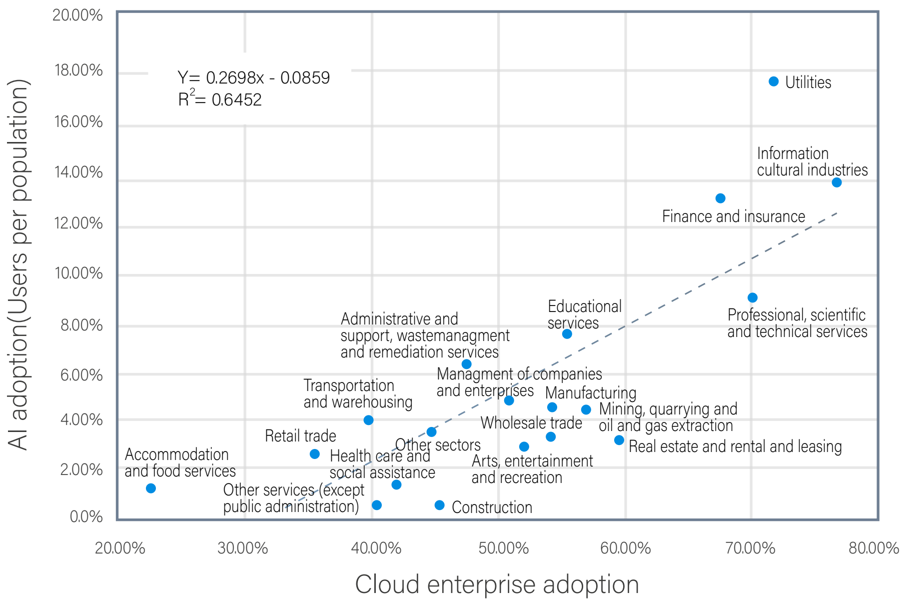
Sources: IMF; Statista; Telecom Advisory Services analysis

As depicted in Graphic 2-5, the highest adoption levels are registered in the utilities industry, followed by information and cultural industries and finance and insurance. At the other end, the lowest levels are detected in construction activities.

2.3 CLOUD-ENABLED AI

As defined in the introduction, technological complementarity reflects the interaction of technologies that work together to enhance or improve their respective overall performance or functionality. A very preliminary indication of the complementarity between cloud computing and AI can be depicted as the correlation in adoption of both technologies in Canadian industries (see graphic 2-6).

Graphic 2-6. Canada: Correlation of industry adoption of cloud computing and AI (2021)



Source: 2021 Survey of Digital Technology and Internet Use; Telecom Advisory Services analysis

The correlation between cloud enterprise adoption and AI population adoption in Canada simply indicates the close association that exists between both technologies as driven by the average level of innovation and IT-intensity in each industry. In light of this, it is critical to understand the causality underlying adoption of both technologies (in other words, determine how the adoption of AI needs to rely on cloud computing) and their cumulative economic contribution.

Firms active in the AI supply chain comprise a whole range of hardware (chipsets, servers, and storage), software (general purpose, analytic toolkits, and industry specific platforms), and services (cloud provision, simulation, installation solutions, and advisory). In particular, cloud computing service providers are extremely active in the provision of AI platforms (see table 2-1).

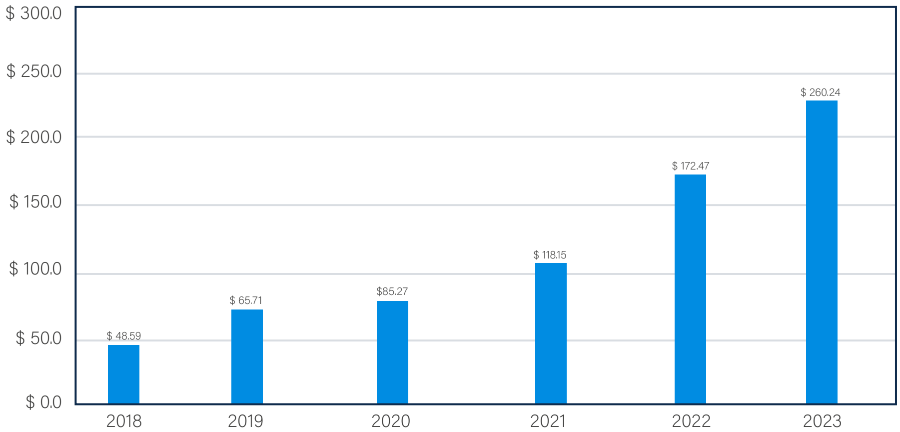
Table 2-1. AI platforms delivered by cloud service providers

Cloud service providers	AI Platforms
Alibaba Group	Alright
AWS	Q, Bedrock, Sqrrl, Veeqo, Wickr
Cisco	BroadSoft, CloudCherry, Duo Security, Epsagon, Kenna Security, Opsani, Portshift
Google	Actifio, AppSheet, Cask Data, Intrigue, Looker, Mandiant, Playspace
Microsoft	AppNexus, Github, Nuance, RiskIQ

Source: Compiled by Telecom Advisory Services

Enterprise spending on AI platforms purchased from cloud service providers in Canada in 2023 amounts to CAD 351.30 million (US$ 260.24 million) (or 14.19% of the total AI market), and it has been growing at 39.88% per year (see Graphic 2-7).

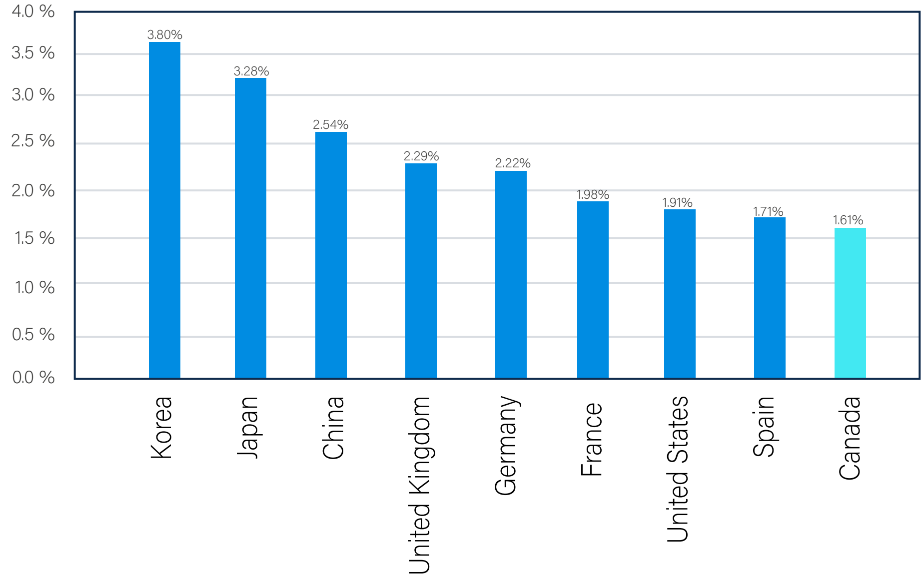
Graphic 2-7. Canada: AI spending delivered by cloud service providers (in US$ million) (2018-2023)



Source: IDC Semiannual Public Cloud Services Tracker- 2024H1 Forecast

On a comparative basis, cloud computing service providers generate 1.61% of their revenue in the provision of AI platforms in Canada. This ratio depicts a lagging position for Canada when compared with other developed economies, as shown in Graphic 2-8.

Graphic 2-8. Spending on AI delivered by cloud service providers (as a percentage of total spending on cloud services) (2023)



Source: IDC Semiannual Public Cloud Services Tracker- 2024H1 Forecast

To understand the drivers underlying the complementarity between cloud computing and AI and estimate their economic impact, it is necessary to specify econometric models, which will be presented in the next chapter.

3. STUDY THEORETICAL MODEL

Research on the macro-economic impact of cloud computing has generated substantial quantitative evidence across world regions. Gal et al. (2019) estimated the impact of cloud computing (among other technologies) on multifactor productivity[10] growth for a sample of 20 European countries, applying a combination of firm-level and industry-level data to a Neo-Schumpeterian growth approach that links innovation and technology diffusion. Their results suggest that a 10-percent point increase in adoption of cloud computing translates into an increase in multifactor productivity growth of 0.9 percentage points. PWC (2021) studied the effects of cloud computing on productivity in Indonesia, by applying a methodology based on Yusuf (2020). Their research uses a recursive-dynamic multi-regional computable general equilibrium model and applies sector-specific labor productivity shocks to it, representing the effect of the new technological changes on the economy. Overall, they estimated that the cumulative productivity benefit to the Indonesian economy of cloud adoption will be US$ 10.7 billion over the period 2021 - 2025. Along these lines, the authors of this reeport have produced several studies estimating the economic impact of cloud computing in OECD countries (Katz and Jung, 2023c), the Middle East and North Africa (Katz and Jung, 2023a), Sub-Saharan Africa (Katz and Jung, 2023b), and Southeast Asia and Pacific (Katz, Jung and Berry, 2024). All studies rely on a 3-stage least squares model incorporating cloud adoption as a term in a production function, measuring the impact on GDP growth. Cloud's contribution is verified in all studies through a positive and significant elasticity coefficient of cloud adoption ranging from 0.299 to 0.271.

Beyond the direct impact it generates, cloud is also expected to enable infrastructure for the use of other technologies such as AI and machine learning, which in turn, should positively influence economic output. This has been highlighted by Pop (2016), who argued that since machine learning is a resource-consuming task, cloud computing can provide valuable support to speed-up the technology execution times. In turn, Omurgonulsen et al. (2021) emphasized the increasing adoption of AI in cloud computing and the challenges associated with supplying workers with the necessary skills to make the most out of it. While research on the economic effect of AI has primarily focused on the impact on labor substitution (Acemoglu and Restrepo, 2018a; 2018b; Lane and Saint-Martin, 2021; Felten, Raj, and Seamans, 2023), studies have recently also started addressing its contribution to productivity.

Taking as a starting point the statistics and estimation results regarding the adoption of AI in Canada presented in the previous chapter, it is reasonable to establish that the technology is already generating an economic impact in terms of growth and productivity. Although statistics on adoption at the functional and sector levels within Canada are lacking, values compiled from global surveys indicate the direction of technology adoption (see Table 3-1).

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[10] Multifactor productivity is a measure of economic performance that compares the amount of output to the number of combined inputs, which includes labor, capital, energy, materials and purchased services

Table 3-1. World: AI adoption by industry and function (percentage of responses) (2022)

	Human Resources	Manufacturing	Marketing and sales	Product development	Risk management	Operations management	Strategy and finance	Supply chain management
Professional services	11 %	10 %	9 %	8 %	16 %	20 %	19 %	12 %
Consumer goods /retailing	14 %	4 %	3 %	4 %	15 %	31 %	29 %	11 %
Financial services	1 %	8 %	7 %	3 %	17 %	24 %	23 %	2 %
Health care	15 %	7 %	2 %	4 %	22 %	12 %	8 %	8 %
Technology and telecommunications	6 %	6 %	4 %	7 %	38 %	21 %	25 %	8 %

Source: McKinsey & Co reported in Stanford (2023). HAI AI Index Report

AI adoption in all sectors reported in this survey is 19% in the operations management function of service industries and 8% in manufacturing, to cite two operational areas. According to these values, it is to be expected that they should generate economic impact, which will be estimated from econometric models.

The focus of this study theoretical model is to assess: (i) the economic impact of cloud computing as a technology and (ii) the economic contribution of AI when enabled by cloud computing in Canada. The empirical strategy selected for this research is supported by a theoretical model that estimates spillover effects in economic output derived from cloud adoption and its potential enabled effects with AI. The analysis is based on a derivation of a Cobb–Douglas production function, where we expect that Total Factor Productivity (TFP), reflecting differences in productive efficiency across industries depends on cloud adoption by firms and AI use. This is reasonable since, as demonstrated in the review of the literature in Appendix A, both technologies are complementary.

These models, presented in detail in Appendix B, would allow us to estimate the contribution to GDP and productivity of: (i) cloud as an autonomous technology, (ii) cloud as an enabler of AI in the aggregate and for specific industries in Canada.

4. ECONOMETRIC MODELS AND RESULTS

To disentangle the effect of ICT-related variables on output, and its inverse, the following micromodel is formalized beyond the aggregated production equation (see Table 4-1 and full details in Appendix B).

Table 4-1. System of simultaneous equations

Aggregate production equation		$VA_{it} = f(K_{it}, L_{it}, CLOUD_{it}, AI_{it})$
Cloud equations	Demand equation Supply equation Infrastructure production	$CLOUD_{it} = g(INCOME_{it}, CLOUD\ COST_{it}, HK_{it}, ICT\ USE_{it})$ $CLOUD\ REVENUES_{it} = h(CLOUD\ COST_{it}, CLOUD\ COMPANIES_{it}, AVAILABILITY\ ZONES_{it})$ $\Delta\ CLOUD_{it} = j(CLOUD\ REVENUES_{it})$
AI equations	Demand equation Supply equation Infrastructure production	$AI_{it} = k(INCOME_{it}, AI\ ARPU_{it}, HK_{it}, ICT\ USE_{it})$ $AI\ REVENUE_{it} = v(AI\ ARPU_{it}, AI\ COMPANIES_{it})$ $\Delta\ AI_{it} = z(AI\ REVENUES_{it})$

Note: i and t denote respectively industry and year.
Source: Telecom Advisory Services

From the results of the econometric model presented in Appendix B, the economic impact of cloud is estimated as follows:

- A 1% increase in cloud adoption will generate a value-added increase of 0.128% in Canadian industries.
- The impact will be even greater in AI-intensive Canadian industries, where a 1% increase in cloud adoption will generate on average a further boost in terms of value-added increase of 0.001%.

The results presented above provide robust evidence of the significant effect that cloud computing has on economic output. In addition, results are clear in pointing out the complementarity of cloud with AI technology. Clearly, the results suggest that AI plays an enhancing effect over cloud computing economic impact. This is explained because cloud is an enabler-technology, meaning that its economic effects are maximized when used to leverage other technologies such as AI. In addition, to be successful AI requires the presence of sound cloud computing services, meaning that firms adopting AI solutions without a solid cloud infrastructure will not be able to make the most out of this technology. The coefficients generated in the econometric model specified in Appendix B will be used to calculate the economic contribution of cloud as well as that of cloud as complementary with AI for 2021.

5. ESTIMATING THE ECONOMIC IMPACT OF CLOUD COMPUTING AND AI IN CANADA

5.1 CLOUD ECONOMIC CONTRIBUTION

The aggregate economic contribution of cloud to GDP is composed of: (i) the domestic revenues generated by cloud service providers and (ii) the spillover effects of cloud services on the total economy. The revenues represent the spending of public and private organizations purchasing cloud services[11], while the spillover effects are the benefits generated by cloud computing in terms of IT cost efficiencies, new product development, support for incubation of startups and the like.[12] By adding the economic benefits generated from the use of cloud services (the spillover effect) to the spending in cloud services (the direct effect) we obtain a measure of the total economic contribution (see table 5-1).

Table 5-1. Revenue and spillover contribution of cloud services to GDP

ITEM	Indicator	Source
(1)	Cloud spending by public and private sector	From Chapter 3
(2)	Spillover effect: Spill-over effect of cloud services	Calculated from elasticities in chapter 4
(3)	Total impact of cloud services to the GDP	(1) + (2)

Source: Telecom Advisory Services

Direct spending includes all revenues of cloud companies when they offer their services in Canada.[13] To estimate the spillovers from cloud adoption growth in 2021, we apply the elasticities derived in the previous chapter. Once estimations were done for all sectors in the sample, total economic contribution of cloud computing for Canada is calculated. **In conclusion, the total economic impact of cloud in Canada in 2021, comprising cloud spending and its spillovers on the economy, is sizable: CAD 33.86 billion** (see table 5-2).

Table 5-2. Canada: Total economic contribution of cloud computing (2021) (in CAD millions)

ITEM	Indicator	Value
(1)	Cloud spending by public and private sector	$ 11,669.96
(2)	Spillover effect: Spill-over effect of cloud services	$ 22,193.53
(3)	Total impact of cloud services to the GDP	$ 33,863.49

Source: Telecom Advisory Services analysis

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[11] The revenues are a measure of market demand that can be met through cloud providers based within the country or beyond the country's borders.
[12] For example, when cloud services enable the adoption of IT services in the SME sector, which benefits from the scalability of IT state-of-the-art, that is considered to be a spillover effect.
[13] The revenues derived from offering AI platforms are excluded since they will be added in the estimation of complementarity between AI and cloud in section 5.2.

5.2 ECONOMIC CONTRIBUTION OF CLOUD-ENABLED AI

The aggregate economic contribution of Cloud-enabled AI is composed of: (i) the domestic revenues generated by Cloud Service Providers for selling AI-related services, and (ii) the indirect effects on the economy arising from the complementarity between AI and the use of cloud computing. By adding the economic benefits generated by the use of AI services (the AI spillover arising from complementarity with cloud computing) to the expenditure on AI services generated by cloud providers (the direct effect) we obtain a measure of the total economic contribution (see Table 5-3).

Table 5-3. Contribution of income and indirect effects of cloud-enabled AI to GDP

ITEM	Indicator	Source
(1)	Expenditure on AI supplied by Cloud Service Providers	From chapter 3
(2)	Spillover from Cloud-enabled AI	Calculated from elasticities of Chapter 4
(3)	Total impact of Cloud-enabled AI to GDP	(1) + (2)

Source: Telecom Advisory Services analysis

Once estimations were done for all the sectors in the sample, total economic contribution of cloud-enabled AI for Canada is calculated (see table 5-4).

Table 5-4. Canada: Total economic contribution of cloud- enabled AI (2021) (in CAD millions)

ITEM	Indicator	Value
(1)	Expenditure on AI supplied by Cloud Service Providers	$ 131.90
(2)	Spillover from Cloud-enabled AI	$ 753.48
(3)	Total impact of Cloud-enabled AI to GDP	$ 885.38

Source: Telecom Advisory Services analysis

The total economic impact of cloud enabled AI in Canada in 2021, comprising both spending and spillovers, accounts for CAD 0.89 billion. It is important to emphasize that this impact does not include the direct effect of cloud spending (beyond that which is generated by cloud service providers) and the spillover generated by standalone AI. Our focus here is only on the complementarity effect.

5.3 TOTAL ECONOMIC CONTRIBUTION UP TO 2030

Next, we project the economic contribution of Canada up to 2030. Spending growth rates are extracted from IDC forecasts up to 2027 and extrapolated to 2030. By considering the growth in spending and the coefficients linking spending and adoption growth from the Cloud infrastructure production estimated for a sample of countries (including Canada), we project the country's average adoption up to 2030 and calculate the associated spillovers. Considering the expected progressive increase in AI adoption, we assume the complementarity coefficient will increase over the years. Table 5-5 presents the aggregate values for the eight-year interval from 2022 to 2030 in Canada.

Table 5-5. Canada: Economic Contribution of Cloud and cloud-enabled AI (in CAD million) (2022-2030)

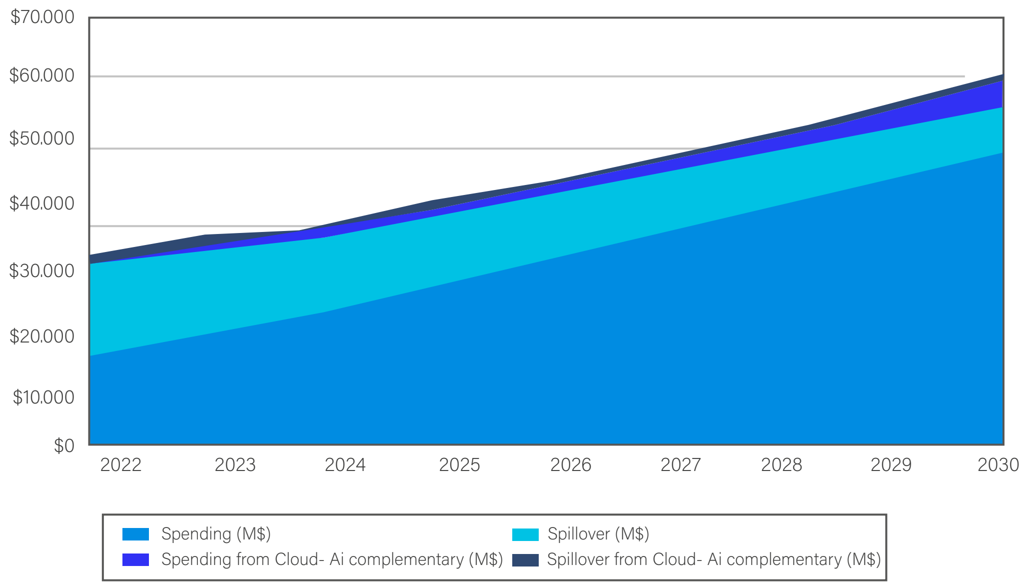
Canada		2022	2023	2024	2025	2026	2027	2028	2029	2030
Cloud	Expenditure	$ 14,469.28	$ 17,777.15	$ 21,172.15	$ 25,211.61	$ 29,381.54	$ 33,737.71	$ 38,221.54	$ 42,775.03	$ 47,343.07
	Spillover	$ 14,885.82	$ 14,338.23	$ 12,115.85	$ 12,383.56	$ 10,934.87	$ 9,967.01	$ 9,084.10	$ 8,278.18	$ 7,542.66
Cloud-enabled AI	Expenditure	$ 192.52	$ 290.50	$ 455.96	$ 699.85	$ 1,066.21	$ 1,576.39	$ 2,265.87	$ 3,171.75	$ 4,330.83
	Spillover	$ 1,319.96	$ 1,437.39	$ 1,270.38	$ 1,347.17	$ 1,234.80	$ 1,156.47	$ 1,082.71	$ 1,010.97	$ 942.55
Total		$ 30,867.59	$ 33,843.28	$ 35,014.33	$ 39,642.19	$ 42,617.43	$ 46,437.58	$ 50,654.22	$ 55,235.93	$ 60,159.10

Sources: IDC ; IMF; Telecom Advisory Services analysis

Over the eight-year timeframe (2022-30), the economic impact of Cloud computing and cloud-enabled AI in Canada will be significant, reaching CAD 394 billion (or 1.98% of projected cumulative GDP).

The main component of the impact will be cloud spending, followed by cloud spillovers (Graphic 5-1). On the other hand, the economic effects from cloud-enabled AI are relatively small in comparison, although they will grow as the rate of change increases over the years.

Graphic 5-1. Projected impact of Cloud and cloud-enabled AI over the period 2022-2030 (in CAD million)



Source: Telecom Advisory Services analysis

5.4 ESTIMATED ECONOMIC IMPACT BY INDUSTRY

Based on the estimates presented above for 2021, we calculate the different economic impact for the industries in the country. Strictly speaking, differences in economic impact could be traced back to variations in Cloud and AI adoption for each sector. Estimates were calculated for the sectors covering all the Canadian economy (see Table 5-6).

Table 5-6: Canada: Economic Contribution of AI (2021) (in CAD million)

Industry	Cloud Impact				
	Spending (M$)	Spillover (M$)	Cloud-enabled AI spending (M$)	Cloud-enabled AI spillover (M$)	Total (M$)
Mining, quarrying, and oil and gas extraction	$ 89.80	$ 943.49	$ 1.01	$ 31.70	$ 1,066.00
Utilities	$ 20.25	$ 187.77	$ 0.23	$ 25.38	$ 233.63
Construction	$ 1,362.00	$ 446.33	$ 15.39	$ 2.79	$ 1,826.52
Manufacturing	$ 547.17	$ 2,818.83	$ 6.18	$ 101.30	$ 3,473.49
Wholesale trade	$ 590.98	$ 1,960.85	$ 6.68	$ 55.15	$ 2,613.67
Retail trade	$ 1,000.98	$ 1,751.94	$ 11.31	$ 38.32	$ 2,802.55
Transportation and warehousing	$ 573.94	$ 2,438.83	$ 6.49	$ 78.12	$ 3,097.37
Information and cultural industries	$ 281.51	$ 200.53	$ 3.18	$ 20.68	$ 505.90
Finance and insurance	$ 559.45	$ 1,146.26	$ 6.32	$ 113.73	$ 1,825.76
Real estate and rental and leasing	$ 671.84	$ 1,953.51	$ 7.59	$ 51.89	$ 2,684.84
Professional, scientific and technical services	$ 2,118.31	$ 206.32	$ 23.94	$ 14.35	$ 2,362.92
Management of companies and enterprises	$ 67.29	$ 14.39	$ 0.76	$ 0.55	$ 82.99
Administrative and support, waste management and remediation services	$ 495.18	$ 429.52	$ 5.60	$ 21.14	$ 951.43
Educational services	$ 164.14	$ 0.00	$ 1.86	$ 0.00	$ 165.99
Health care and social assistance	$ 1,078.18	$ 1,070.45	$ 12.19	$ 13.38	$ 2,174.20
Arts, entertainment and recreation	$ 186.75	$ 79.75	$ 2.11	$ 1.93	$ 270.55
Accommodation and food services	$ 361.98	$ 250.59	$ 4.09	$ 2.55	$ 619.21
Other services (except public administration)	$ 886.18	$ 64.39	$ 10.02	$ 0.45	$ 961.04
Other sectors	$ 614.03	$ 6,229.76	$ 6.94	$ 180.08	$ 7,030.81
Total	$ 11,669.96	$ 22,193.53	$ 131.90	$ 753.48	$ 34,748.87

Source: Telecom Advisory Services analysis

The following conclusions can be drawn from these estimates:

- **On average, the total economic impact of Cloud computing (including cloud-enabled AI) accounted for US$ 34.7 billion in 2021, or 1.66% of Canada's GDP.**
- The highest total economic impact in 2021 is registered by the manufacturing sector (CAD 3.5 billion) and transportation and warehousing (CAD 3.1 million).
- When measured as a percentage of GDP, the highest impact in 2021 is in transportation and warehousing (4.1%), while the lowest is in educational services (0.14%).
- Given the significant economic impact, if the country supports a more proactive approach towards Cloud and AI development it will be expected to maximize their impact.

6. ESTIMATION OF GENERATIVE AI ECONOMIC IMPACT

The econometric model developed to estimate the economic impact of cloud-enabled AI adoption presented in chapter 5 is mainly based on AI applications that precede generative AI since data on AI adoption used in Appendix B estimations is based mostly on machine learning applications.[14]

Since their launch at the end of 2022, generative AI models have moved from being "modular specialists" (generating images from captions, transcribing text to speech) to getting integrated into applications such writing assistance, intelligent data gathering, coding, and translation used in several industries. Most research conducted up to date on the economic impact of generative AI refers to its potential for enhancing productivity. Brynjolfsson, Li, and Raymond (2023) studied the impact of AI-based conversational assistants in customer care on agent productivity, and determined a productivity increase of 14%, as measured by issues resolved per hour. The effect resulted in this case from disseminating behavior of most productive agents through the workforce, therefore benefitting less experienced workers. While the prior research was based on a real-world setting, Noy and Zhang (2023) analyzed the productivity effect of generative AI in an online experiment of mid-level college-level professionals (marketeers, grant writers, HR professionals) confronted with occupation-specific writing tasks. The productivity effect of the treatment group benefitting from the use of ChatGPT increased 37% in a task that required 30 minutes to be completed. Eloundou et al (2023) conducted an occupational analysis of the US workforce based on the O*NET database, an analysis similar to the one conducted by Frey and Osborne (2017) to assess the impact of machine learning. Each occupation is subjectively rated in terms of their potential to be impacted by Large Language Models by experts. The study estimated that with the basic capability of Large Language models, 15% of all worker tasks in the US could be completed "faster with the same level of quality. When incorporating software and tooling built on top of LLMs, this share increases to between 47% and 56% of all tasks." A similar analysis based on the assessment of occupations in the O*NET database was conducted by Briggs and Kodnani (2023), concluding that 25% of US employment is at least partially exposed to generative AI solutions. Based on this estimate, the authors estimate that widespread adoption of generative AI could raise overall labor productivity between 0.3 to 3.0 percentage points per year, although this is contingent upon, among other things the speed of adoption of the technology (see range of scenarios in table 6-1).

[14] ChatGPT-3, developed by OpenAI was released on November 30, 2022. ChaptGPT-4, the paid version was introduced on March 14, 2023. Bard, developed by Google, was launched on March 21, 2023. Claude, developed by Anthropic, was originally released in March 2013, and a version 2 was introduced in July 2023. Companies gain access to these platforms and models to build and scale applications by accessing cloud services such as Microsoft Azure and Amazon Web services.

Table 6-1. Generative AI impact on aggregate labor productivity

Scenario	Impact (in percentage points)
Much less powerful AI	0.3
Slower adoption (30 years)	0.5
Slower adoption (20 years)	0.7
Slightly less powerful AI	0.8
No labor displacement	1.3
Baseline	1.5
Slightly more powerful AI	2.4
More labor displacement	2.4
Much more powerful AI	2.9

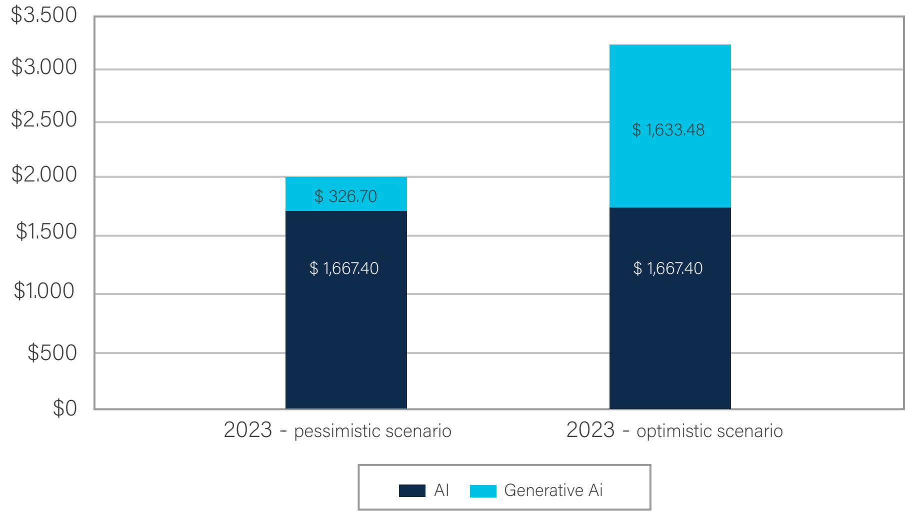
Source: Briggs and Kodnani (2023)

Generative AI requires an inordinate amount of computing[15], which can be met by cloud service providers. Along these lines, a potential extrapolation of economic impact, when considering generative AI, could be based on an increase of AI adoption (by running sensitivity analysis on the demand equation of the AI set of equations in table 5-6). However, re-running the econometric model purely based on an increase in adoption would be underestimating its economic impact as a result of the implementation of new use cases (enhanced revenue), and an enhancement of labor productivity. Another way of approaching this extrapolation would be to rely on the range of productivity impact on the elasticity coefficients presented in table 6-1.

Labor productivity in Canada in 2023 is estimated at an average CAD 108,899 per worker.[16] Taking as a reference the estimated impact of AI on productivity in the US, one could estimate that increased AI adoption improves productivity levels in Canada, adding CAD 1,667 per worker in 2023. However, these estimates do not consider the accelerating factor that can be attributed to generative AI, as the regression coefficients come from a period of analysis prior to the adoption of generative AI. Adding the impact on labor productivity presented in Table 6-1 that can be attributed exclusively to generative AI, we can calculate an estimate of the additional effect. We take as reference two elasticities presented in Table 6-1. The most pessimistic scenario assumes a 0.3% increase in labor productivity due to generative AI, while the most optimistic scenario is based on a 1.5% increase in labor productivity. The estimated effects of AI on labor productivity, including both scenarios associated with generative AI, are presented in Graphic 6-1.

[15] *According to Chat GPT-4 size and architecture, the system is based on eight models with 220 billion parameters each, for a total of approximately 1.76 trillion parameters (Source: The decoder).*
[16] *Calculated taking as a reference the GDP and the number of workers.*

Graphic 6-1. Canada: Indirect effects of AI with the accelerating effect of Generative AI (CAD per worker)



Source: Telecom Advisory Services Analysis

This means that the accelerating effect of Generative AI would account for 19.6% of the original effect in the pessimistic scenario, and 98.0% in the optimistic scenario. As expected, these effects do not account for the intangible capital accumulation required for technological adoption.

7. CONCLUSIONS

The objective of this study was to evaluate the economic contribution of cloud computing and to assess the interaction benefits of enabling AI with the cloud computing in Canada. To this end, we first presented the current state of cloud and AI in the country, considering available data. In addition, an econometric model was estimated to identify not only the recent impact of Cloud, but also the impact associated with its complementarity with AI.

The Canadian cloud computing market is evolving fast, having reached CAD 21.86 billion (US$ 16.19 billion) in spending in 2023,[17] which represents 0.8% of the country's GDP. As in the case of cloud computing, AI spending in Canada is also growing, amounting to CAD 2.47 billion (US$ 1.83 billion).[18] In particular, while spending by Canadian businesses in purchasing AI technology from cloud service providers for 2023 amounts to CAD 351.30 million (US$ 260.24 million) (or 14.19% of the total AI market), it has been growing at 39.88% per year.

The economic contribution of cloud and AI includes not only user spending, but also indirect effects in terms of production efficiency for the entire economy. **The total GDP contribution of cloud computing in Canada in 2021, comprising cloud spending and its spillovers on the economy, is sizable: CAD 34.7 billion. In addition, the contribution to GDP derived from AI enabled by cloud computing in the same year amounted to CAD 0.9 billion in the same year. Over the eight-year timeframe (2022-30), the economic impact of Cloud (and cloud-enabled AI) in Canada will be significant, reaching CAD 394 billion (or 1.98% of projected cumulative GDP).**

The empirical analysis carried out has made it possible to estimate the economic impact compared between industries in the country, from which the following conclusions can be drawn:

CLOUD COMPUTING

- On average, the economic impact of Cloud computing (not considering the complementarity effects with AI) accounted for CAD 33.8 billion in 2021, or 1.62% of Canada's GDP.
- TThe highest total economic impact in 2021 is registered in the manufacturing industry (CAD 3.4 billion), while the lowest is management services (CAD 82 million).
- When measured as a percentage of sectoral output, the highest impact in 2023 is in the transportation sector (3.97%), while the lowest is educational services (0.14%).

[17] *Source: IDC Semiannual Public Cloud Services Tracker (2024H1 Release)*
[18] *Source: IDC.*

CLOUD-ENABLED AI

- The economic impact of Cloud-enabled AI accounted for CAD 0.9 billion in 2021, or 0.04% of Canada's GDP.
- The highest total economic impact in 2021 is registered in the financial industry (CAD 120 million), while the lowest is management services (CAD 1.31 million).
- When measured as a percentage of sectoral output, the highest impact in 2021 is in the transportation sector (0.11%), while the lowest is educational services (0.002%).
- The estimates of economic impact of cloud-enabled AI adoption presented above are mainly based on AI applications that precede generative AI. Since their launch at the end of 2022, generative AI models have moved from being "modular specialists" (generating images from captions, transcribing text to speech) to getting integrated into applications such writing assistance, coding, translation in multiple industries. **Productivity gains from AI, estimated at CAD 1,667 per worker in 2023, can increase in a magnitude that ranges from CAD 327 (pessimistic scenario) to CAD 1633 (optimistic scenario) due to Generative AI.**

These results demonstrate the importance of cloud computing and AI for the economic development of Canada, and the relevance of creating an enabling policy and regulatory environment to maximize its impact. A relevant aspect to address is the still low adoption of this technology, which should be accelerated to maximize the positive effects on citizens and businesses.

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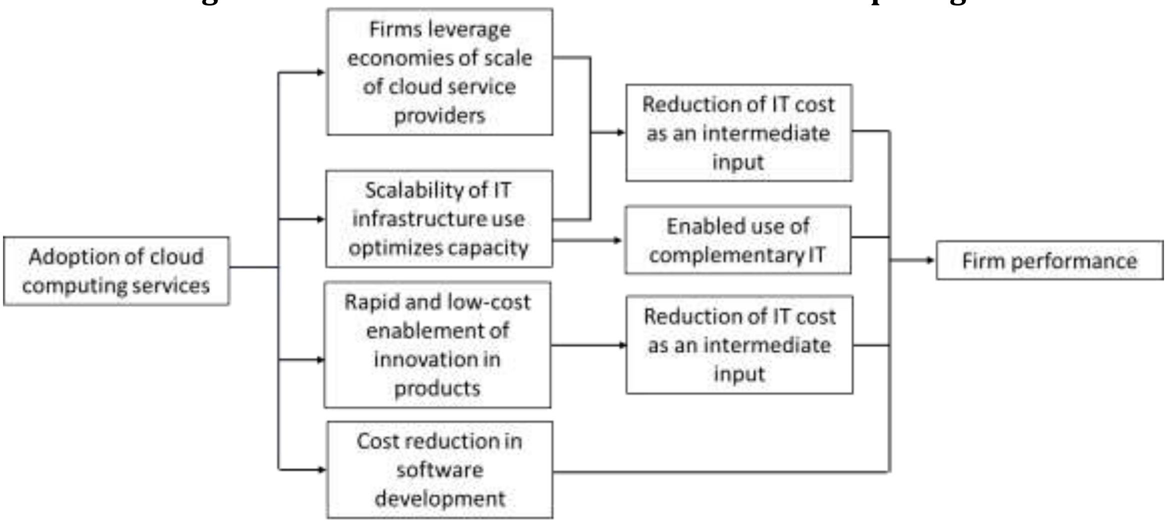
APPENDIX A. RESEARCH LITERATURE REVIEW

Three bodies of research literature have been identified as framing this study: (i) investigations of the economic impact of cloud computing; (ii) research on the contribution of AI to economic growth and productivity, and (iii) the analysis of technological complementarity between both technologies. The following review examines each area and relies on it to frame the current study hypotheses.

A.1. The economic impact of Cloud Computing

Cloud Computing is a crucial contribution to firms' digitization process, through several internal effects that can be summarized as depicted in Figure 1.

Figure A-1. Microeconomic effects of Cloud Computing



Source: Telecom Advisory Services

Supported by cloud computing, the provision of IT-based services has experienced a significant transformation. The ability to share and access computing resources such as servers, storage areas, and network service applications remotely with high reliability and scalability is one of cloud computing's primary advantages (Park and Ryoo, 2013; Ebadi and Jafari Navimipour, 2019; Naseri and Jafari Navimipour, 2019; Khayer et al., 2020; Vu et al., 2020). Moreover, these computational resources can be accessed online at a minimal additional cost thanks to cloud technology. This means that businesses will not have to spend significant resources developing their own infrastructure.[1] As a result, firms that use cloud services can gain from advantages like cost savings, flexibility, and scalability. Businesses can also automatically scale software and storage in response to load by utilizing cloud computing, which helps them save resources (Armbrust et al., 2010). Spending less on resources improves a company's margins and, as a result, its monetary value, which is, in turn, translated into economic contribution.

[1] In the past, businesses had to build their own data centers, acquire the necessary hardware and software, and hire skilled personnel to manage them when cloud computing was not commercially available. This limited the benefits of this technology primarily to large companies.

Moreover, SaaS cloud services can have a potential impact on firm-driven ICT-enabled innovation (e.g., product development) (Chou et al., 2017; Kathuria et al., 2018; Chen et al., 2022), although the effect appears to be modest, according to some authors (Loukis et al., 2019; PWC, 2021).

Lastly, the economic impact of cloud services on software development is expected to be significant. According to Byrne et al. (2018), software development work is made easier when cloud vendors implement technologies that allow them to create products "higher up the stack" and provide services with higher abstractions. This is because companies can now concentrate solely on writing code and deploying it, which reduces development costs. This ultimately results in increased margins and possibly higher sales.

Initially, the empirical research on the economic effects of cloud computing concentrated on firm-level analysis and frequently on specific economic sectors. These studies gauged the performance of the company using a variety of factors, including financial indicators, productivity, and innovation. Schniederjans and Hales (2016) used transaction cost economics to examine how cloud computing facilitates supply chain cooperation and enhances businesses' financial and environmental performance. The authors gathered survey-based information from 247 supply chain and IT professionals, and they used structural equation modeling (SEM) to demonstrate how cloud computing can improve business performance and foster greater cooperation among supply chain participants. Similarly, Loukis et al. (2019) found that SaaS cloud technologies' operational and innovative benefits have a positive impact on business performance, leading to enhanced operations and higher rates of innovation. The study surveyed 102 Dutch firms, identifying the significance of a firm's absorptive capacity, defined as its capacity to identify, obtain, and assimilate important new knowledge from the external environment. Interestingly, Chou et al. (2017) discovered a positive correlation between cloud adoption and service innovation after analyzing data from 165 companies across a range of Taiwanese industries, including IT, travel and tourism, finance, and banking. Bolwin et al. (2022) measured the effect of AWS cloud computing on business performance through a comprehensive survey of 1,504 German companies. By extending the survey findings to all businesses, they calculated that 1.25 million German enterprises depend on the cloud, generating 11.2 billion euros in additional value growth using AWS technologies.

The goal of another research body has been to understand the factors that enhance cloud computing's influence on firm performance. Garrison et al. (2015) used SEM to analyze a survey of 302 Korean firms, determining that the impact of cloud computing on firm performance is positively influenced by managerial, technical, and relational IT capabilities, with managerial capability having the largest impact. On a global scale, Chen et al. (2022) estimated the relationship between cloud computing and firm-level performance metrics (e.g., ROA and Tobin's Q) using Difference-in-Difference econometric techniques on a world sample of firms from 2010 to 2016. Their analysis revealed a positive correlation, indicating that firms adopting cloud computing experienced significantly improved profitability and market value. The authors also identified variations in the impact of cloud computing on performance based on industry type and firm size, with manufacturing firms showing greater profitability gains after adopting cloud services compared to service firms.

Complementing the research on the economic contribution of cloud to firm performance, the focus has moved to understanding the impact at a macroeconomic level. Gal et al. (2019) estimated the impact of cloud computing (among other technologies) on multifactor productivity[2] growth for a sample of 20 European countries, applying a combination of firm-level and industry-level data to a Neo-Schumpeterian growth approach that links innovation and technology diffusion. Their results suggest that a 10-percentage point increase in adoption of cloud computing would translate into an increase in multifactor productivity growth by 0.9 percentage points. PWC (2021) studied the effects of cloud computing on productivity in Indonesia, by applying a methodology based on Yusuf (2020). Their research uses a recursive-dynamic multi-regional computable general equilibrium model and applies sector-specific labor productivity shocks to it, representing the effect of the new technological changes on the economy. Overall, they estimated that the cumulative productivity benefit to the Indonesian economy of cloud adoption will be US$ 10.7 billion over the period 2021 - 2025.

The authors of this study have produced several studies estimating the economic impact of cloud computing in the Middle East and North Africa (Katz and Jung, 2023a), Sub-Saharan Africa (Katz and Jung, 2023b), and Southeast Asia (Katz, Jung and Berry, 2024). All studies rely on a 3-stage least squares model incorporating cloud adoption as a term in a production function, measuring the impact on GDP growth. Cloud's contribution is verified in all studies through a positive and significant elasticity coefficient of cloud adoption ranging from 0.299 to 0.271.

A.2. The economic contribution of AI

While research on the economic effect of AI has primarily focused on the impact on labor substitution (Acemoglu and Restrepo, 2018a; 2018b; Lane and Saint-Martin, 2021; Felten, Raj, and Seamans, 2023), studies have recently started addressing the contribution to productivity. Initially, such studies have been affected by the lack of firm AI adoption data. In fact, many studies measure the use of AI among firms by relying on proxy variables, such as job postings ((Alekseeva et al., 2020, 2021; Babina et al., 2021), or patent registration data (Damioli et al., 2021; Alderucci et al., 2020.; Yang, 2022). For example, Alderucci et al. (2020) measure the intensity of AI patent grants in the US as a metric of firm AI innovation. They found that this metric is positively associated with firm growth and labor demand. Firms with high level of AI innovation appear to have 25% faster employment growth and 40% faster revenue growth than the rest of firms in the sample. A consistent conclusion is generated by Bessen and Righi (2020). The metric they rely in this case is large custom software investment and estimate that these events are associated with 7% increase in employment and 11% in revenues. While still affected by the paucity of data, other studies have emphasized innovations in their empirical approach. For example, Lu (2021) relies on a three-stage endogenous model where AI is assumed

[2] Multifactor productivity is a measure of economic performance that compares the amount of output to the amount of combined inputs, which includes labor, capital, energy, materials and purchased services.

to have the capability to accumulate through resource allocation and based on the elasticity of substitution between labor and capital. The study concludes that if the accumulation of AI leads to a rising productivity in the firms, the technology drives a positive contribution to economic growth.

More recent studies on the economic impact of AI have benefitted from the availability of data captured in national surveys. For example, Czarnitzki, Fernandez and Rammer (2022) built a classical production function incorporating AI adoption as another term and implemented an instrumental variable approach within a two-stage regression to control for endogeneity. Data on AI adoption was captured from a panel survey of German firms for 2018. In this case, the authors found positive and significant effects in the range of 6% and 4% caused by the increase of the use of AI on German firms' productivity, when measured by sales. That being said, the impact of AI on productivity based on national statistics of AI adoption has not always consistently proven to be positive. Song and Cho rely on AI adoption in Korean firms, according to Statistics Korea data for 2017 and 2018, and implement OLS and IV models. Recognizing that their approach could be limited by small sample size and endogeneity, the authors conclude that not all firms exhibit productivity improvements as a result of AI adoption although multi-plants firms appear to benefit from efficiency gains.

A.3. Technological complementarity between AI and cloud computing

The ability of cloud computing to scale IT infrastructure also makes it easier for businesses to use other cloud-enabled technologies like big data, AI machine learning, and the Internet of Things. Because these technologies allow for a fundamental transformation of business management practices, they play a significant role in some of the economic impact that digitization generates.

Despite the above-mentioned advances in the research literature, there is still a lack of analysis regarding to the role of cloud computing and its complementarity effects with other cutting-edge technologies. Cloud service providers might offer database management software, content delivery, analytics (which might include real time video and data streams analysis, and using third party data), machine learning (including deep learning inference, identifying insights and relationship in text), and security applications. Because of that, cloud computing and AI can be conceptualized as being complementary technologies.

Complementarity has been initially studied as enabler of interdependencies supporting the stimulation of demand of capital goods. This effect operates in the technology field at two levels: (i) a given technology enables the production of another one by lowering manufacturing and distribution costs (Dosi et al., 1990; Schmookler, 1966), and (ii) one technology addresses bottlenecks in the diffusion and adoption of a second one (Rosenberg, 1976). The first effect focusses on reducing the cost of intermediate inputs, while the second one addresses user needs.

The study of sector interdependencies has been extended to address the complementarity within value chains (Mäkitie et al., 2022). The authors analyze three mechanisms by which complementarity emerges: (i) **synchronization**, which depicts “the simultaneous and mutually supporting development between the input and user sectors in a technology value chain”; (ii) **amplification**, where a technology accelerates the adoption of a another one; and (iii) **integration,** whereby technological advances in one sector spill in accelerating the development and adoption of technology in another one. In particular, the principle of “amplification” is defined as follows:

> *“Diffusion of a novel technology in a user sector creates demand for products and services in the input sectors of the [technology value chain], making it imperative that input sectors are scalable enough to ensure a balance between supply and demand. Thus, economies of scale may emerge, driving further development and deployment in the user sector due to reduced costs, network effects, and increased availability of necessary services and products.” (p.9)*

The case under study of complementarity between cloud computing, and AI appears to be a clear example of amplification. Each technology was developed independently, although their combination acts as a multiplier of demand and impact.

Beyond the direct impact it may generate, cloud is also expected to enable infrastructure for the use of other technologies such as AI and machine learning, which in turn, should positively influence output. This has been highlighted by Pop (2016), who argues that since machine learning is a resource-consuming task, cloud computing can provide valuable alternatives to speed-up the execution times. In turn, Omurgonulsen et al. (2021) emphasizes the increasing adoption of AI in cloud computing and the challenges associated with equipping workers with the necessary skills to make the most of it. The study also underscores the importance of ensuring enough security measures and compliance requirements before deploying cloud-based AI services.

Soni and Kumar (2022) discuss the integration of machine learning techniques in emerging cloud computing paradigms, emphasizing the study of "intelligent" AI systems. This research presents a detailed taxonomy of AI and cloud computing integration, highlighting the potential for enhanced performance through the combination of these technologies. Furthermore, Collins et al (2021) provides insights into the strategic potential of AI, emphasizing the importance of organizational resources, including technical and non-technical aspects, to fully exploit the benefits of AI. Their study also mentions the provision of infrastructure for machine learning in the cloud by large companies, such as Google, Amazon, and Microsoft, further underlining the integration of AI and cloud computing (Enholm et al, 2022). Additionally, El Khatib et al. (2019) present a case study on the integration of cloud computing with AI in the telecommunications sector, highlighting the benefits of leveraging cloud services with network function virtualization (NFV) and machine learning to improve customer experience and operational efficiency. The study emphasizes the correlation between cloud computing and AI, showcasing their interrelated nature and the support they provide to enhance agility, deploy services faster, and improve operational intelligence.

Complementarity between cloud and other technologies has already been studied by the authors of this research. In a study of economic spillovers of cloud computing in OECD countries, Katz and Jung (2023c) determined empirically that the economic impact of cloud computing depends on fixed broadband adoption. To estimate cloud economic spillovers, the authors combine high speed broadband and cloud adoption in a production function estimating gross value added and productivity. The results suggest that broadband effectively enhances cloud's economic contribution. In a similar vein, Katz, Jung and Goldman (2023) studied the economic impact of cloud computing, big data and machine learning in Israeli firms. By relying on a SEM, the authors determined that cloud computing indirectly leads to more reliance on machine learning and big data applications, although the impact of these technologies on productivity is only positive and significant for large firms.

In summary, the literature review findings underscore the potential of integrating cloud computing and AI to enhance firm-level performance, emphasizing the need for skill development, security measures, and the strategic utilization of organizational resources to fully exploit the benefits of this integration. However, despite these theoretical arguments in favor of the complementary nature of both technologies, empirical research is still lacking in this field.

A.4. Conclusions of research literature review

The review of the research literature has highlighted the progress and opportunities for further development (see table A-1).

Table A-1. Research on the economic impact of cloud computing, AI and their complementarity: Progress and development of opportunities

	Progress	Development for further research
Economic impact of cloud computing	• Contribution of cloud to firm performance (productivity, product development, IT cost efficiency, profitability) • Impact of cloud on GDP growth in high- middle- and low-income economies	• Factors driving differential GDP impact of cloud within sub-sovereign geographies in high income economies
Economic impact of AI	• Impact of AI on labor substitution/creation • Link between AI adoption and firm productivity, albeit for multi-plant firms • Association between AI adoption and revenue growth	• Impact of AI on aggregate firm performance indicators (e.g., sales growth and profitability) • Impact of AI on GDP growth and productivity based on national industrial statistics
Complementarity between AI and cloud computing	• Precision in the definition of complementarity between cloud and AI (resource optimization, time required for product development) • Economic impact of cloud computing, big data and machine learning on firm performance	• Marco-economic impact of the complementarity of AI and cloud computing

In summary, this study will address the gaps in the research literature along the following objectives:

- Understand the bases of differentiated cloud economic contribution within sub-sovereign geographic entities (e.g., States)
- Base the analysis in panel data derived from reliable databases on cloud and AI adoption in enterprises
- Impact of AI on GDP growth and productivity based on national industrial statistics
- Focus the empirical strategy on exploring the complementarity between both technologies

APPENDIX B. ECONOMETRIC MODEL TO ESTIMATE CLOUD AND AI ECONOMIC IMPACT

B.1. The theoretical model

The focus of the study theoretical model is to assess (i) the economic contribution of cloud computing as a technology and (ii) the complementary economic impact of cloud computing and AI in Canada. The empirical strategy selected for this research is supported by a theoretical model that estimates spillover effects in economic output derived from cloud adoption and its potential complementarity with AI. To estimate these effects, we start with an empirical model where output is explained through a Cobb–Douglas production function:

$$VA_{it} = A_{it}K_{it}^{\alpha}L_{it}^{\beta} \tag{1}$$

In equation (1), VA represents value-added, K is the physical capital stock, and L is labor. Subscripts *i,* and t denote, respectively, industry, and year. The term A represents the Total Factor Productivity (TFP), reflecting differences in productive efficiency across industries.

We expect TFP to depend on cloud adoption by firms (denoted by $CLOUD$), and beyond it, we assume that higher AI use will enhance cloud impact. This is reasonable since, as demonstrated in the review of the literature in appendix A, both technologies are complementary. As a result, TFP is proposed as:

$$A_{it} = \Omega_i \zeta_t CLOUD_{it}^{\Phi+\delta AI_{it}} \tag{2}$$

According to equation (2), TFP depends on industry-level time-invariant characteristics represented by Ω_i, capturing idiosyncratic productivity effects. In addition, ζ_t reflects time-level unobservables.

As it is assumed that cloud adoption contributes to increased productivity, we expect $\Phi > 0$. As another important aspect that could shape the impact of cloud on productivity is AI use, the empirical exercise will consist in identifying the sign and significance level of the parameter δ. If we verify that $\delta > 0$, this means that AI enhances the positive impact of cloud computing. Along these lines, for two sectors with the same level of cloud adoption, we expect to observe a higher economic impact for that one with higher intensity of AI use. Inserting equation (2) into (1), we obtain:

$$VA_{it} = \Omega_i \zeta_t CLOUD_{it}^{\Phi+\delta AI_{it}} K_{it}^{\alpha}L_{it}^{\beta} \tag{3}$$

Applying logs to linearize, we get the final empirical specification for the output equation:

$$\log(VA_{it}) = \varrho_i + \eta_t + \alpha\log(K_{it}) + \beta\log(L_{it}) + \Phi\log(CLOUD_{it}) + \delta AI_{it}\log(CLOUD_{it})$$

where $\mu_i = \log(\Omega_i)$ is a sector-level fixed effect, and η_s represents the temporal unobservables through a year fixed effects. In sum, we understand that the evolution of VA depends on some specific unobserved characteristics, on the capital stock, on labor, on cloud adoption and, on the complementary use of cloud and AI.

From the last equation, we can calculate the economic impact of cloud, which is expected to depend on the intensity of AI use:

$$\frac{\partial \log(VA_{it})}{\partial \log(CLOUD_{it})} = \Phi + \delta AI_{it}$$

These models would allow us to estimate the contribution to VA and productivity of (i) cloud as an autonomous technology, (ii) cloud as a complementary technology to AI in the aggregate and for specific industries.

The contribution of cloud to VA is estimated through the parameter Φ estimated through the output equation, that represents the elasticity: a 1% increase in cloud adoption will yield an increase in output of Φ%. The contribution to VA of AI as a complementary technology to cloud is estimated through the parameter δ estimated in the output equation in interaction with the logarithm of cloud adoption. Thus, the elasticity derived from a 1% increase in cloud adoption will reach $(\Phi + \delta AI)$%.

B.2. The dataset

The data sample to be used in the model specification consists of 84 Canadian industries during the period 2019-2021 (see list in table B-1).

Table B-1. Sectors included in the sample

Mining and oil and gas extraction	Miscellaneous store retailers
Utilities	Non-store retailers
Construction of buildings	Air transportation
Engineering construction	Rail transportation
Food manufacturing	Water transportation
Beverage and tobacco product manufacturing	Truck transportation
Textile and textile product mills	Transit, ground passenger and scenic and sightseeing transportation
Clothing and leather and allied product manufacturing	Support activities for transportation
Wood product manufacturing	Pipeline transportation
Paper manufacturing	Postal service and couriers and messengers
Printing and related support activities	Warehousing and storage
Petroleum and coal product manufacturing	Publishing industries (except internet)
Chemical manufacturing	Motion picture and sound recording industries
Plastics and rubber products manufacturing	Broadcasting (except internet)
Non-metallic mineral product manufacturing	Telecommunications
Primary metal manufacturing	Other information services
Fabricated metal product manufacturing	Depository credit intermediation and monetary authorities
Machinery manufacturing	Insurance carriers and related activities

Computer and electronic product manufacturing	Financial investment services, funds and other financial vehicles
Electrical equipment, appliance and component manufacturing	Real estate
Transportation equipment manufacturing	Rental and leasing services
Furniture and related product manufacturing	Lessors of non-financial intangible assets (except copyrighted works)
Miscellaneous manufacturing	Legal services
Farm product wholesaler-distributors	Accounting, tax preparation, bookkeeping and payroll services
Petroleum product wholesaler-distributors	Architectural, engineering and related services
Food, beverage and tobacco wholesaler-distributors	Specialized design services
Personal and household goods wholesaler-distributors	Management, scientific and technical consulting services
Motor vehicle and parts wholesaler-distributors	Scientific research and development services
Building material and supplies wholesaler-distributors	Other professional, scientific and technical services
Machinery, equipment and supplies wholesaler-distributors	Computer systems design and related services
Miscellaneous wholesaler-distributors	Advertising, public relations, and related services
Wholesale electronic markets, and agents and brokers	Administrative and support services
Motor vehicle and parts dealers	Waste management and remediation services
Furniture and home furnishings stores	Educational services
Electronics and appliance stores	Ambulatory health care services
Building material and garden equipment and supplies dealers	Nursing and residential care facilities
Food and beverage stores	Social assistance
Health and personal care stores	Performing arts, spectator sports and related industries, and heritage institutions
Gasoline stations	Amusement, gambling and recreation industries
Clothing and clothing accessories stores	Accommodation services
Sporting goods, hobby, book and music stores	Food services and drinking places
General merchandise stores	Other private services

Source: Telecom Advisory Services analysis

The variables to be used in the empirical analysis are detailed in Table B-2.

Table B-2. Variables to be used in the empirical analysis

Item	Description	Source
VA	Sectoral value added in chained 2017 CAD dollars	Statistics Canada
K	Hyperbolic end-year net stock of capital in chained 2017 CAD dollars	Statistics Canada
L	Number of people employed	Statistics Canada
AI	Software and hardware using artificial intelligence (AI) (% enterprises)	Statistics Canada
AI ARPU	AI ARPU as a share of average income of firm (in thousand CAD)	Statista / Statistics Canada
AI REVENUES M	AI ARPU multiplied by the number of firms adopting cloud in the sector	Statista / Statistics Canada
Firms per AI companies	Number of firms per AI company operating in the country	Statistics Canada / Crunchbase / TAS
CLOUD	Companies using cloud computing (%)	
CLOUD COST	Cloud cost as a share of average income of firm (in thousand CAD)	Telegeography / Statistics Canada
CLOUD REVENUE M	Cloud ARPU multiplied by the number of firms adopting cloud in the sector	IDC / Statistics Canada
Firms per Cloud companies	Number of firms per cloud company operating in the country	Statistics Canada / Crunchbase / TAS
AVAILABILITY ZONES	Number of availability zones deployed in cloud regions	Telegeography
CRM	Firms using customer relationship management (CRM) software (%)	Statistics Canada
ERP	Firms using enterprise resource planning (ERP) software (%)	Statistics Canada
FTTH	Business with fiber optic internet connection (%)	Statistics Canada
No ICT	Business not using information and communication technologies (ICT) (%)	Statistics Canada
Firms in Ontario (%)	Share of firms located in Ontario	Statistics Canada
Firms in British Columbia (%)	Share of firms located in British Columbia	Statistics Canada
Publications in University of Toronto	AI related publications from the University of Toronto (in thousands)	OECD
Publications in University of British Columbia	AI related publications from the University of British Columbia (in thousands)	OECD
Ventura Capital in AI	Venture capital investments in AI (in billion CAD)	OECD

Source: Telecom Advisory Services analysis

Most variables are extracted from the Statistics Canada website. Since the data for ICT indicators is only available for 2019 and 2021, we interpolate 2020 figures assuming a constant compound annual growth rate within the period. The descriptive statistics used in the econometric analysis are presented in Table B-3.

Table B-3. Descriptive statistics

Item	Mean	Standard deviation
VA	167423100.0	196745000.0
K	37030.72	131472.7
L	159741.5	181236.5
AI	4.627	4.804
AI ARPU	80.230	75.189
AI REVENUES M	42.377	88.024
Firms per AI companies	16.659	25.411
CLOUD	51.446	16.412
CLOUD COST	0.332	0.327
CLOUD REVENUE M	107.323	150.362
Firms per Cloud companies	105.118	160.226
AVAILABILITY ZONES	11.667	3.097
CRM	21.418	12.703
ERP	11.920	9.421
FTTH	36.538	10.989
No ICT	12.312	7.387
Firms in Ontario (%)	0.364	0.075
Firms in British Columbia (%)	0.156	0.043
Publications in University of Toronto	25.997	2.088
Publications in University of British Columbia	18.502	1.361
Ventura Capital in AI	2.977	1.547

Source: Telecom Advisory Services analysis

The econometric models and results used to estimate the economic impact of cloud and artificial intelligence are presented in the next chapter. The approach to be used in this case is inspired on Roller and Waverman (2001) and Koutroumpis (2009, 2019), consisting of a structural econometric model with a production function and a supply and demand framework that endogenizes ICT related variables. To control for the concern that both cloud computing and AI may be potentially endogenous, the framework proposed by Roller and Waverman (2001) and Koutroumpis (2009, 2019) captures these two-way relationships between economic output and ICTs, by explicitly accounting for these effects in a simultaneous equations model.

B.3. Econometric model

To disentangle the effect of ICT-related variables on output, and its inverse, the following micromodel is formalized beyond the aggregated production equation (Table B-4).

Table B-4. System of simultaneous equations

Aggregate production equation		$\text{VA}_{it} = \text{f}(\text{K}_{it}, \text{L}_{it}, \text{CLOUD}_{it}, \text{AI}_{it})$
Cloud equations	Demand equation	$\text{CLOUD}_{it} = \text{g}(\text{INCOME}_{it}, \text{CLOUD COST}_{it}, \text{HK}_{it}, \text{ICT USE}_{it})$
	Supply equation	$\text{CLOUD REVENUES}_{it} = \text{h}(\text{CLOUD COST}_{it}, \text{CLOUD COMPANIES}_{it}, , \text{AVAILABILITY ZONES}_{it})$
	Infrastructure production equation	$\Delta\text{CLOUD}_{it} = \text{j}(\text{CLOUD REVENUES}_{it})$
AI equations	Demand equation	$AI_{it} = \text{k}(\text{INCOME}_{it}, \text{AI ARPU}_{it}, \text{HK}_{it}, \text{ICT USE}_{it})$
	Supply equation	$\text{AI REVENUES}_{it} = \text{v}(\text{AI ARPU}_{it}, \text{AI COMPANIES}_{it})$
	Infrastructure production equation	$\Delta\text{AI}_{it} = \text{z}(\text{AI REVENUES}_{it})$

Note: i and t denote respectively industry and year.
Source: Telecom Advisory Services

Results for the output equation are presented in Table B-5. The estimation is conducted through 3-Stage Least Squares (3SLS) simultaneous equation approach.

The results of the main equation are in line with expectations, with capital and labor being positive variables in explaining variations in VA. On the other hand, it is verified that cloud computing presents a positive and significant effect. The interaction between cloud and AI also shows a positive and significant coefficient when considering AI as endogenous (see table B-5).

Table B-5. 3SLS Simultaneous equations model estimation

Dependent variable: log (VA)	(i)	(ii)	(iii)	(iv)	(v)	(vi)
Log(K)	0.733***	0.709***	0.711***	0.709***	0.711***	0.718***
	[0.034]	[0.019]	[0.019]	[0.020]	[0.019]	[0.019]
Log(L)	0.260***	0.281***	0.273***	0.274***	0.275***	0.269***
	[0.037]	[0.022]	[0.022]	[0.022]	[0.022]	[0.022]
Log (Cloud)	0.082*	0.131**	0.144***	0.138**	0.128**	0.107*
	[0.043]	[0.053]	[0.055]	[0.060]	[0.057]	[0.060]
Log (Cloud) # AI				0.000	0.001*	0.017*
				[0.001]	[0.001]	[0.010]
AI						-0.068
						[0.043]
Dependent variable: log (Cloud)						
Log(income)		0.008	0.020	0.020	0.020	0.020
		[0.019]	[0.020]	[0.020]	[0.020]	[0.020]
Cloud cost		0.046	0.079	0.079	0.085	0.085
		[0.057]	[0.064]	[0.064]	[0.063]	[0.064]
ICT HK		0.004**	0.005***	0.005***	0.005***	0.005***
		[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
Log (FTTH)		0.125**	0.097	0.097	0.101*	0.102*
		[0.058]	[0.060]	[0.060]	[0.060]	[0.060]
Firms not requiring ICT		-0.019***	-0.020***	-0.020***	-0.020***	-0.020***
		[0.002]	[0.002]	[0.002]	[0.002]	[0.002]
Log (CRM)		0.129***	0.127***	0.127***	0.138***	0.138***
		[0.033]	[0.032]	[0.032]	[0.032]	[0.032]
Log (ERP)		0.000	0.000	0.000	-0.003	-0.002
		[0.024]	[0.024]	[0.024]	[0.024]	[0.024]
Dependent variable: log (Cloud Revenue)						
Cloud cost		0.351**	0.122	0.122	0.113	0.12
		[0.174]	[0.179]	[0.179]	[0.156]	[0.156]
Firms per cloud companies		0.005***	0.005***	0.005***	0.005***	0.005***
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Availability zones # Ontario (%)		0.156***	0.391***	0.391***	0.393***	0.394***
		[0.034]	[0.061]	[0.061]	[0.059]	[0.059]
Availability zones # British Columbia (%)		0.003	0.224***	0.224***	0.290***	0.291***
		[0.064]	[0.079]	[0.079]	[0.078]	[0.078]
Dependent variable: Delta Cloud						
Log (Cloud Revenue)		1.234***	0.515**	0.508*	0.698***	0.690***
		[0.334]	[0.263]	[0.263]	[0.258]	[0.257]
Dependent variable: log (AI)						
Log (income)					0.093**	0.093**
					[0.037]	[0.037]
AI ARPU					-0.003***	-0.003***
					[0.001]	[0.001]
ICT HK					0.008***	0.008***
					[0.003]	[0.003]
Log (FTTH)					0.142	0.138
					[0.105]	[0.105]
Firms not requiring ICT					-0.010**	-0.010**
					[0.004]	[0.004]
Log (CRM)					0.197***	0.195***
					[0.056]	[0.056]

Log (ERP)					0.039	0.044
					[0.043]	[0.043]
Dependent variable: log (AI Revenue)						
AI ARPU					-0.005***	-0.004***
					[0.001]	[0.001]
Firms per AI companies					0.031***	0.031***
					[0.003]	[0.003]
AI publications U Toronto # Ontario					0.126***	0.126***
					[0.031]	[0.031]
AI publications U BC # British Columbia					0.067	0.067
					[0.064]	[0.064]
VC on AI # Ontario					0.424**	0.424**
					[0.205]	[0.205]
VC on AI # British Columbia					0.357	0.356
					[0.324]	[0.324]
Dependent variable: Delta AI						
Log (AI Revenue)					0.418***	0.393***
					[0.097]	[0.091]
Treatment for Cloud	Exogenous	Endogenous	Endogenous	Endogenous	Endogenous	Endogenous
Treatment for AI				Exogenous	Endogenous	Endogenous
Sector 2-digit Fixed Effects	YES	YES	YES	YES	YES	YES
Year Fixed Effects	NO	NO	YES	YES	YES	YES
R-squared (ɤ)	0.967	0.97	0.971	0.971	0.97	0.971
Observations	252	250	250	250	249	249

*Note: *** p<0.01, ** p<0.05, * p<0.1. Standard errors in brackets.*
(ɤ) refers to production function equation.
Source: Telecom Advisory Services analysis

From the above results, the economic impact of cloud is estimated as follows:

- A 1% increase in cloud adoption will generate a baseline value-added increase of 0.128% in Canada.
- The impact will be even greater in AI-intensive industries, due to the coefficient associated with the interaction term